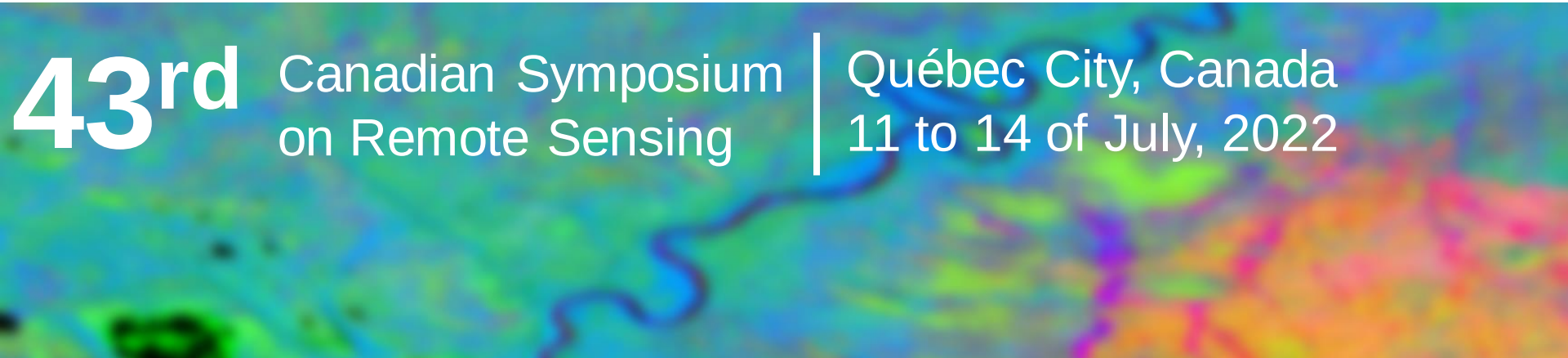
RELATING SENTINEL-1 TIME-SERIES TO BOREAL FOREST ATTRIBUTES USING CONVOLUTIONAL AUTOENCODERS

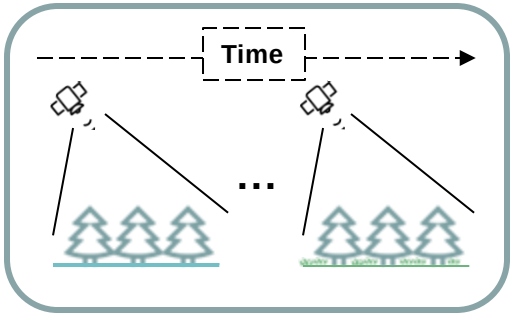
Thomas Di Martino[1,2], *André Beaudoin*[3], *Régis Guinvarc'h*[1], *Lætitia Thirion-Lefevre*[1], *Elise Colin*[2]

[1]SONDRA, CentraleSupélec, Université Paris-Saclay, 91190 Gif-sur-Yvette, France
[2]ONERA, Traitement de l'information et systèmes, Université Paris-Saclay, 91123 Palaiseau, France
[3]Natural Resources Canada, Canadian Forest Service – Laurentian Forestry Centre, Québec, QC, Canada, G1V 4C7



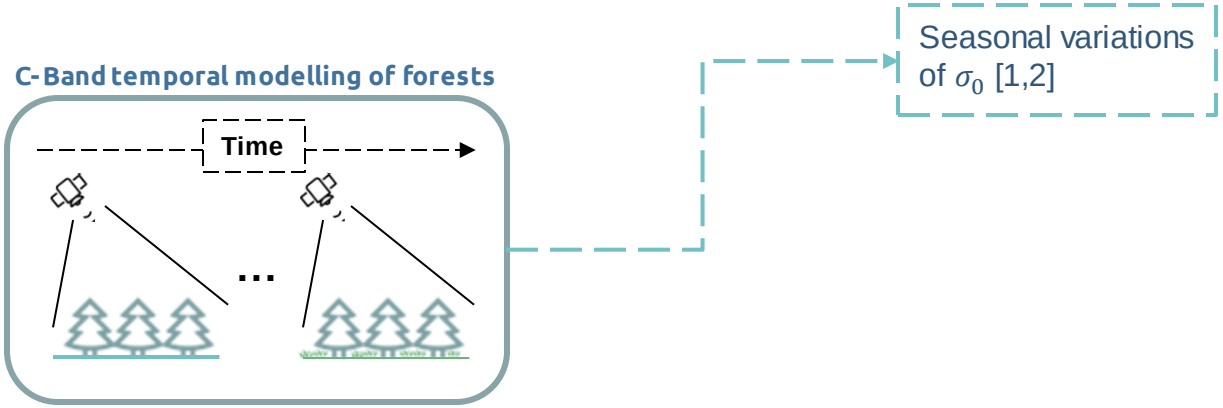
C-Band SAR Time Series & Forest Monitoring

C-Band temporal modelling of forests



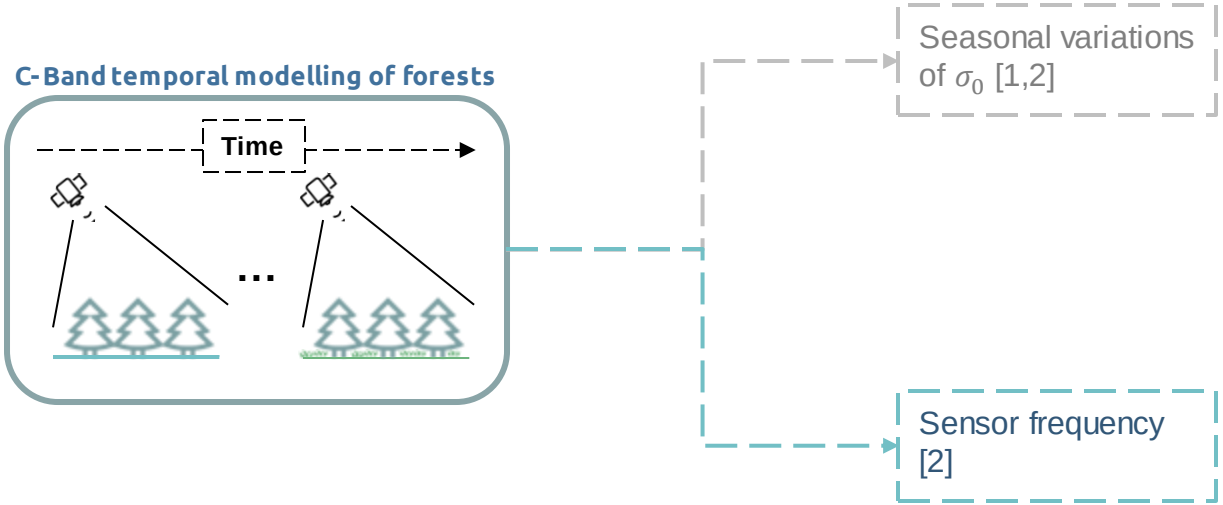
[1] E. Rignot and J. B. Way, "Monitoring freeze-thaw cycles along north-south Alaskan transects using ERS-1 SAR", Remote Sensing of Environment, vol. 49, no. 2, pp. 131-137, 1994.
[2] J. Cohen, K. Rautiainen J. Lemmetyinen, T. Smolander, J. Vehviläinen and J. Pulliainen, "Sentinel-1 based soil freeze/thaw estimation in boreal forest environments", Remote Sensing of Environment, vol. 254, P. 112267, 2021.

C-Band SAR Time Series & Forest Monitoring



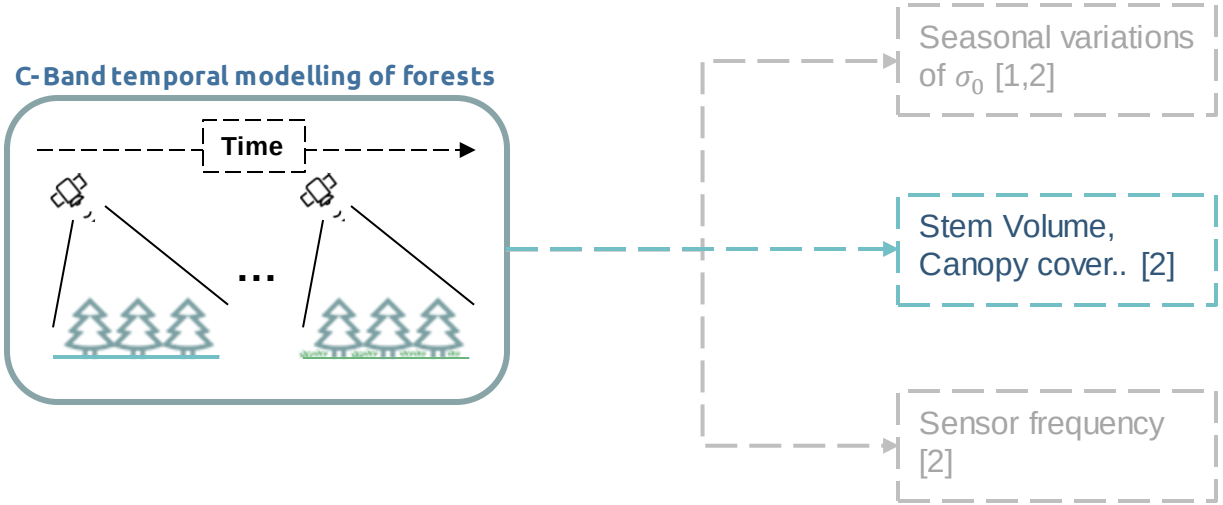
[1] E. Rignot and J. B. Way, "Monitoring freeze-thaw cycles along north-south Alaskan transects using ERS-1 SAR", Remote Sensing of Environment, vol. 49, no. 2, pp. 131-137, 1994.
[2] J. Cohen, K. Rautiainen J. Lemmetyinen, T. Smolander, J. Vehviläinen and J. Pulliainen, "Sentinel-1 based soil freeze/thaw estimation in boreal forest environments", Remote Sensing of Environment, vol. 254, P. 112267, 2021.

C-Band SAR Time Series & Forest Monitoring



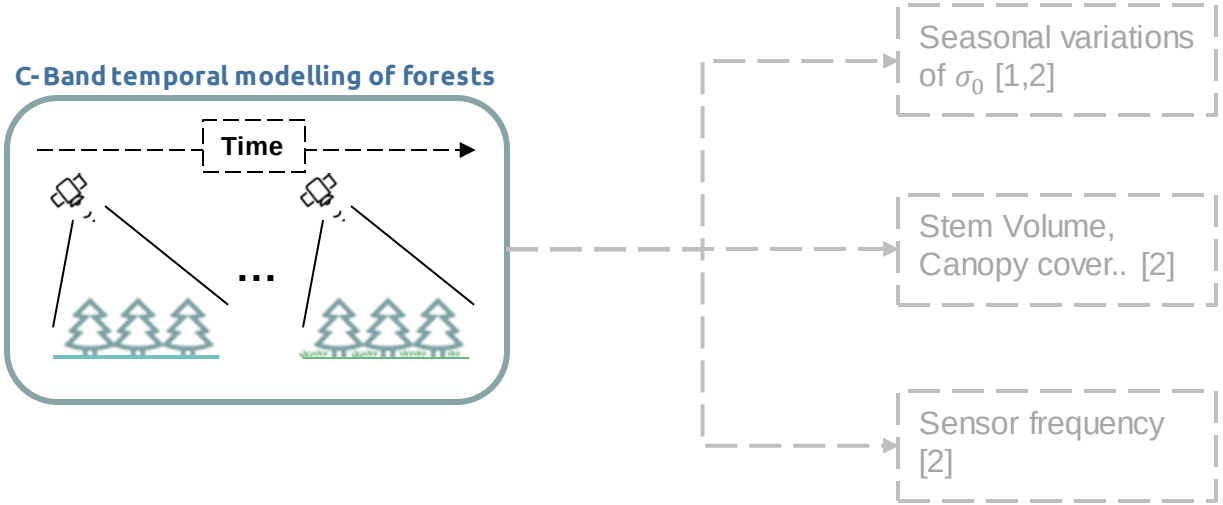
[1] E. Rignot and J. B. Way, "Monitoring freeze-thaw cycles along north-south Alaskan transects using ERS-1 SAR", Remote Sensing of Environment, vol. 49, no. 2, pp. 131-137, 1994.
[2] J. Cohen, K. Rautiainen J. Lemmetyinen, T. Smolander, J. Vehviläinen and J. Pulliainen, "Sentinel-1 based soil freeze/thaw estimation in boreal forest environments", Remote Sensing of Environment, vol. 254, P. 112267, 2021.

C-Band SAR Time Series & Forest Monitoring



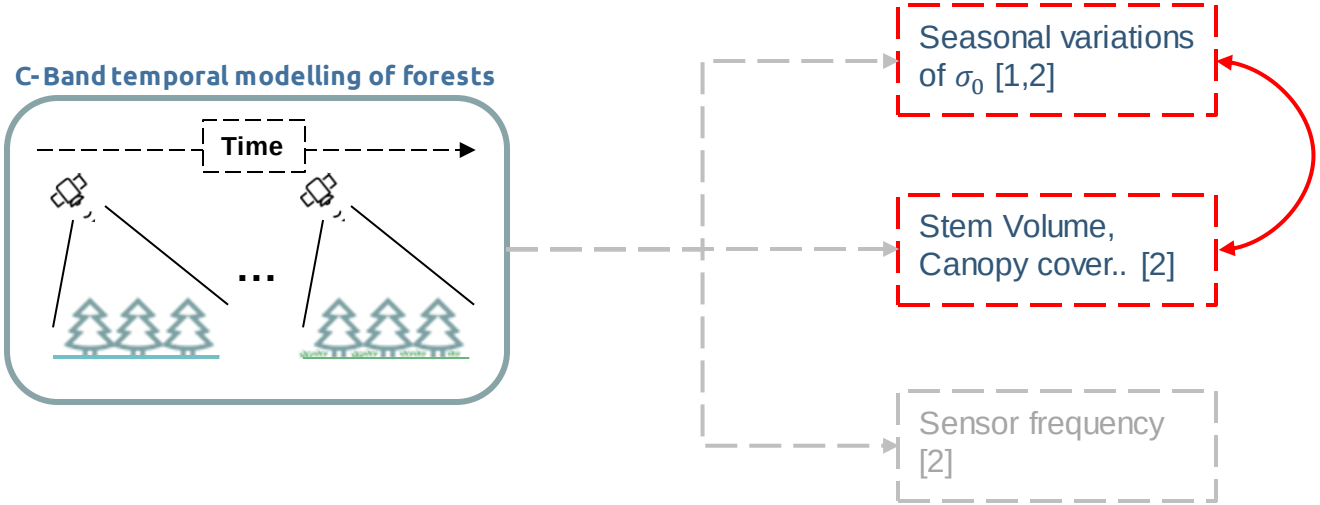
[1] E. Rignot and J. B. Way, "Monitoring freeze-thaw cycles along north-south Alaskan transects using ERS-1 SAR", Remote Sensing of Environment, vol. 49, no. 2, pp. 131-137, 1994.
[2] J. Cohen, K. Rautiainen J. Lemmetyinen, T. Smolander, J. Vehviläinen and J. Pulliainen, "Sentinel-1 based soil freeze/thaw estimation in boreal forest environments", Remote Sensing of Environment, vol. 254, P. 112267, 2021.

C-Band SAR Time Series & Forest Monitoring



[1] E. Rignot and J. B. Way, "Monitoring freeze-thaw cycles along north-south Alaskan transects using ERS-1 SAR", Remote Sensing of Environment, vol. 49, no. 2, pp. 131-137, 1994.
[2] J. Cohen, K. Rautiainen J. Lemmetyinen, T. Smolander, J. Vehviläinen and J. Pulliainen, "Sentinel-1 based soil freeze/thaw estimation in boreal forest environments", Remote Sensing of Environment, vol. 254, P. 112267, 2021.

C-Band SAR Time Series & Forest Monitoring



[1] E. Rignot and J. B. Way, "Monitoring freeze-thaw cycles along north-south Alaskan transects using ERS-1 SAR", Remote Sensing of Environment, vol. 49, no. 2, pp. 131-137, 1994.
[2] J. Cohen, K. Rautiainen J. Lemmetyinen, T. Smolander, J. Vehviläinen and J. Pulliainen, "Sentinel-1 based soil freeze/thaw estimation in boreal forest environments", Remote Sensing of Environment, vol. 254, P. 112267, 2021.

Links between variations of σ_0 and tree physiology

A

[1] E. Rignot and J. B. Way, “Monitoring freeze-thaw cycles along north-south Alaskan transects using ERS-1 SAR”, Remote Sensing of Environment, vol. 49, no. 2, pp. 131-137, 1994.
[2] J. Cohen, K. Rautiainen J. Lemmetyinen, T. Smolander, J. Vehviläinen and J. Pulliainen, “Sentinel-1 based soil freeze/thaw estimation in boreal forest environments”, Remote Sensing of Environment, vol. 254, P. 112267, 2021.

Links between variations of σ_0 and tree physiology

A

Seasonal variations of σ_0 [1,2]

[1] E. Rignot and J. B. Way, "Monitoring freeze-thaw cycles along north-south Alaskan transects using ERS-1 SAR", Remote Sensing of Environment, vol. 49, no. 2, pp. 131-137, 1994.
[2] J. Cohen, K. Rautiainen J. Lemmetyinen, T. Smolander, J. Vehviläinen and J. Pulliainen, "Sentinel-1 based soil freeze/thaw estimation in boreal forest environments", Remote Sensing of Environment, vol. 254, P. 112267, 2021.

Links between variations of σ_0 and tree physiology

A

Seasonal variations of σ_0 [1,2]

B

[1] E. Rignot and J. B. Way, "Monitoring freeze-thaw cycles along north-south Alaskan transects using ERS-1 SAR", Remote Sensing of Environment, vol. 49, no. 2, pp. 131-137, 1994.
[2] J. Cohen, K. Rautiainen J. Lemmetyinen, T. Smolander, J. Vehviläinen and J. Pulliainen, "Sentinel-1 based soil freeze/thaw estimation in boreal forest environments", Remote Sensing of Environment, vol. 254, P. 112267, 2021.

Links between variations of σ_0 and tree physiology

A

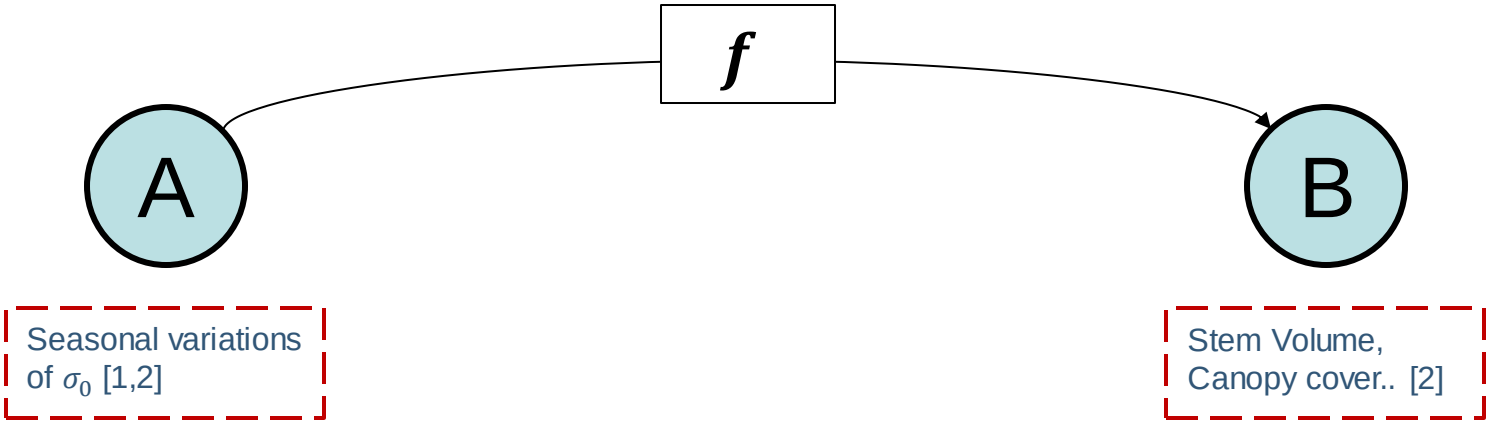
Seasonal variations of σ_0 [1,2]

B

Stem Volume, Canopy cover.. [2]

[1] E. Rignot and J. B. Way, "Monitoring freeze-thaw cycles along north-south Alaskan transects using ERS-1 SAR", Remote Sensing of Environment, vol. 49, no. 2, pp. 131-137, 1994.
[2] J. Cohen, K. Rautiainen J. Lemmetyinen, T. Smolander, J. Vehviläinen and J. Pulliainen, "Sentinel-1 based soil freeze/thaw estimation in boreal forest environments", Remote Sensing of Environment, vol. 254, P. 112267, 2021.

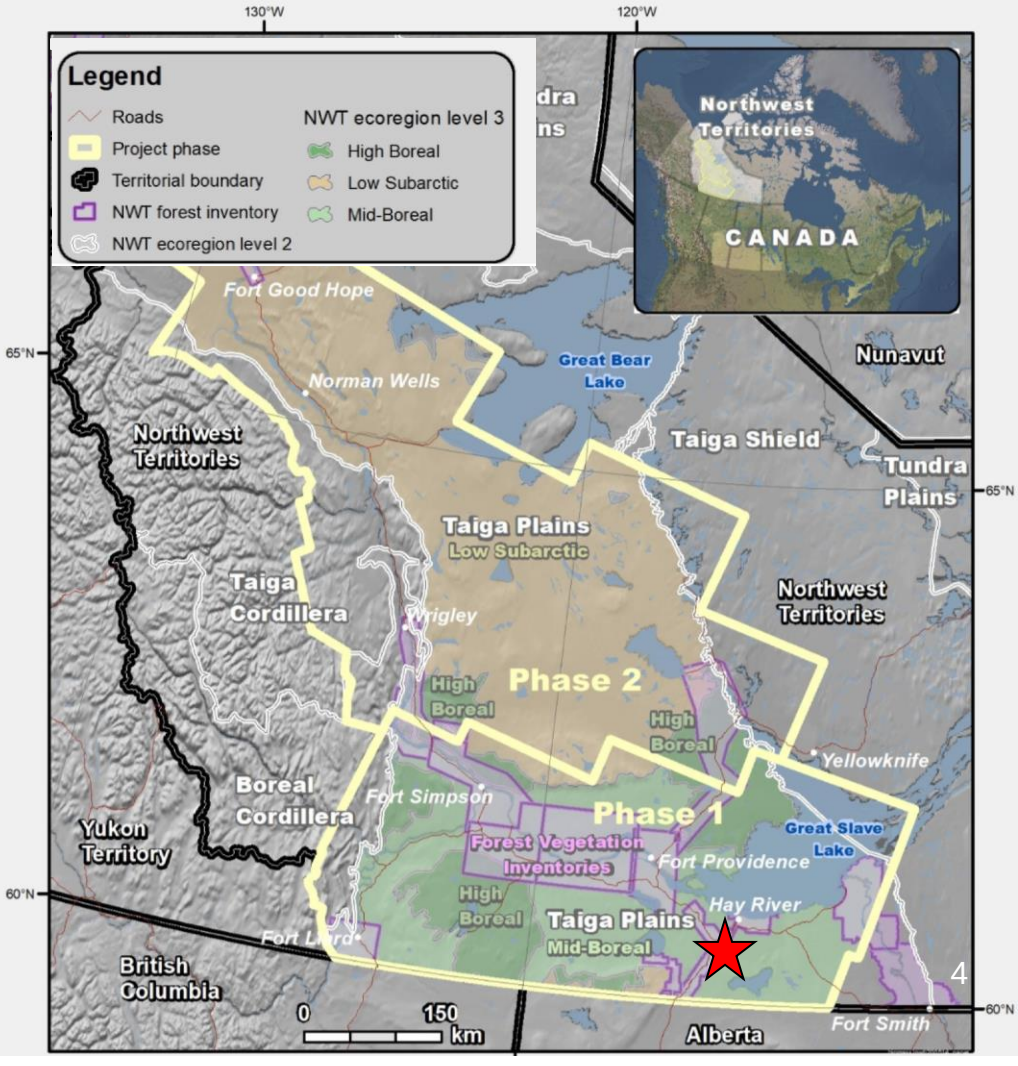
Links between variations of σ_0 and tree physiology



[1] E. Rignot and J. B. Way, "Monitoring freeze-thaw cycles along north-south Alaskan transects using ERS-1 SAR", Remote Sensing of Environment, vol. 49, no. 2, pp. 131-137, 1994.
[2] J. Cohen, K. Rautiainen J. Lemmetyinen, T. Smolander, J. Vehviläinen and J. Pulliainen, "Sentinel-1 based soil freeze/thaw estimation in boreal forest environments", Remote Sensing of Environment, vol. 254, P. 112267, 2021.

Hay River & the Multisource Vegetation Inventory (MVI)

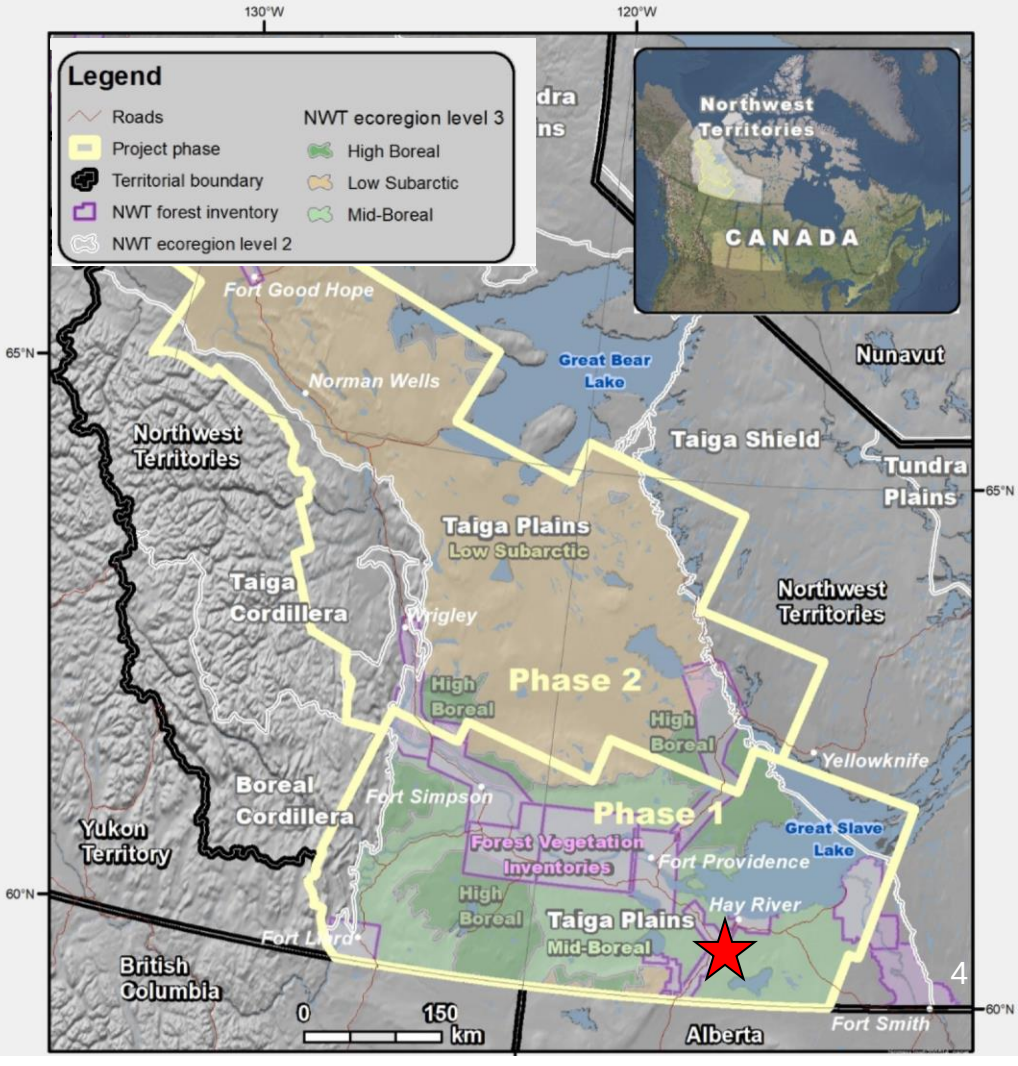
- Study Site: located near **Hay River** town, NWT, Canada



Source: Castilla, G.; Hall, R.J.; Skakun, R.; Filiatrault, M.; Beaudoin, A.; Gartrell, M.; Smith, L.; Groenewegen, K.; Hopkinson, C.; van der Sluijs, J. The Multisource Vegetation Inventory (MVI): A Satellite-Based Forest Inventory for the Northwest Territories Taiga Plains. Remote Sens. 2022, 14, 1108. https://doi.org/10.3390/rs14051108

Hay River & the Multisource Vegetation Inventory (MVI)

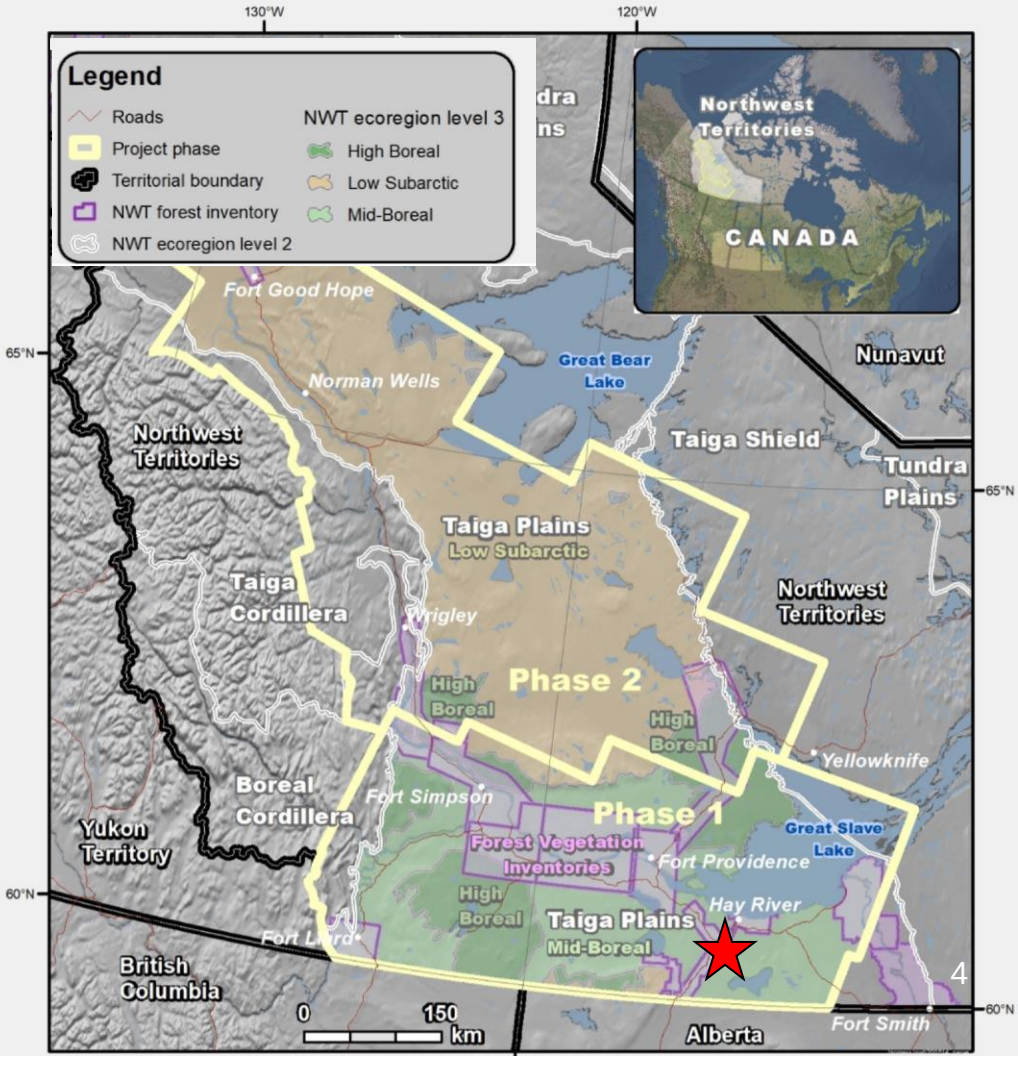
- Study Site: located near **Hay River** town, NWT, Canada
- Dominated by upland **coniferous forests**, treed/non-treed **wetlands**, **water bodies** and **burned areas**



Source: Castilla, G.; Hall, R.J.; Skakun, R.; Filiatrault, M.; Beaudoin, A.; Gartrell, M.; Smith, L.; Groenewegen, K.; Hopkinson, C.; van der Sluijs, J. The Multisource Vegetation Inventory (MVI): A Satellite-Based Forest Inventory for the Northwest Territories Taiga Plains. Remote Sens. 2022, 14, 1108. https://doi.org/10.3390/rs14051108

Hay River & the Multisource Vegetation Inventory (MVI)

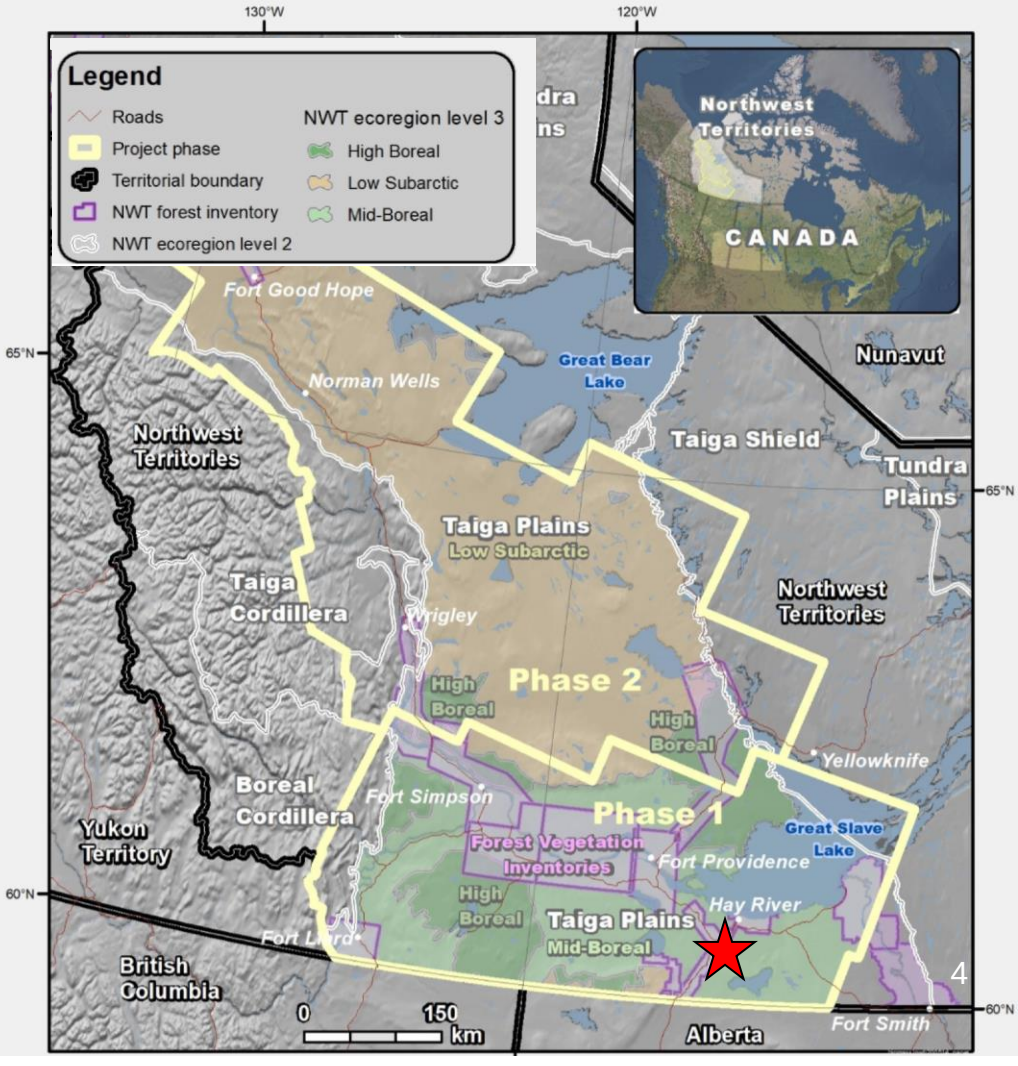
- Study Site: located near **Hay River** town, NWT, Canada
- Dominated by upland **coniferous forests**, treed/non-treed **wetlands**, **water bodies** and **burned areas**
- **39** 400-m2 **forest inventory (FI) ground plots** with a suite of plot-level forest structural attributes derived from tree-level measurements



Source: Castilla, G.; Hall, R.J.; Skakun, R.; Filiatrault, M.; Beaudoin, A.; Gartrell, M.; Smith, L.; Groenewegen, K.; Hopkinson, C.; van der Sluijs, J. The Multisource Vegetation Inventory (MVI): A Satellite-Based Forest Inventory for the Northwest Territories Taiga Plains. Remote Sens. 2022, 14, 1108. https://doi.org/10.3390/rs14051108

Hay River & the Multisource Vegetation Inventory (MVI)

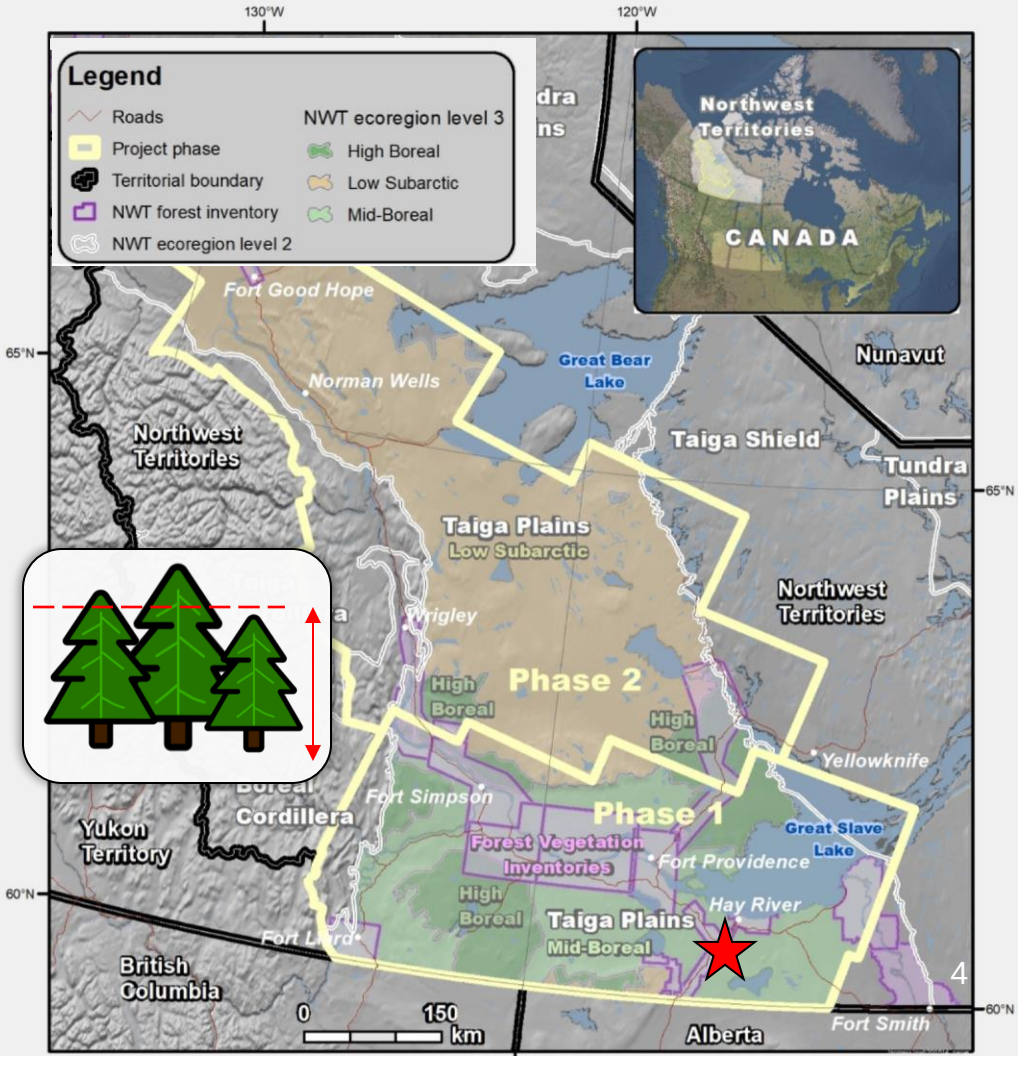
- Study Site: located near **Hay River** town, NWT, Canada
- Dominated by upland **coniferous forests**, treed/non-treed **wetlands**, **water bodies** and **burned areas**
- **39** 400-m2 **forest inventory (FI) ground plots** with a suite of plot-level forest structural attributes derived from tree-level measurements
- Plot-level attributes include:



Source: Castilla, G.; Hall, R.J.; Skakun, R.; Filiatrault, M.; Beaudoin, A.; Gartrell, M.; Smith, L.; Groenewegen, K.; Hopkinson, C.; van der Sluijs, J. The Multisource Vegetation Inventory (MVI): A Satellite-Based Forest Inventory for the Northwest Territories Taiga Plains. Remote Sens. 2022, 14, 1108. https://doi.org/10.3390/rs14051108

Hay River & the Multisource Vegetation Inventory (MVI)

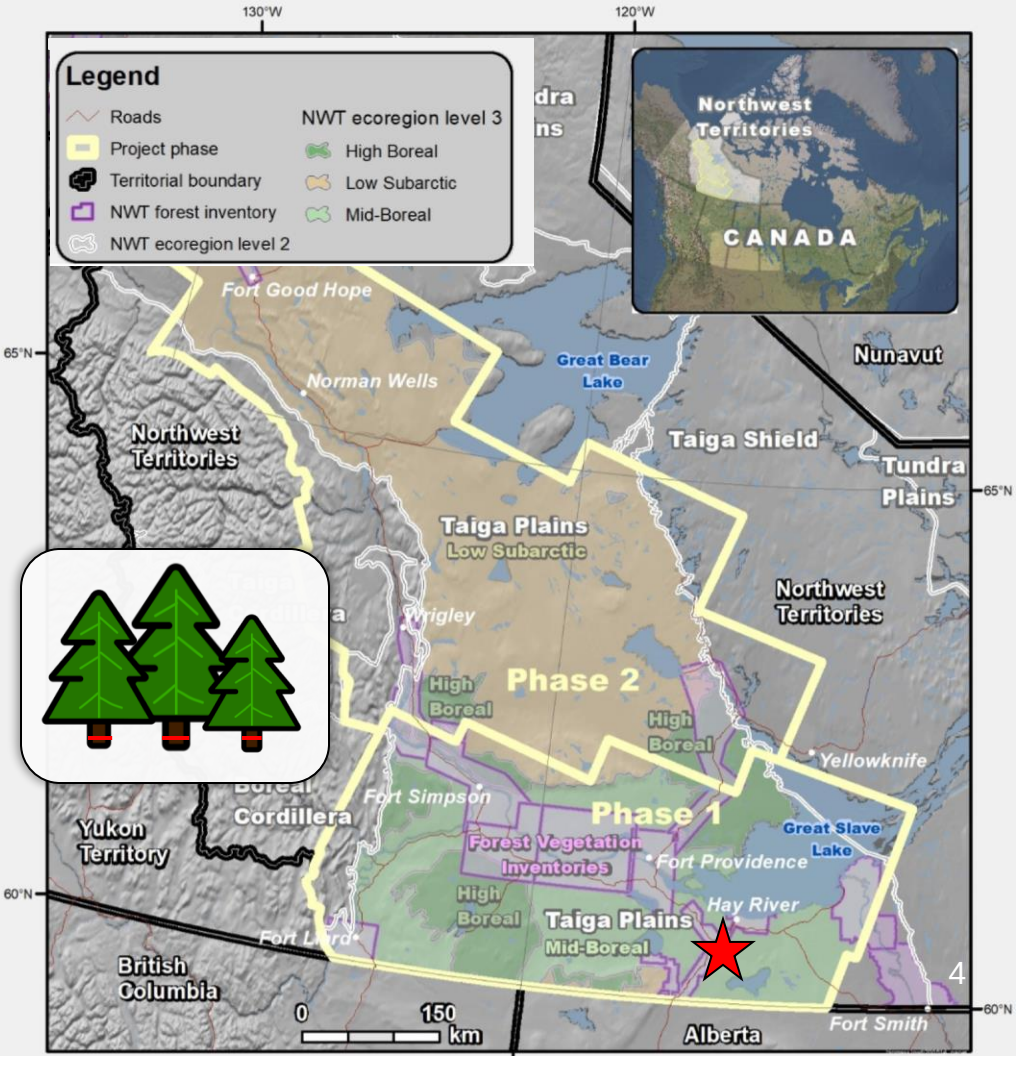
- Study Site: located near **Hay River** town, NWT, Canada
- Dominated by upland **coniferous forests**, treed/non-treed **wetlands**, **water bodies** and **burned areas**
- **39** 400-m2 **forest inventory (FI) ground plots** with a suite of plot-level forest structural attributes derived from tree-level measurements
- Plot-level attributes include:
  - Stand Height (StH, m)



Source: Castilla, G.; Hall, R.J.; Skakun, R.; Filiatrault, M.; Beaudoin, A.; Gartrell, M.; Smith, L.; Groenewegen, K.; Hopkinson, C.; van der Sluijs, J. The Multisource Vegetation Inventory (MVI): A Satellite-Based Forest Inventory for the Northwest Territories Taiga Plains. Remote Sens. 2022, 14, 1108. https://doi.org/10.3390/rs14051108

Hay River & the Multisource Vegetation Inventory (MVI)

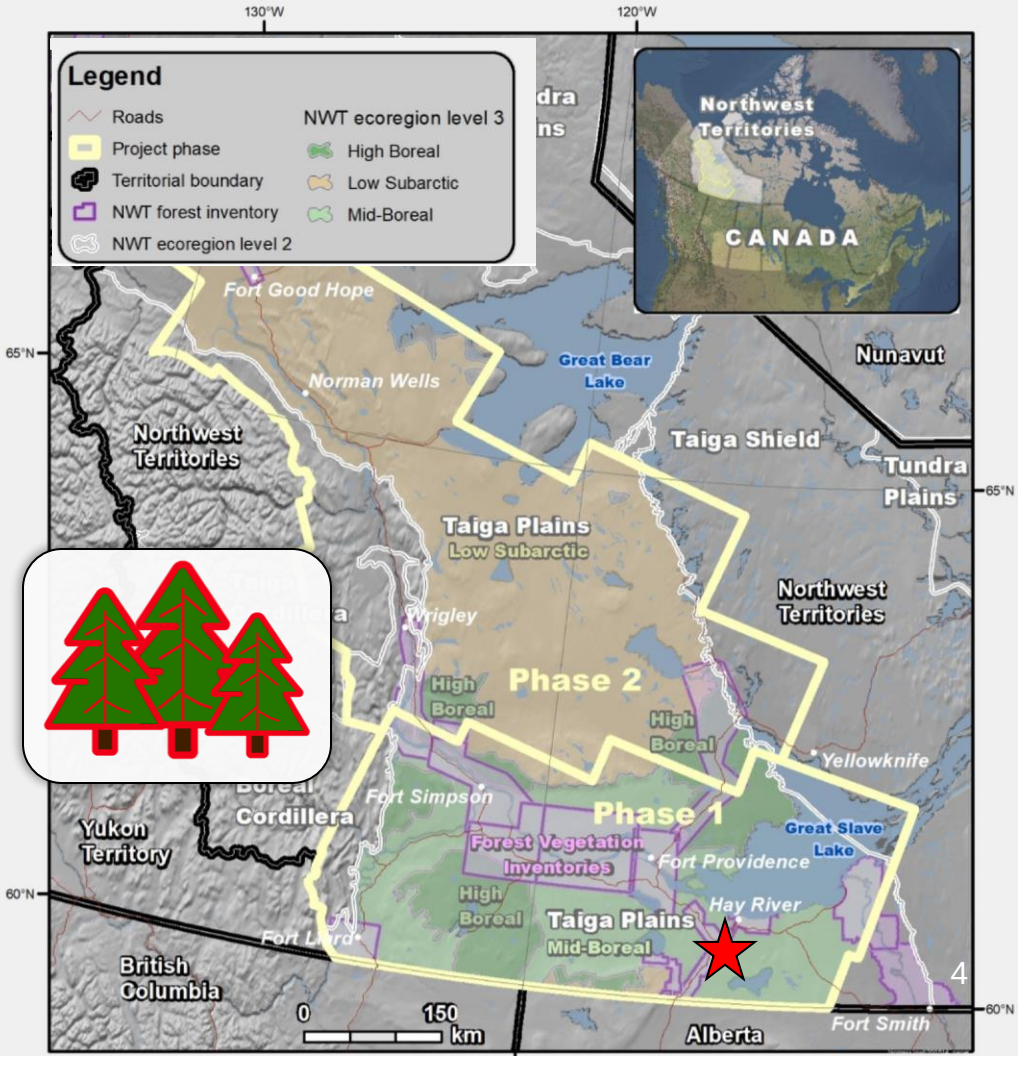
- Study Site: located near **Hay River** town, NWT, Canada
- Dominated by upland **coniferous forests**, treed/non-treed **wetlands**, **water bodies** and **burned areas**
- **39** 400-m2 **forest inventory (FI) ground plots** with a suite of plot-level forest structural attributes derived from tree-level measurements
- Plot-level attributes include:
  - Stand Height (StH, m)
  - Quadratic Mean Diameter (QMD, cm)



Source: Castilla, G.; Hall, R.J.; Skakun, R.; Filiatrault, M.; Beaudoin, A.; Gartrell, M.; Smith, L.; Groenewegen, K.; Hopkinson, C.; van der Sluijs, J. The Multisource Vegetation Inventory (MVI): A Satellite-Based Forest Inventory for the Northwest Territories Taiga Plains. Remote Sens. 2022, 14, 1108. https://doi.org/10.3390/rs14051108

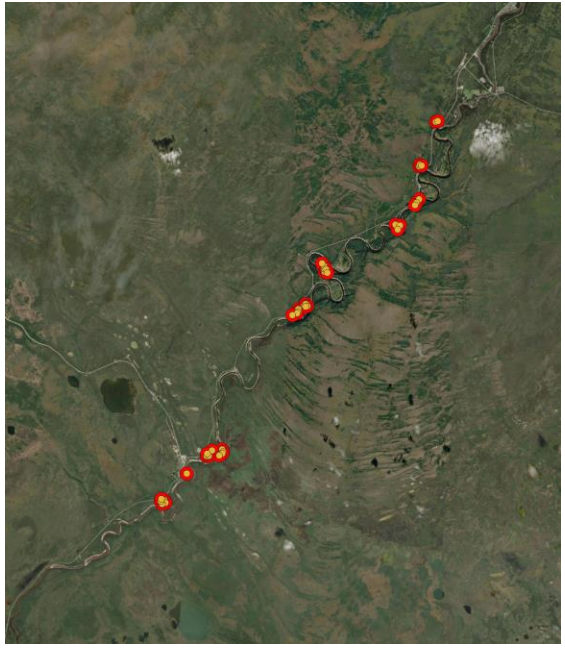
Hay River & the Multisource Vegetation Inventory (MVI)

- Study Site: located near **Hay River** town, NWT, Canada
- Dominated by upland **coniferous forests**, treed/non-treed **wetlands**, **water bodies** and **burned areas**
- **39** 400-m2 **forest inventory (FI) ground plots** with a suite of plot-level forest structural attributes derived from tree-level measurements
- Plot-level attributes include:
  - Stand Height (StH, m)
  - Quadratic Mean Diameter (QMD, cm)
  - Above Ground Biomass (AGB, t/ha)



Source: Castilla, G.; Hall, R.J.; Skakun, R.; Filiatrault, M.; Beaudoin, A.; Gartrell, M.; Smith, L.; Groenewegen, K.; Hopkinson, C.; van der Sluijs, J. The Multisource Vegetation Inventory (MVI): A Satellite-Based Forest Inventory for the Northwest Territories Taiga Plains. Remote Sens. 2022, 14, 1108. https://doi.org/10.3390/rs14051108

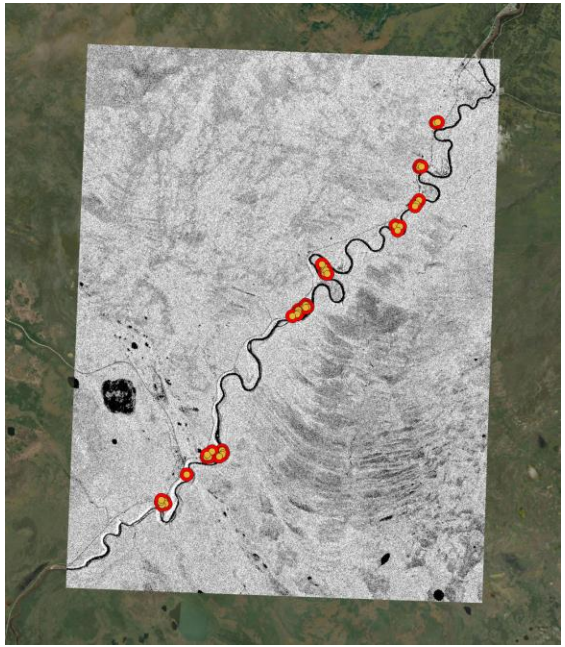
Hay River & the Multisource Vegetation Inventory (MVI)



Ground plots

Source: Castilla, G.; Hall, R.J.; Skakun, R.; Filiatrault, M.; Beaudoin, A.; Gartrell, M.; Smith, L.; Groenewegen, K.; Hopkinson, C.; van der Sluijs, J. The Multisource Vegetation Inventory (MVI): A Satellite-Based Forest Inventory for the Northwest Territories Taiga Plains. Remote Sens. 2022, 14, 1108. https://doi.org/10.3390/rs14051108

Sentinel-1 Acquisitions over the Hay River region



- 111 Sentinel-1 acquisitions between May 2017 and Dec. 2020
- Orbit number: 42
- Orbit mode: Descending
- Polarizations: VV, VH
- Approx 15M pixels
- 150,000 Ha

Data-driven approaches to finding an approximation of f

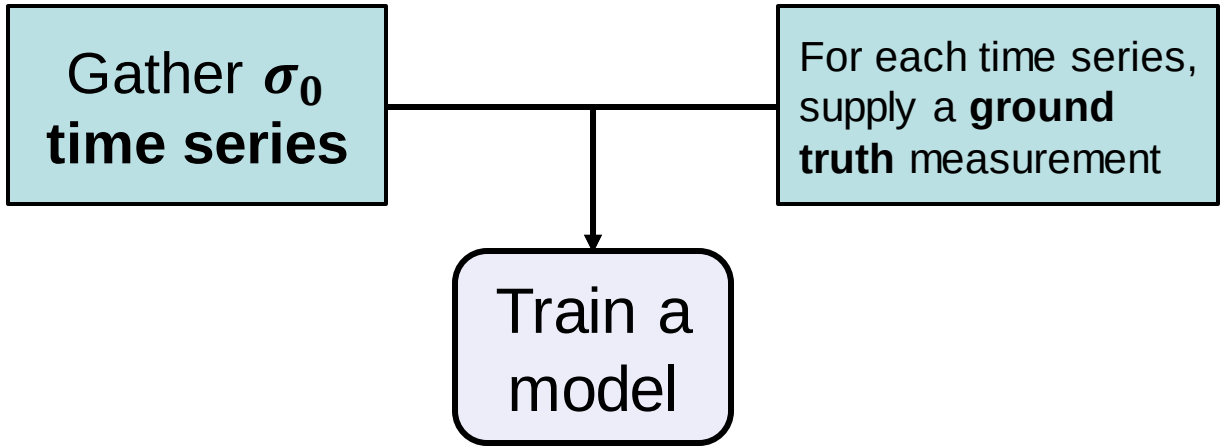
Gather σ_0 **time series**

Data-driven approaches to finding an approximation of f

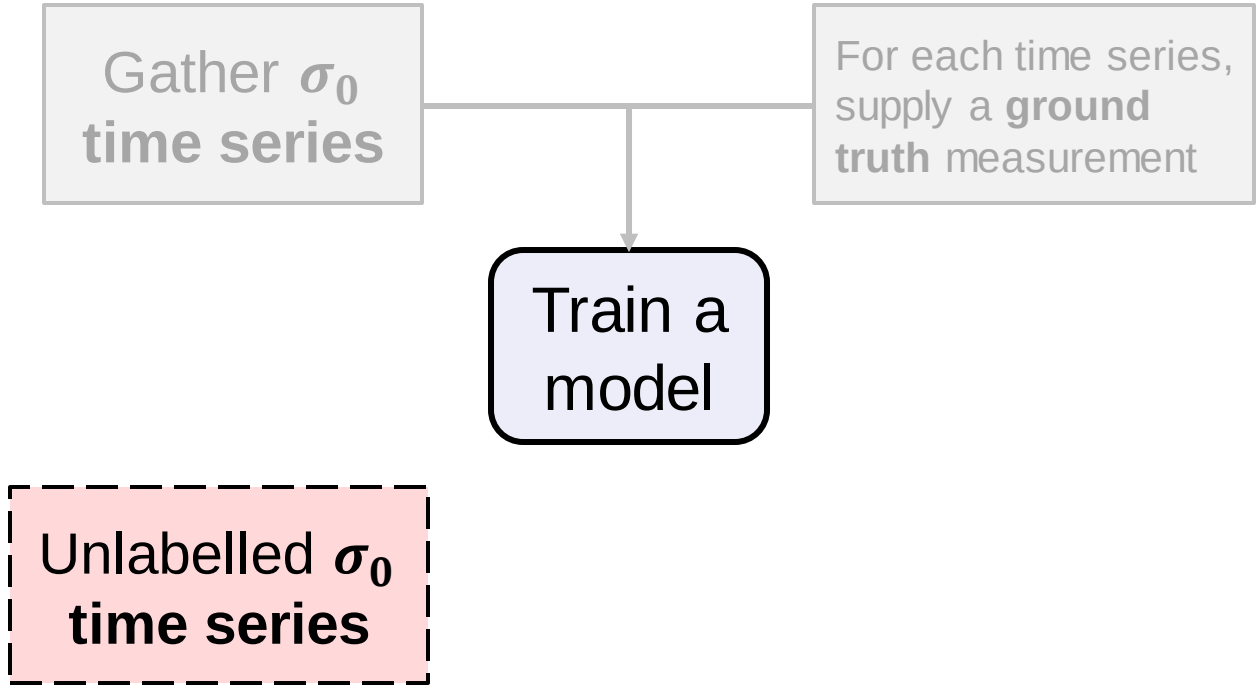
Gather σ_0 **time series**

For each time series, supply a **ground truth** measurement

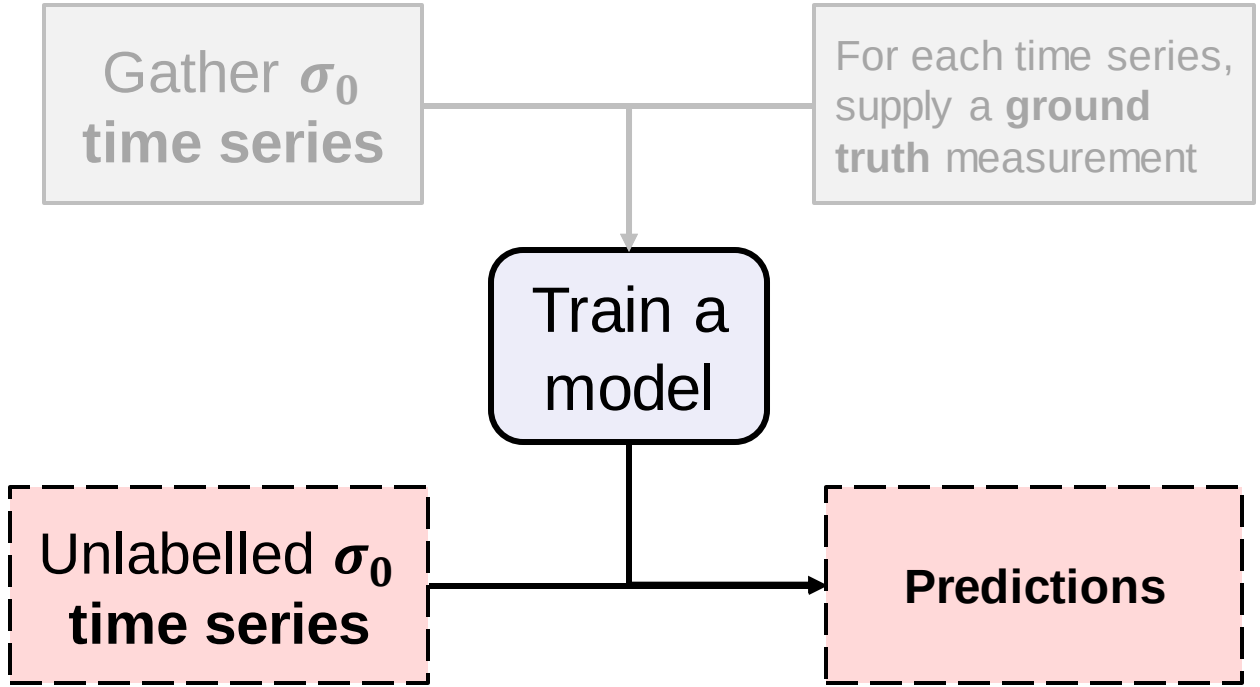
Data-driven approaches to finding an approximation of f



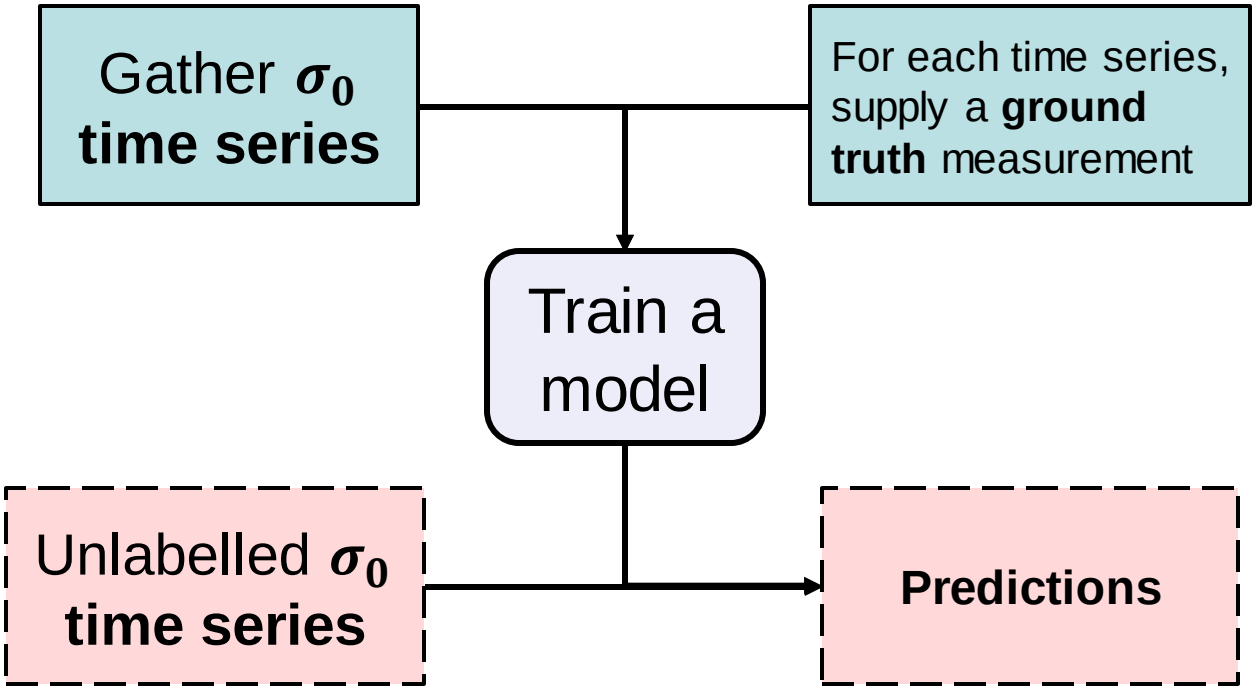
Data-driven approaches to finding an approximation of f



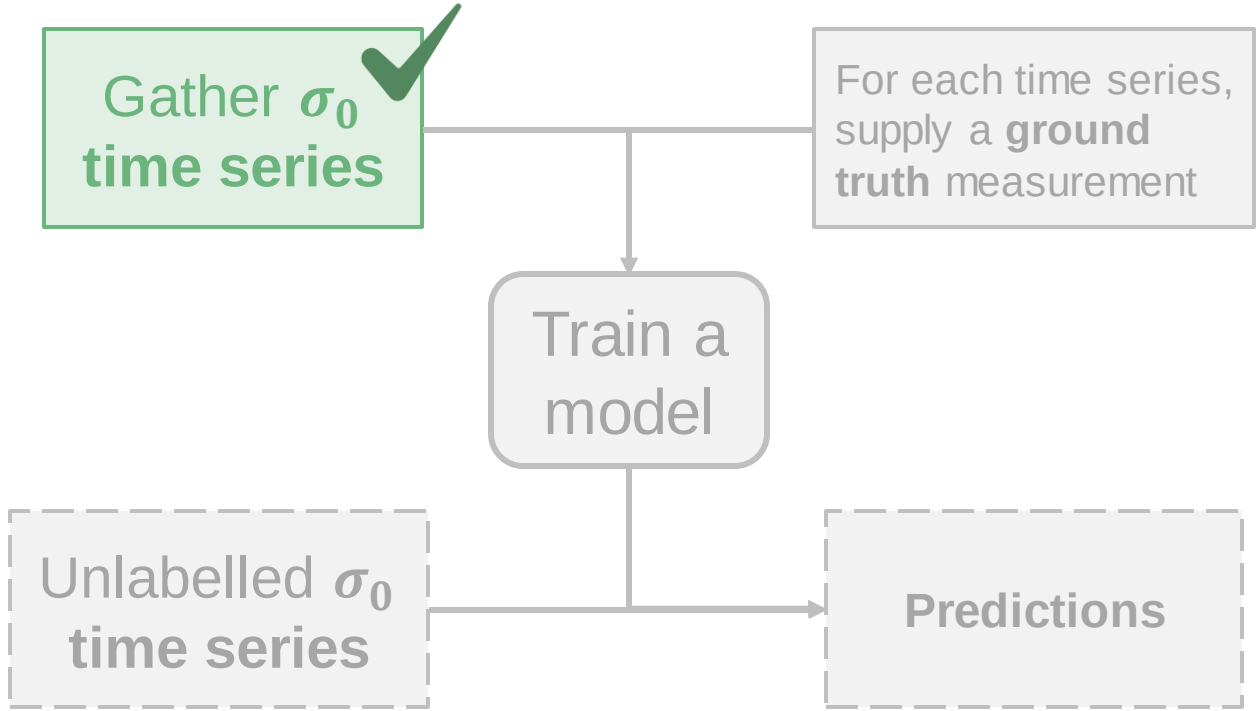
Data-driven approaches to finding an approximation of f



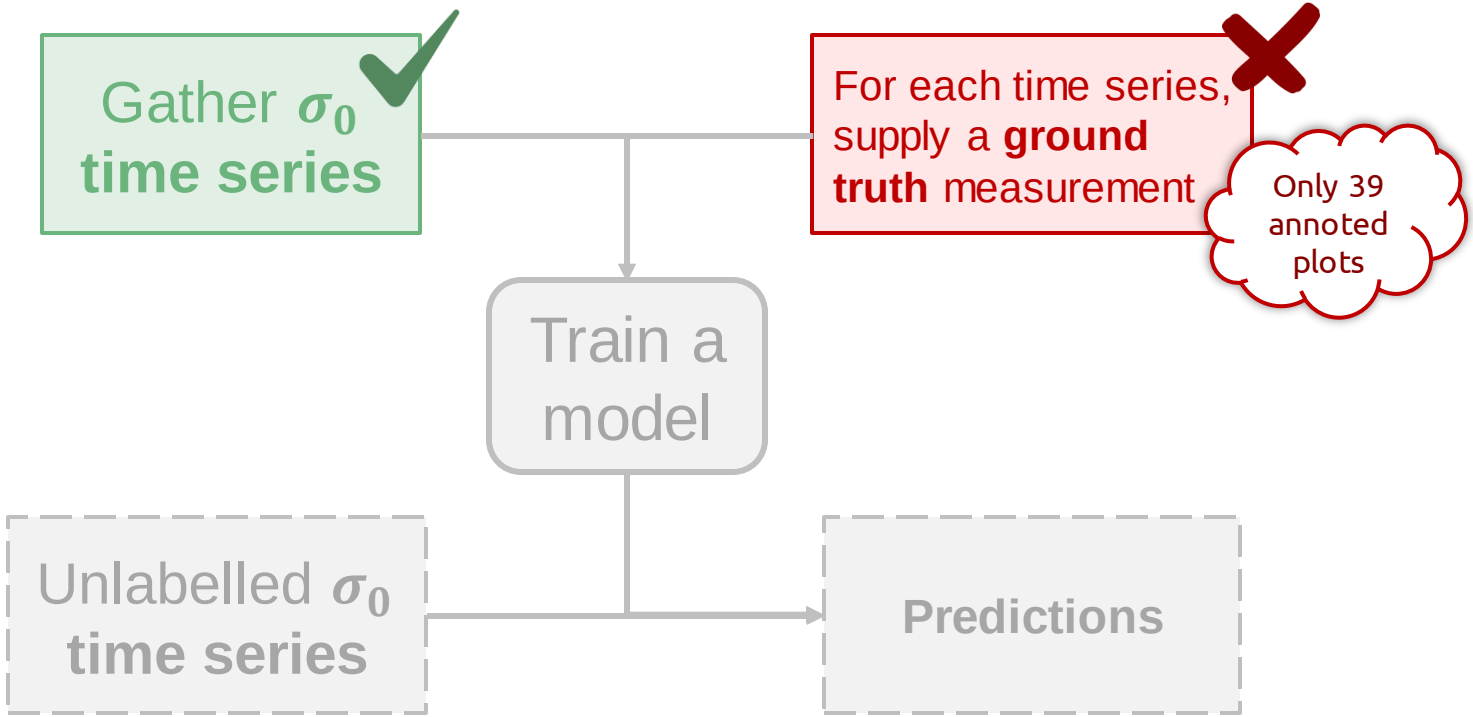
Data-driven approaches to finding an approximation of f



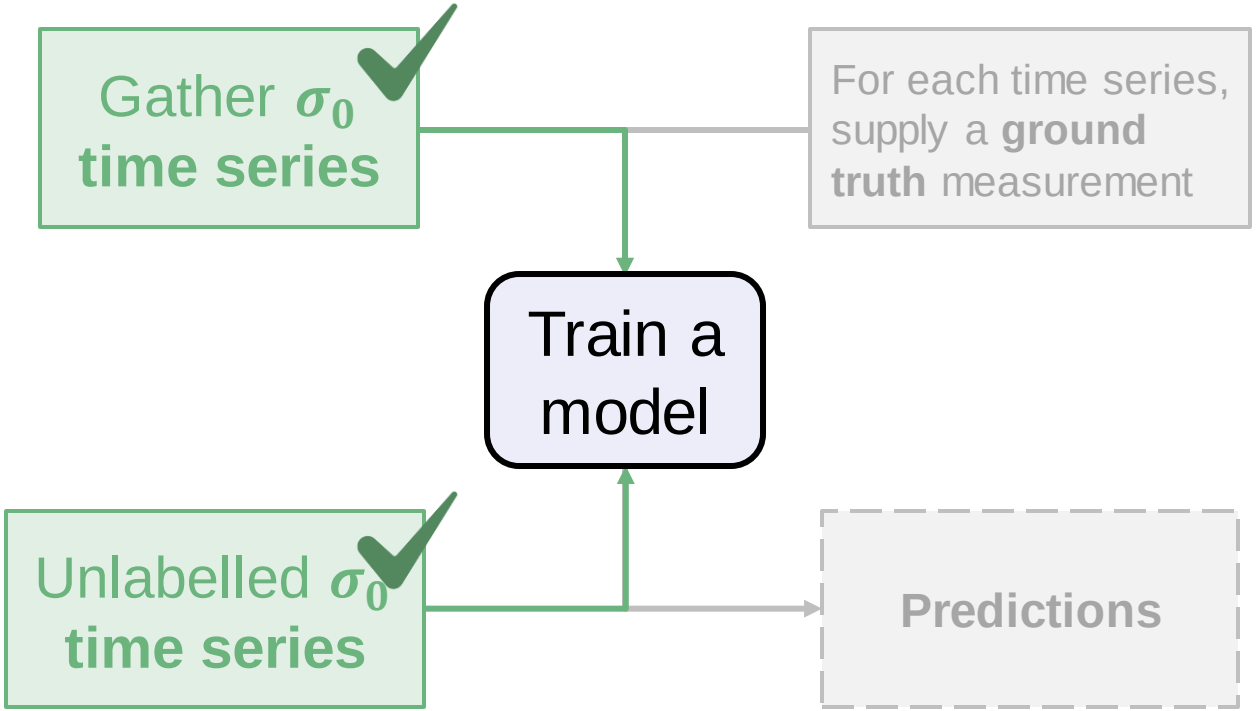
Data-driven approaches to finding an approximation of f



Data-driven approaches to finding an approximation of f



Data-driven approaches to finding an approximation of f



Unsupervised learning modelling of SAR Time Series

If a physiological parameter plays a role in C-Band temporal profile of vegetation

[3] Thomas Di Martino, Régis Guinvarc'h, Laetitia Thirion-Lefevre and Élise Colin, "Beets or Cotton? Blind Extraction of Fine Agricultural Classes Using a Convolutional Autoencoder Applied to Temporal SARSignatures," IEEE Transactions on Geoscience and Remote Sensing, vol. 60, pp. 1-18, 2022.

Unsupervised learning modelling of SAR Time Series

If a physiological parameter plays a role in C-Band temporal profile of vegetation

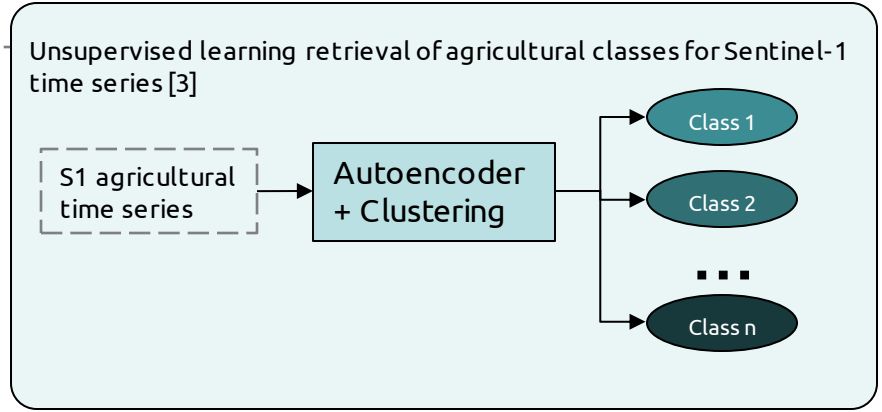
They should be picked on by unsupervised learning

[3] Thomas Di Martino, Régis Guinvarc'h, Laetitia Thirion-Lefevre and Élise Colin, "Beets or Cotton? Blind Extraction of Fine Agricultural Classes Using a Convolutional Autoencoder Applied to Temporal SARSignatures," IEEE Transactions on Geoscience and Remote Sensing, vol. 60, pp. 1-18, 2022.

Unsupervised learning modelling of SAR Time Series

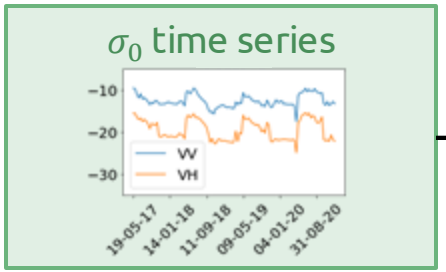
If a physiological parameter plays a role in C-Band temporal profile of vegetation

They should be picked on by unsupervised learning



[3] Thomas Di Martino, Régis Guinvarc'h, Laetitia Thirion-Lefevre and Élise Colin, "Beets or Cotton? Blind Extraction of Fine Agricultural Classes Using a Convolutional Autoencoder Applied to Temporal SAR Signatures," IEEE Transactions on Geoscience and Remote Sensing, vol. 60, pp. 1-18, 2022.

Unsupervised learning modelling of SAR Time Series



Labelled σ_0 time series

Unlabelled σ_0 time series

Train an **unsupervised** model

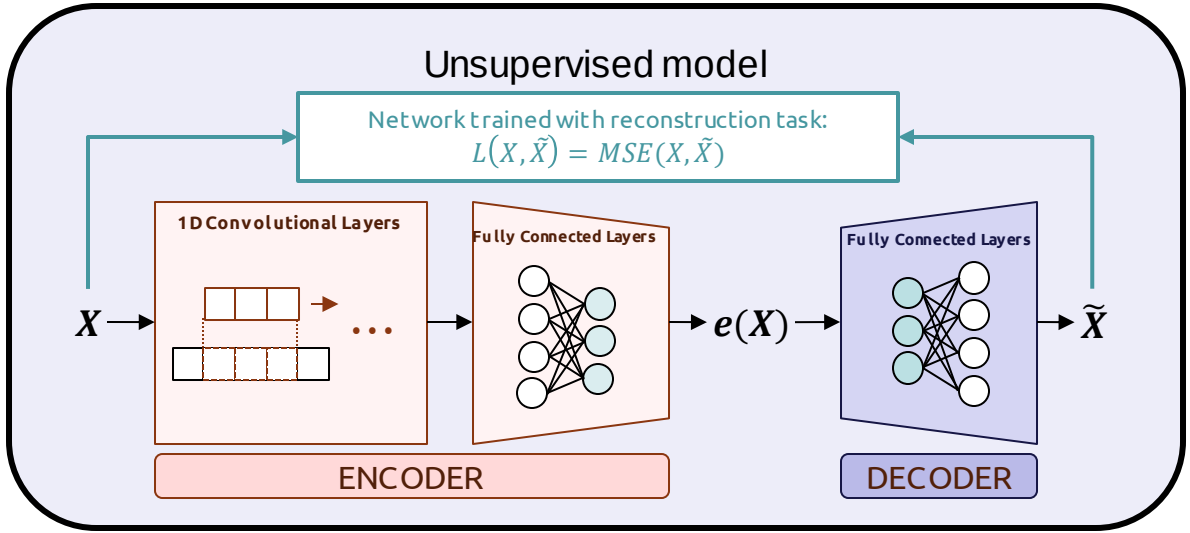
Unsupervised learning modelling of SAR Time Series

Labelled σ_0 time series

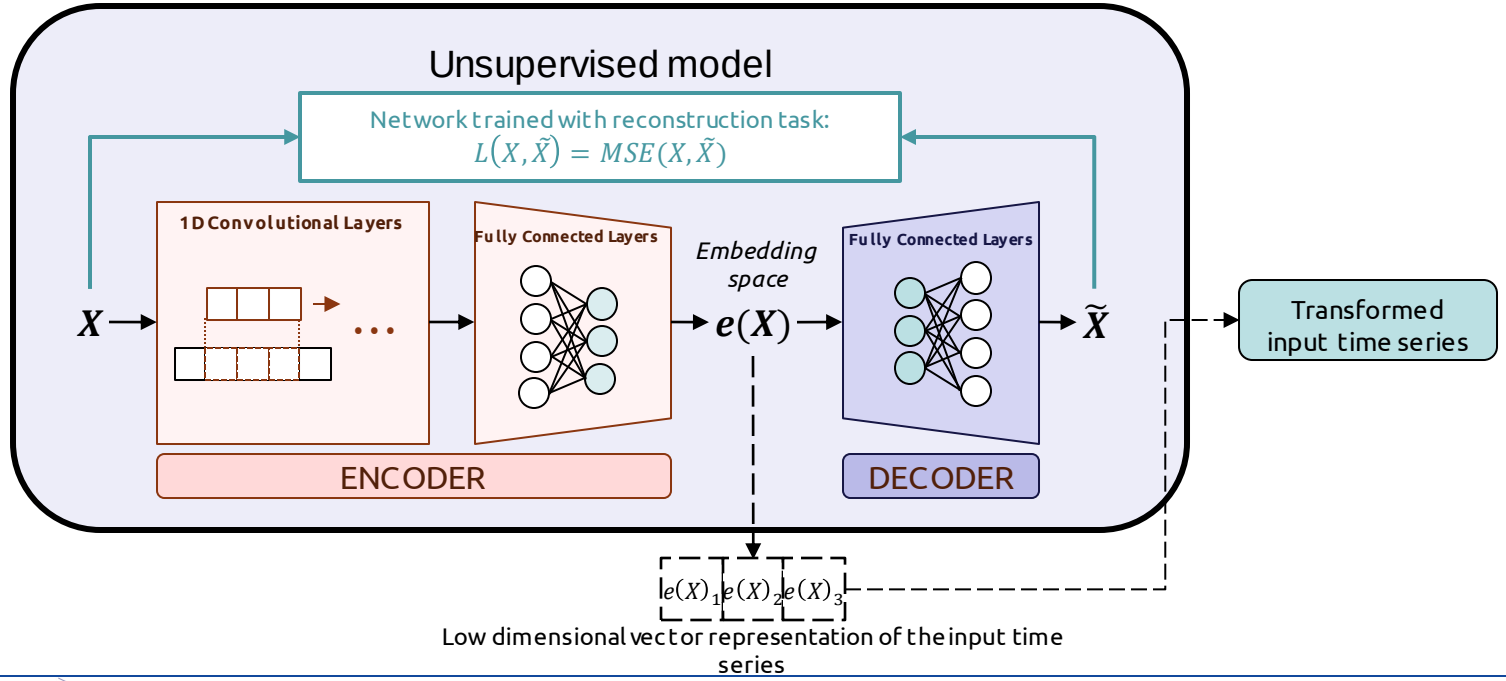
Unlabelled σ_0 time series

Train an **unsupervised** model

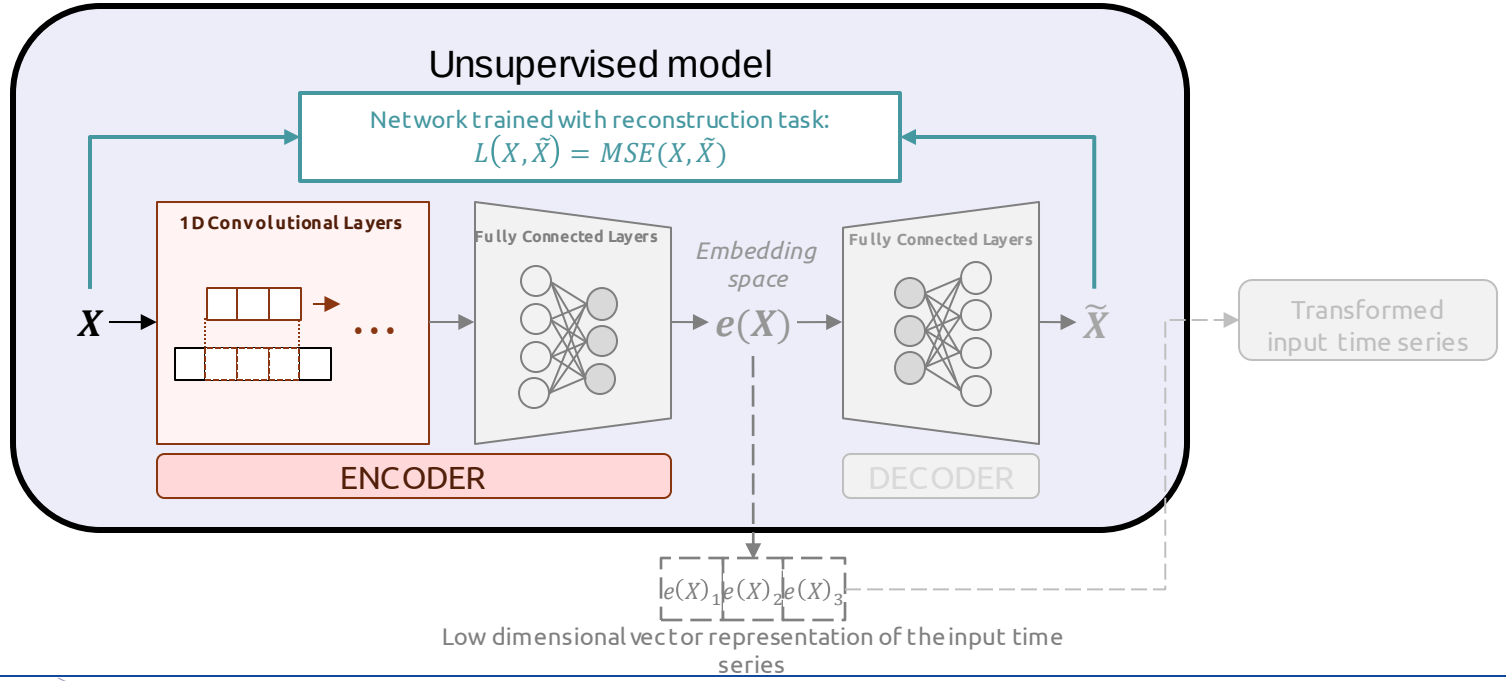
Unsupervised modelling of SAR Time Series



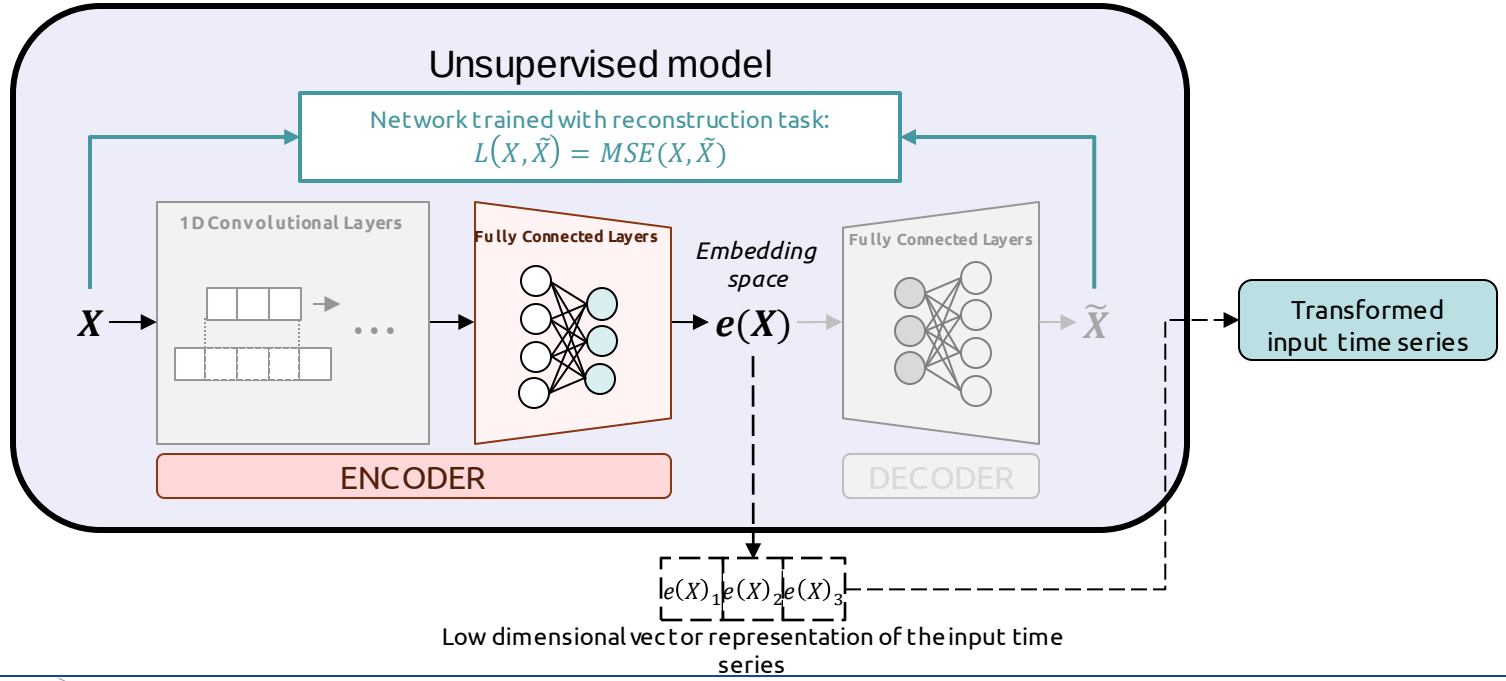
Unsupervised modelling of SAR Time Series



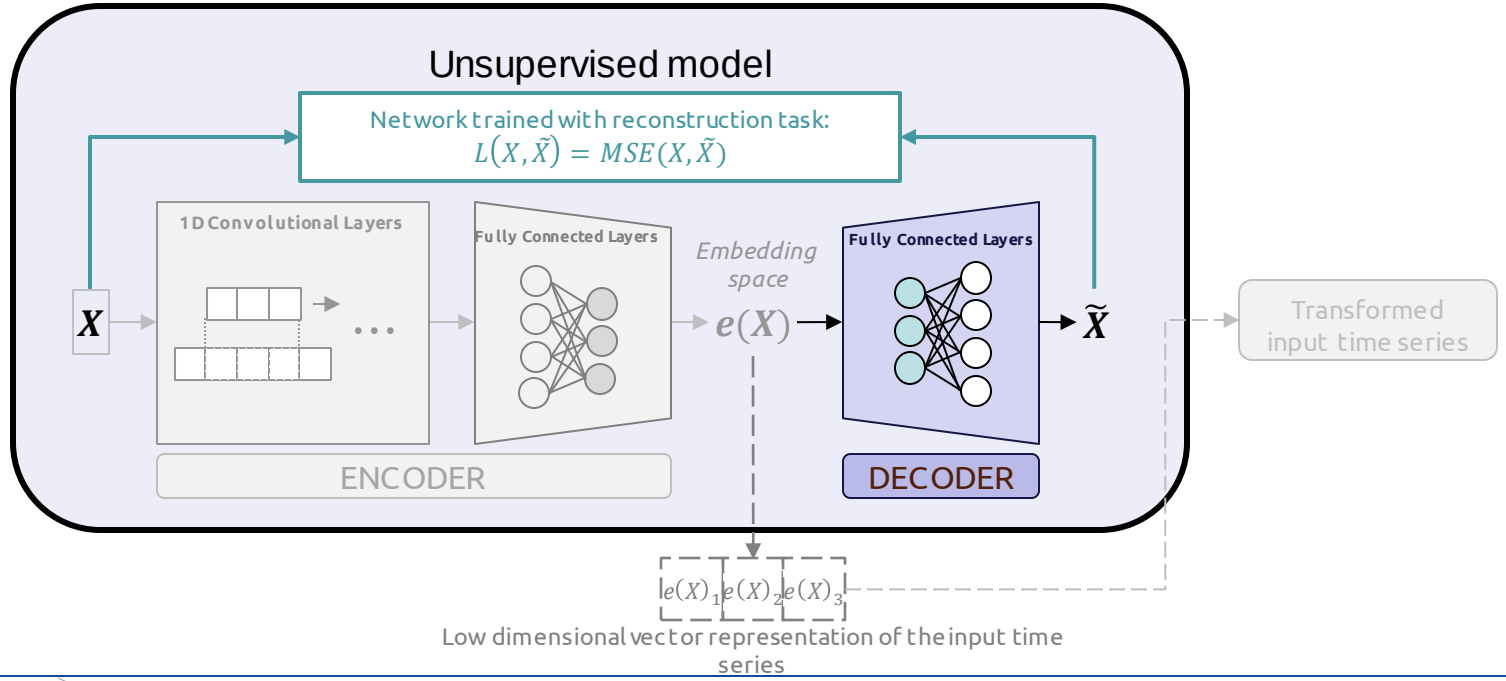
Unsupervised modelling of SAR Time Series



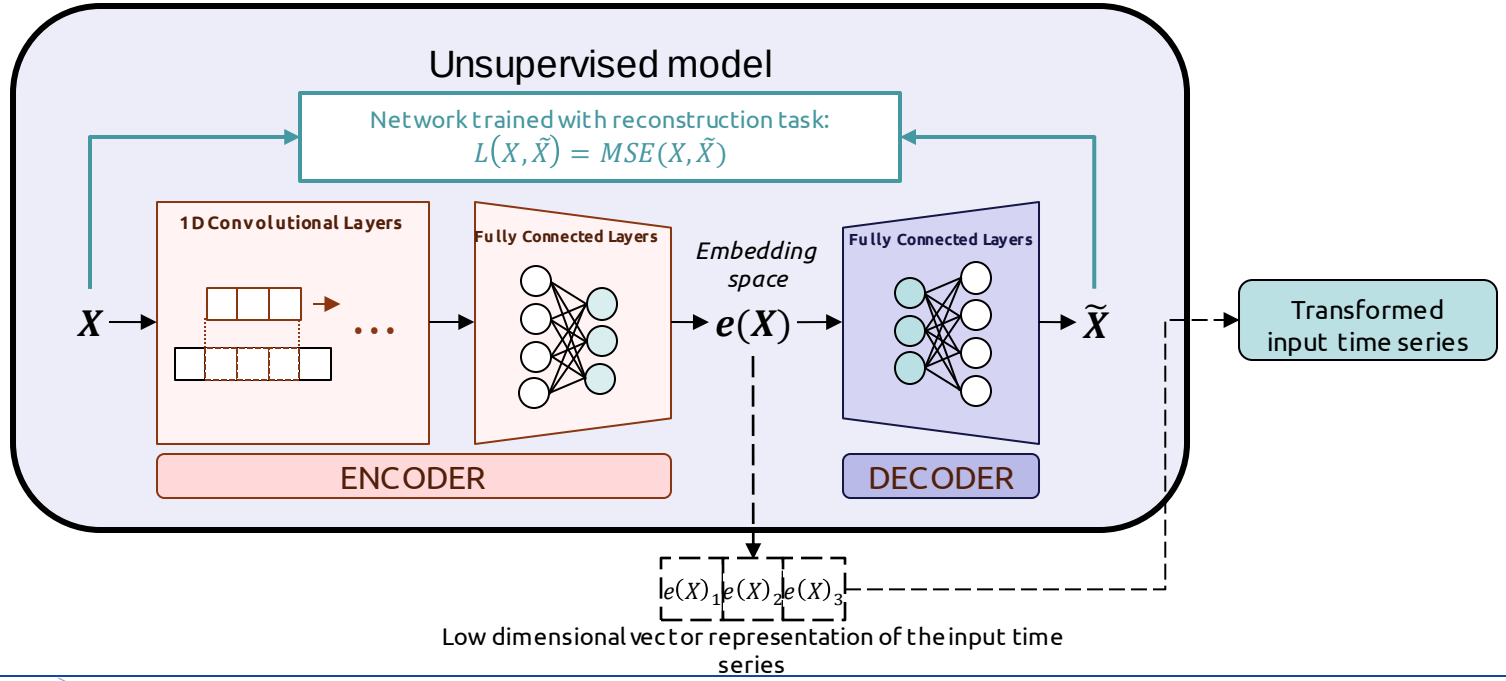
Unsupervised modelling of SAR Time Series



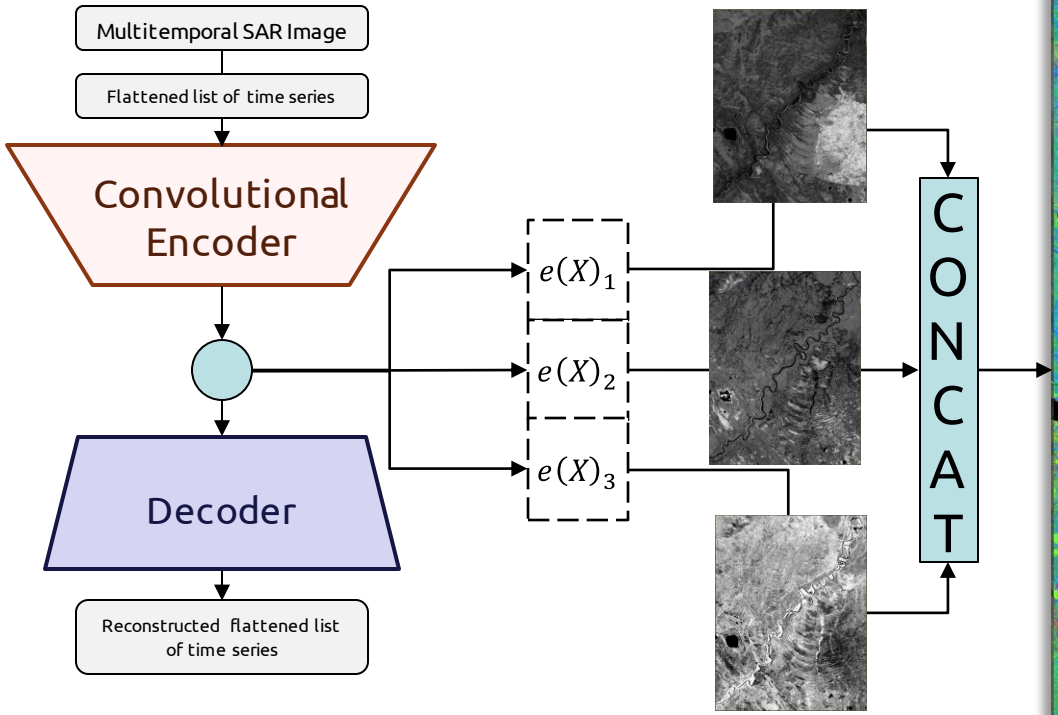
Unsupervised modelling of SAR Time Series

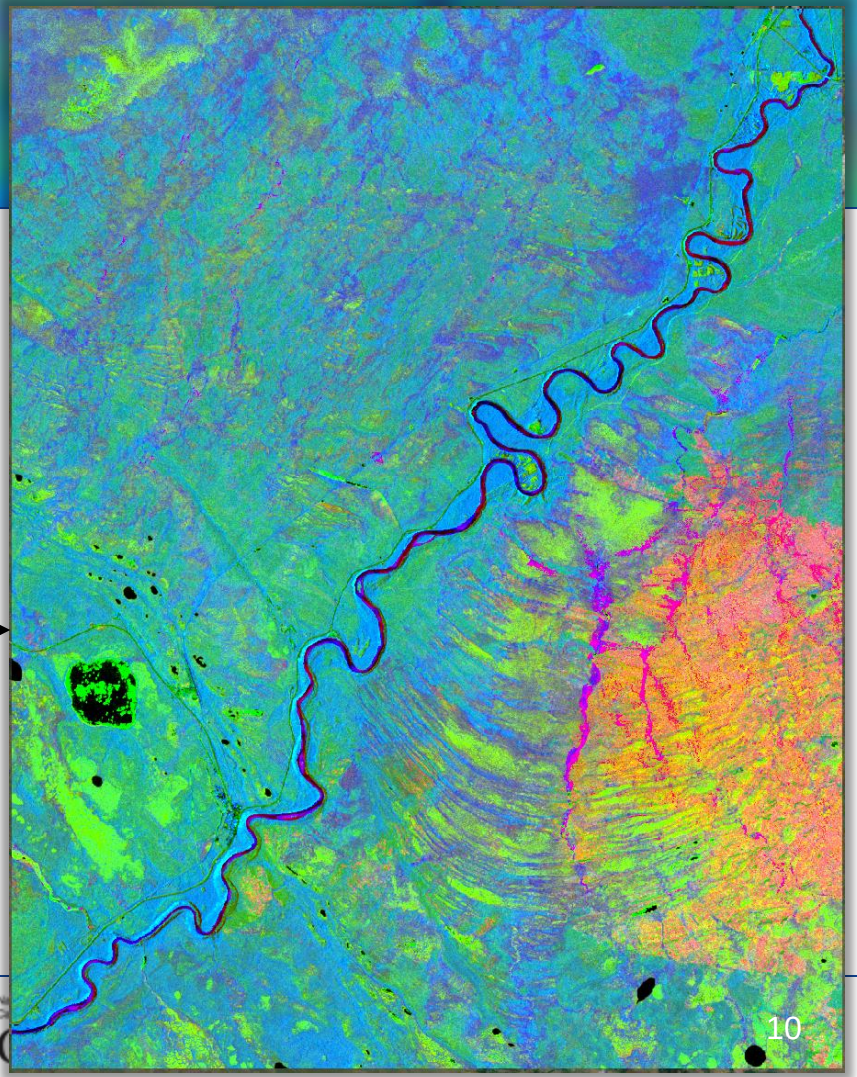


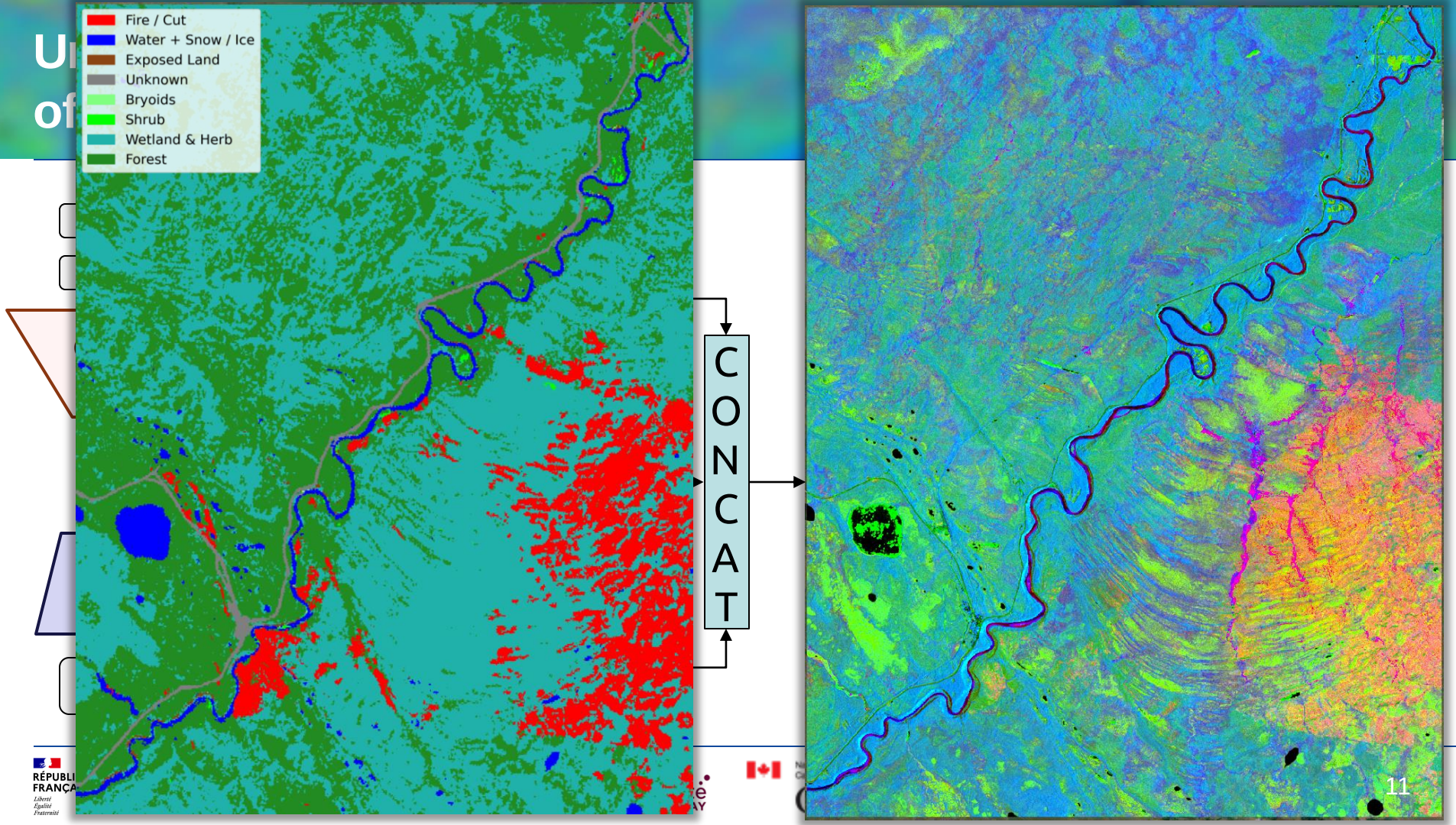
Unsupervised modelling of SAR Time Series



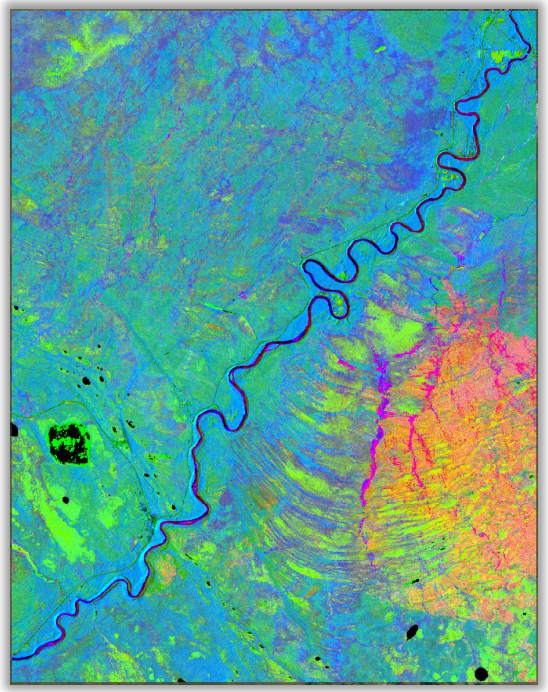
Unsupervised modelling of SAR Time Series

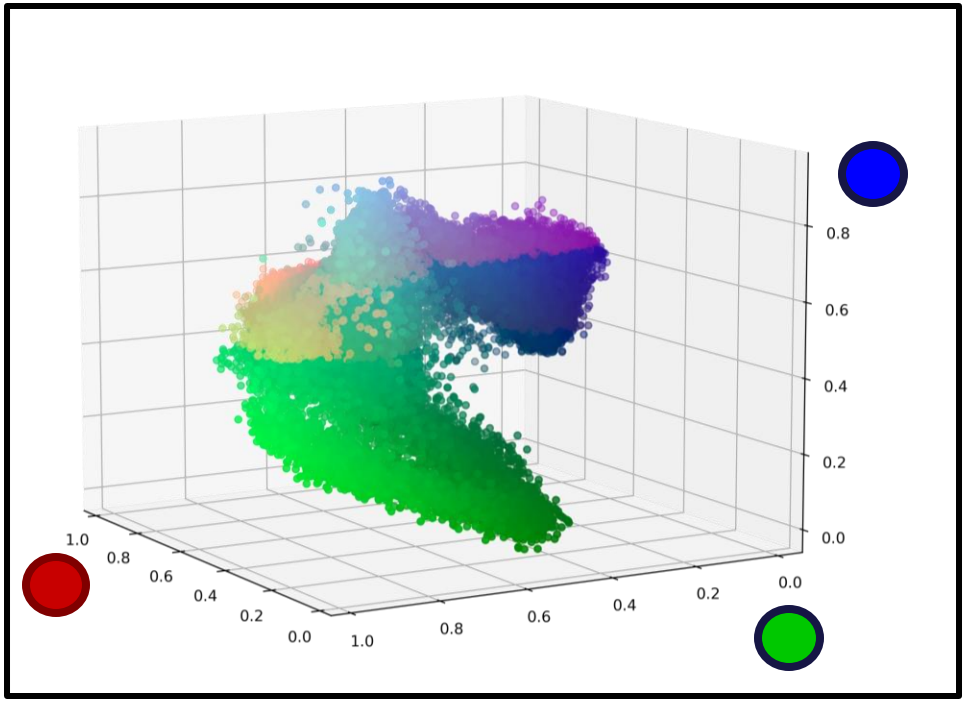




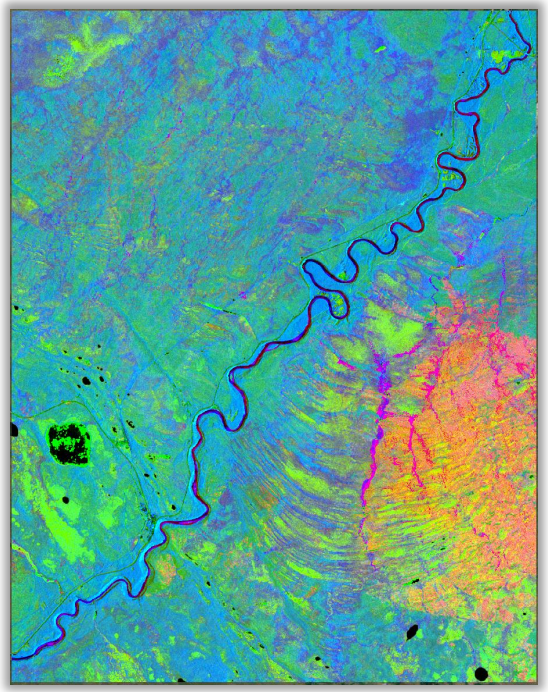

Fire / Cut
Water + Snow / Ice
Exposed Land
Unknown
Bryoids
Shrub
Wetland & Herb
Forest
CONCAT

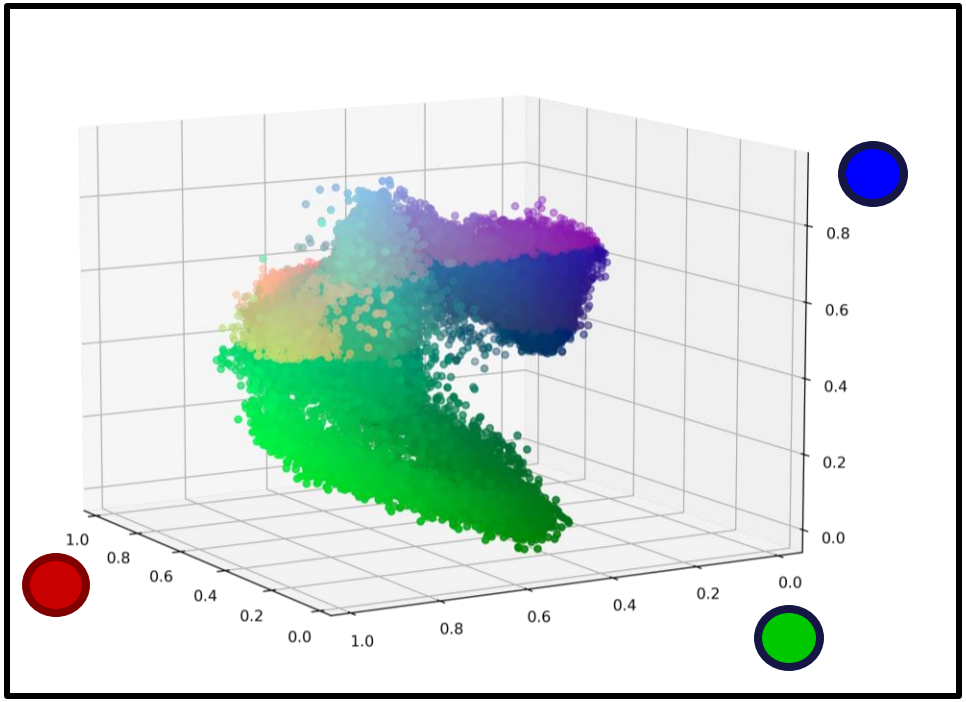
Unsupervised modelling of SAR Time Series



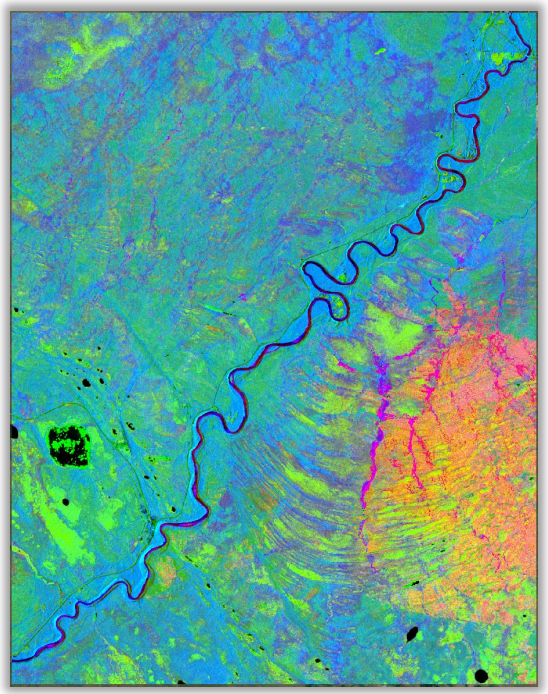


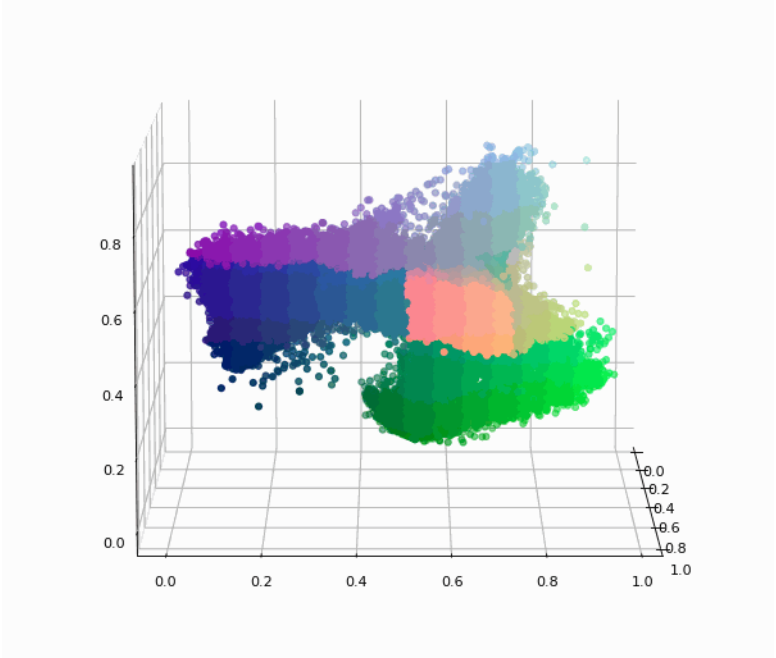
Unsupervised modelling of SAR Time Series



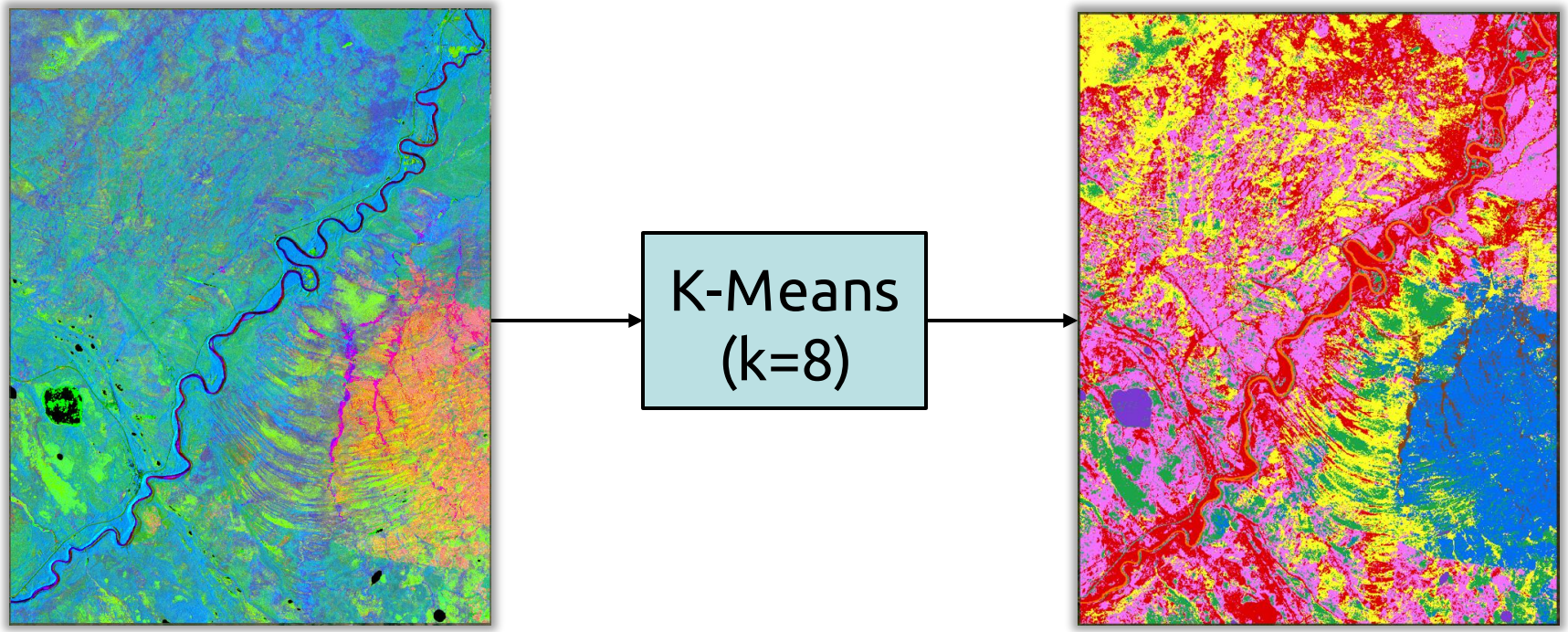


Unsupervised modelling of SAR Time Series

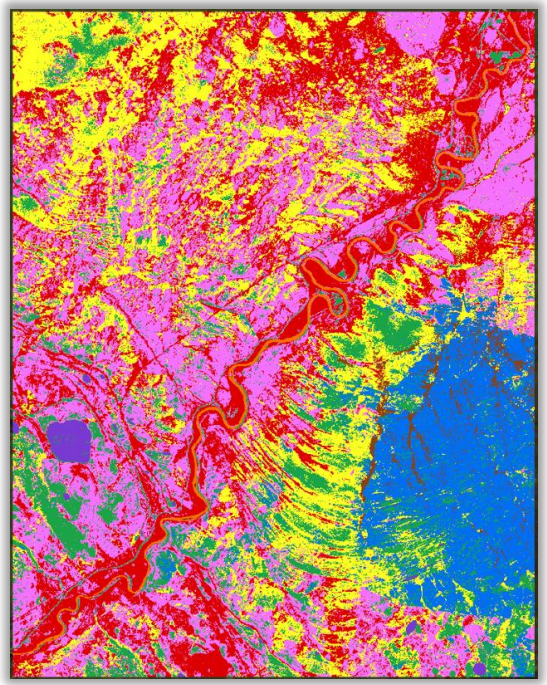


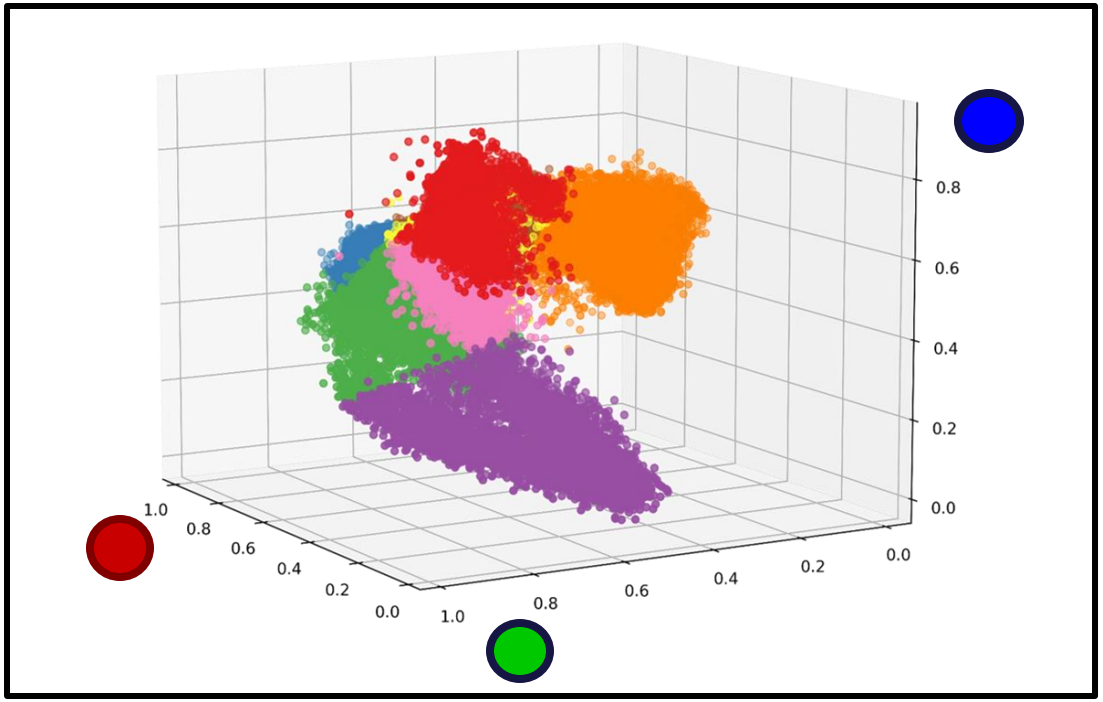


Clustering of the embedding space (8 clusters)

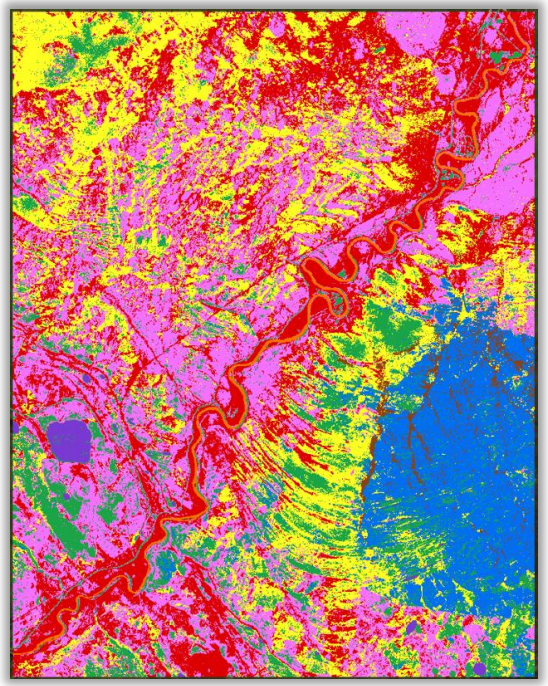


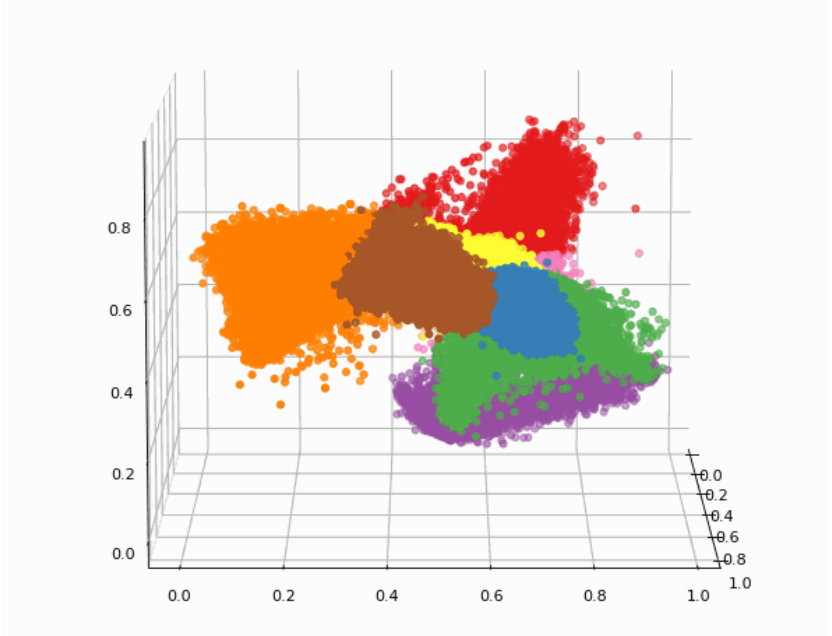
Clustering of the embedding space (8 clusters)



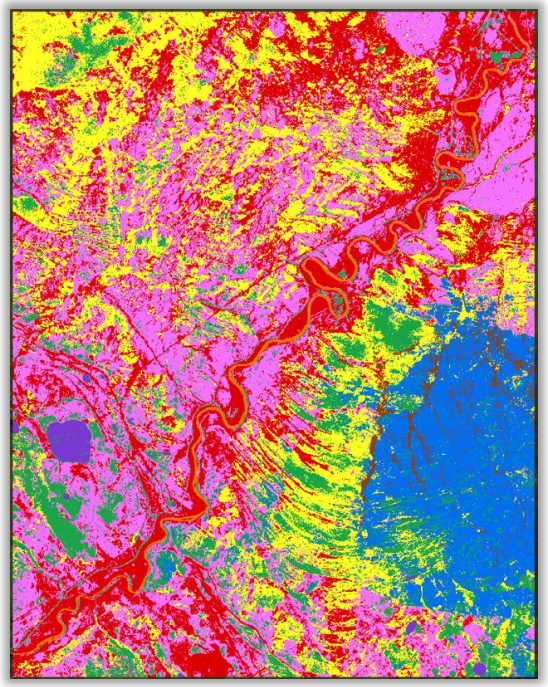


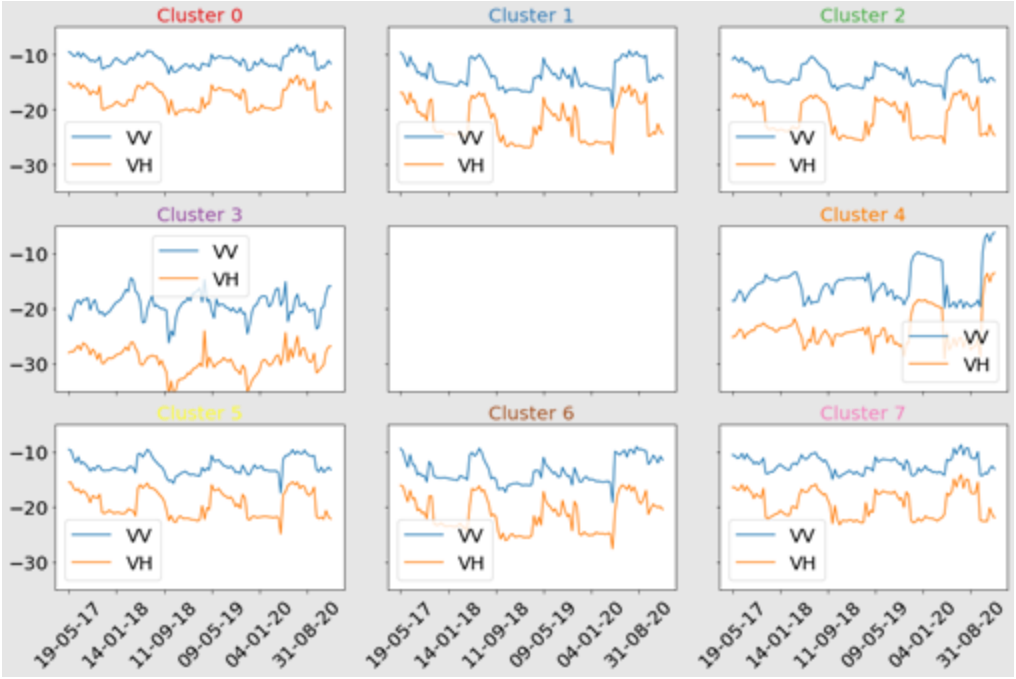
Clustering of the embedding space (8 clusters)



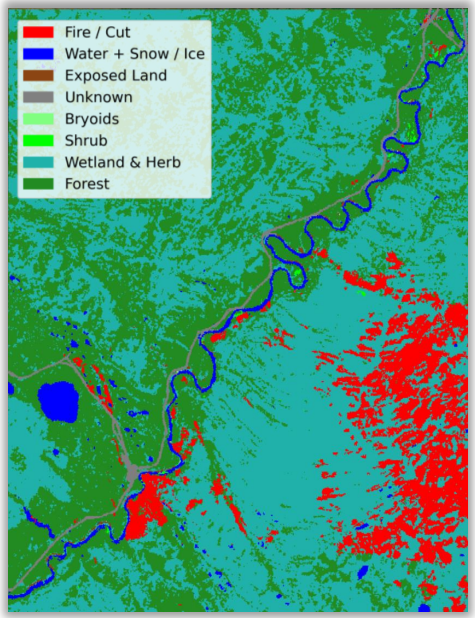


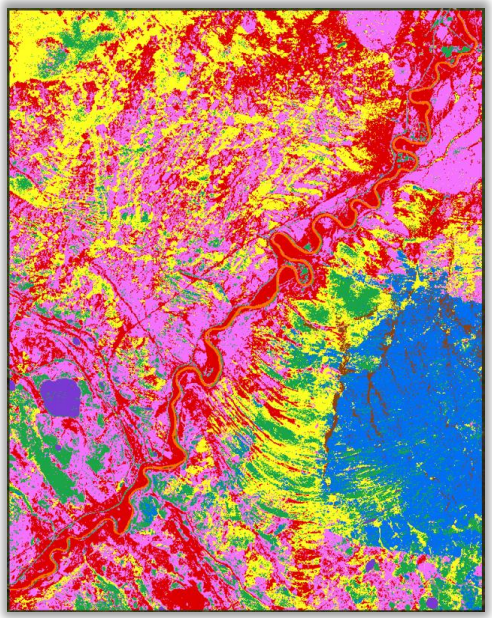
Clustering of the embedding space (8 clusters)



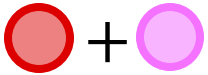


Clustering of the embedding space (8 clusters)

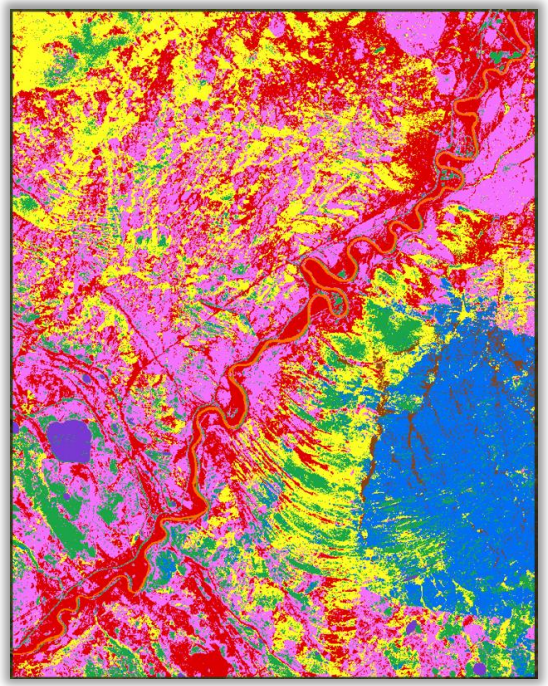


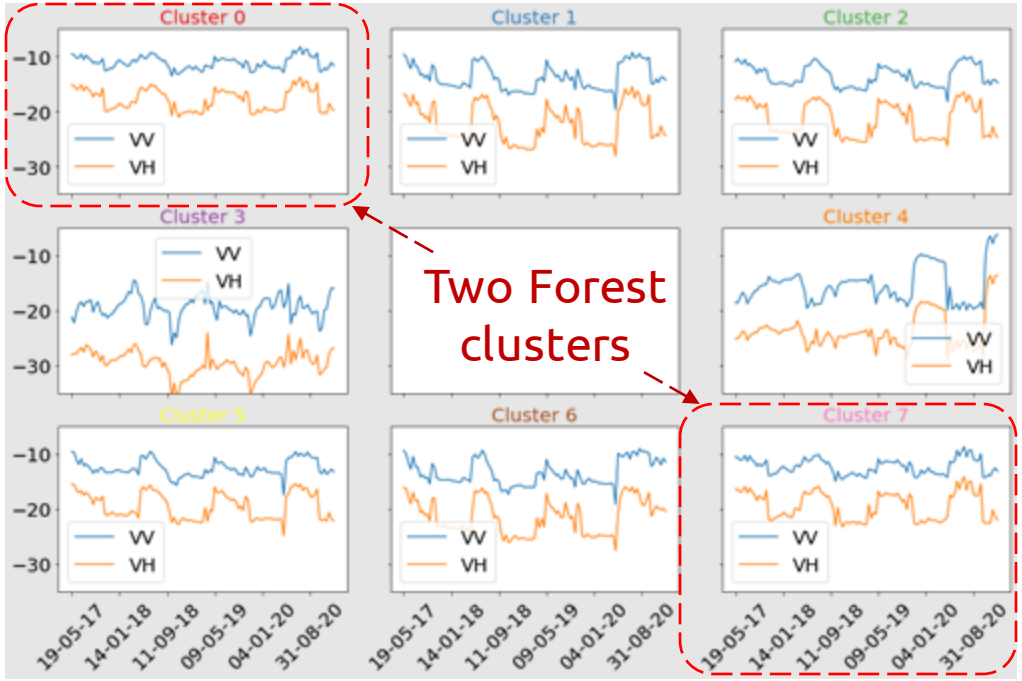


≈

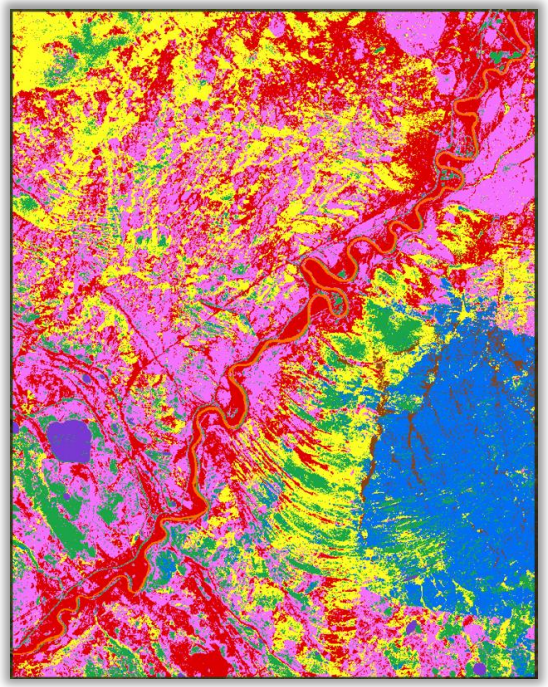


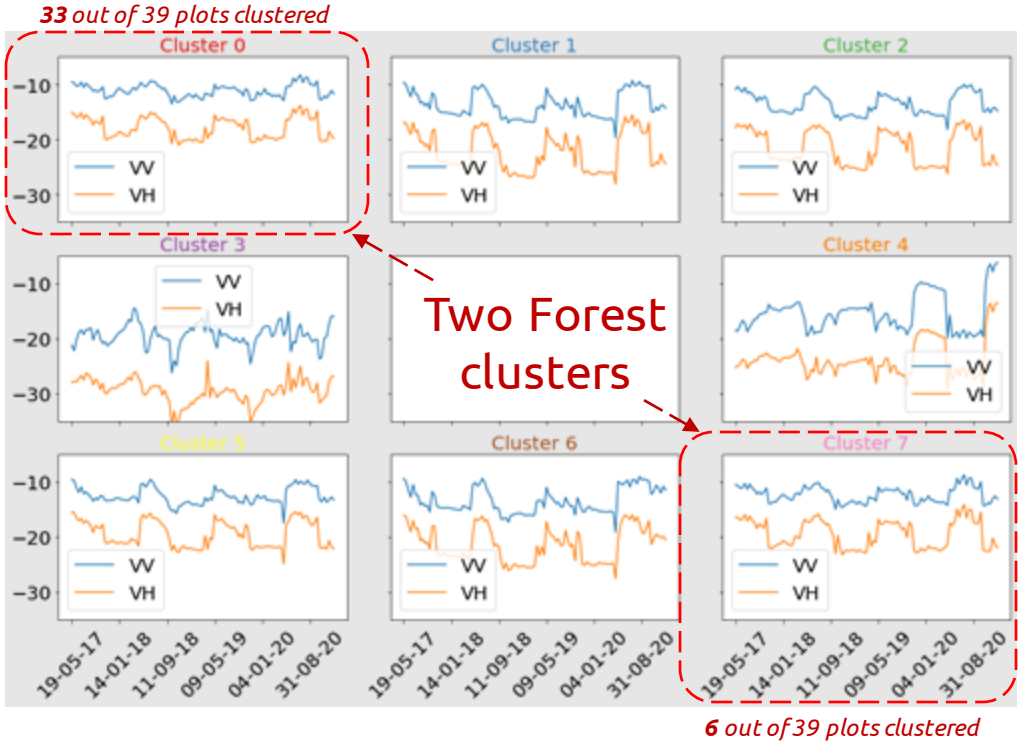
Clustering of the embedding space (8 clusters)



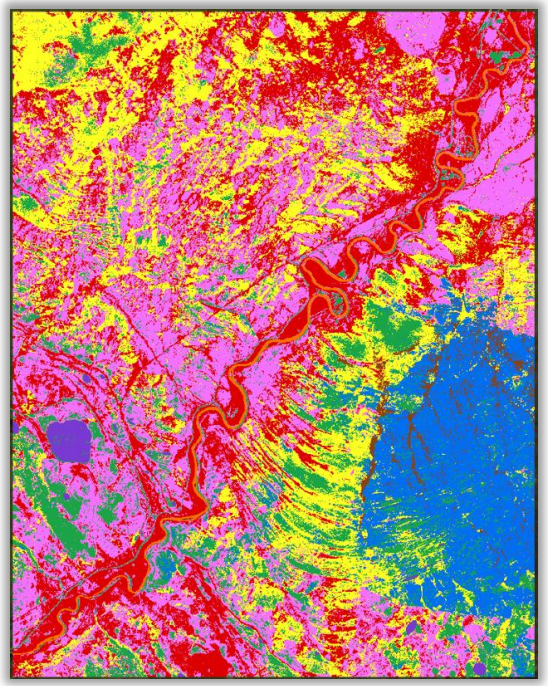


Clustering of the embedding space (8 clusters)



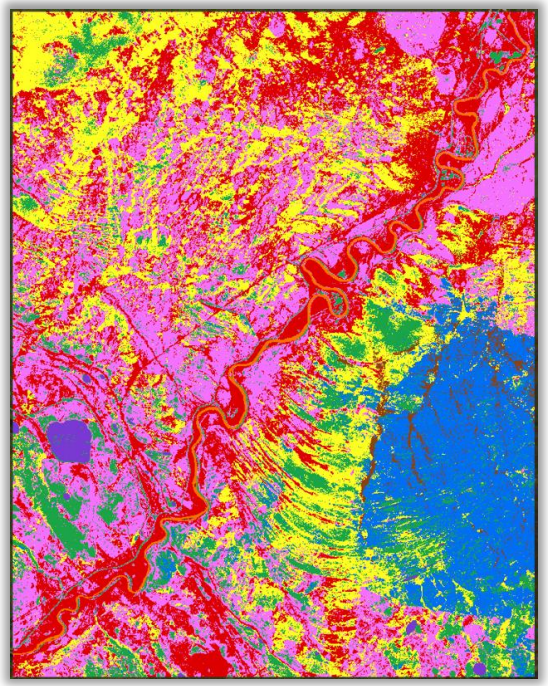


Clustering of the embedding space (8 clusters)



Tree Measurement Statistics		Cluster 0	Cluster 7
Quadratic Mean Diameter (cm)	Mean	18.94	10.33
	Median	19.25	10.61
	Min	9.84	7.28
	Max	25.75	12.75
	10th percentile	13.85	8.52
	90th percentile	24.47	11.87
Stem Height (m)	Mean	21.296	12.09
	Median	22.13	13.01
	Min	11.12	8.84
	Max	28.85	13.82
	10th percentile	16.10	9.53
	90th percentile	26.32	13.75
Above Ground Biomass (tonnes/ha)	Mean	143.27	49.89
	Median	136.34	46.54
	Min	74.69	30.47
	Max	223.87	71.59
	10th percentile	97.8	33.88
	90th percentile	199.83	69.26

Clustering of the embedding space (8 clusters)



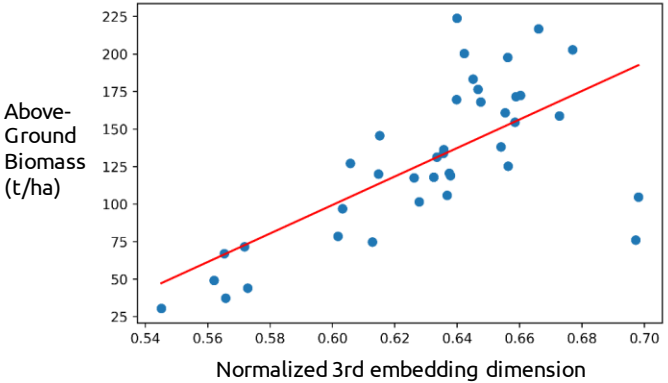
Tree Measurement Statistics		Cluster 0	Cluster 7
Quadratic Mean Diameter (cm)	Mean	18.94	10.33
	Median	19.25	10.61
	Min	9.84	7.28
	Max	25.75	12.75
	10th percentile	13.85	8.52
	90th percentile	24.47	11.87
Stem Height (m)	Mean	21.296	12.09
	Median	22.13	13.01
	Min	11.12	8.84
	Max	28.85	13.82
	10th percentile	16.10	9.53
	90th percentile	26.32	13.75
Above Ground Biomass (tonnes/ha)	Mean	143.27	49.89
	Median	136.34	46.54
	Min	74.69	30.47
	Max	223.87	71.59
	10th percentile	97.8	33.88
	90th percentile	199.83	69.26

Main difference: **larger trees** in Cluster 0 than in Cluster 7

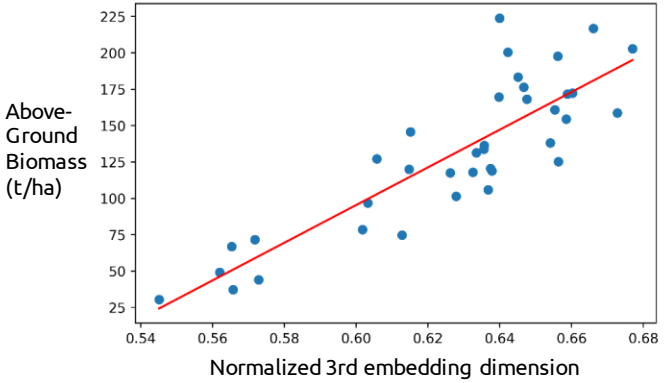
Automatic tree differentiation through the processing of S1 time series with **autoencoders**

Relating 3rd embedding with forest attributes

With outliers: ***R2=0.468***

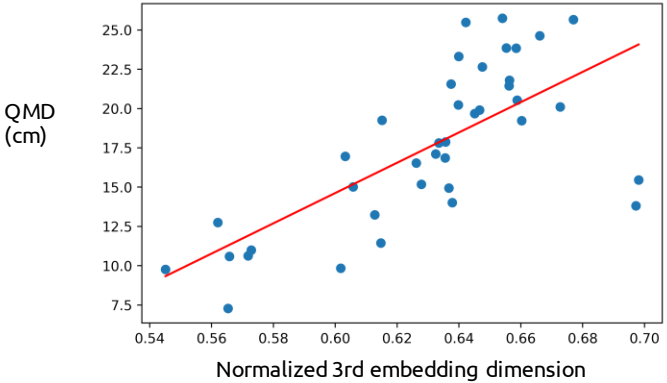


Without outliers: ***R2=0.736***

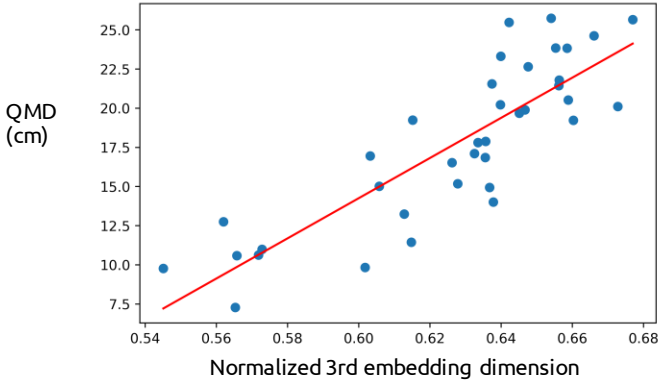


Relating 3rd embedding with forest attributes

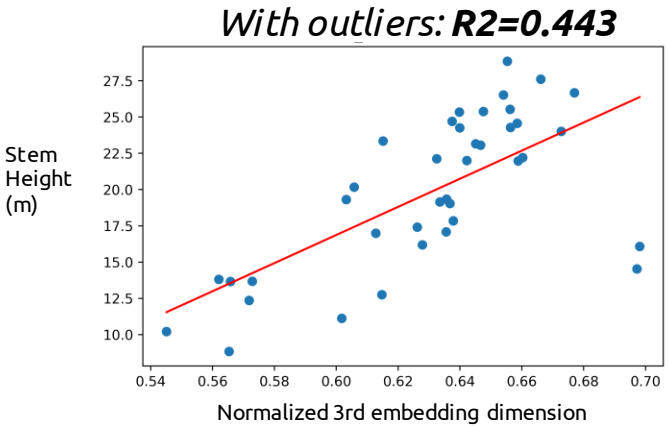
With outliers: ***R2=0.486***

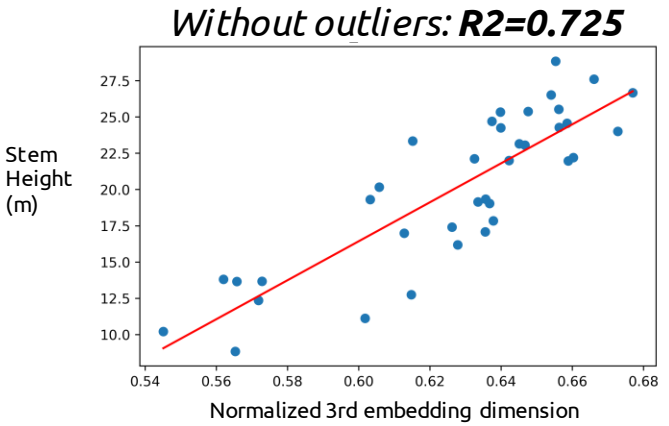


Without outliers: ***R2=0.717***



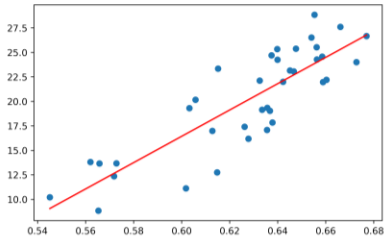
Relating 3rd embedding with forest attributes



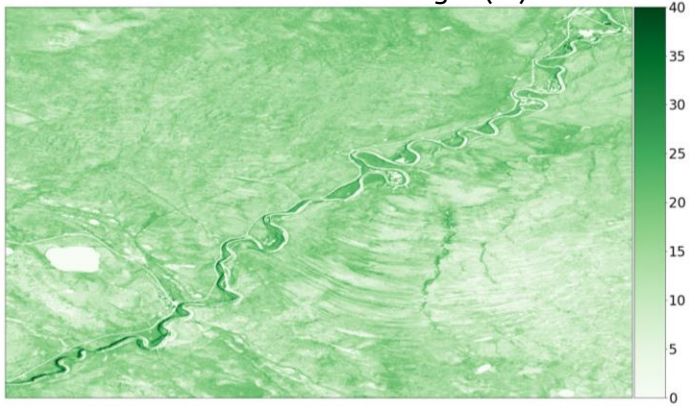


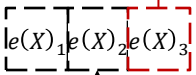
Applicative potentials of embeddings & Sentinel-1 data

- Use embeddings of Sentinel-1 time series as input features for height mapping models



Predicted Stem Height (m)



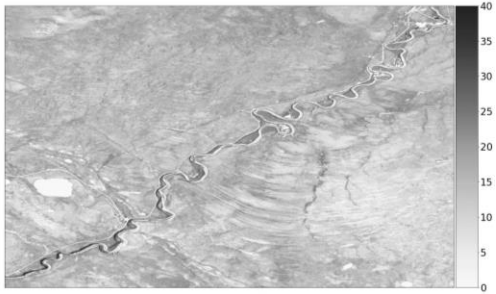


Unlabelled σ_0 time series

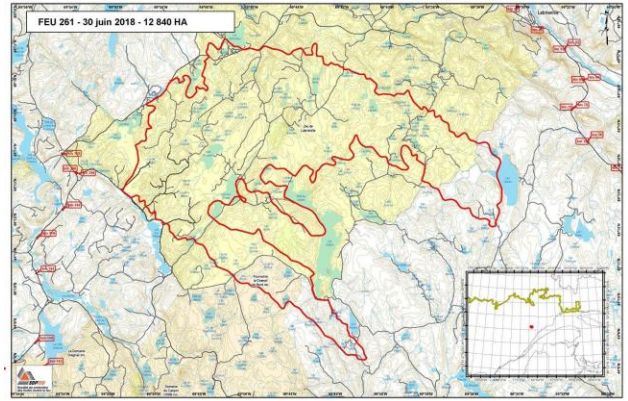
Convolutional Autoencoder

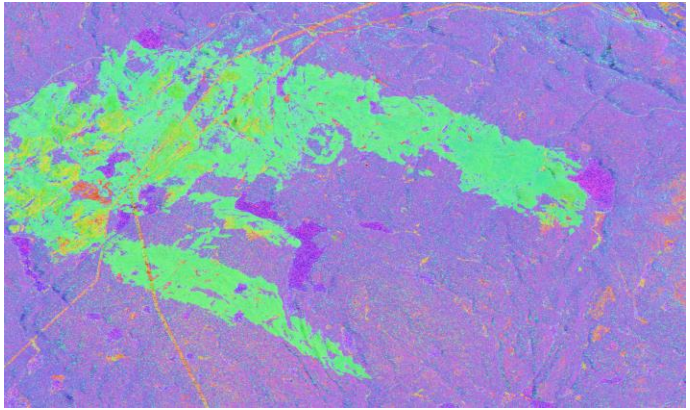
Applicative potentials of embeddings & Sentinel-1 data

- Use embeddings of Sentinel-1 time series as input features for height mapping models



- Use embeddings for anomaly detection within a forested environments



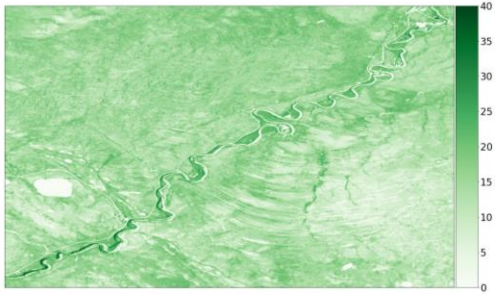


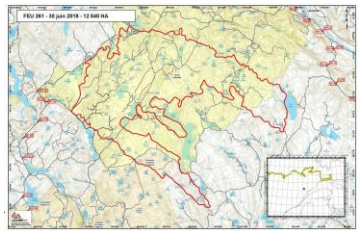
Applicative potentials of embeddings & Sentinel-1 data

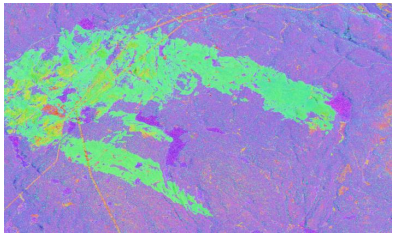
- Use embeddings of Sentinel-1 time series as input features for height mapping models

- Use embeddings for anomaly detection within a forested environments

- And many more..







...

Conclusion

Successful application of an autoencoder to σ_0 time series of boreal forests:

- Generation of homogeneous clusters of σ_0 time series
- Separation of forest into two clusters with trees of various physiologies
- Direct correlation of the embedding space with tree physiology

Contacts

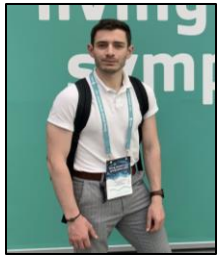
Thank your for listening !

For contact purposes:

thomas.di-martino@centralesupelec.fr

https://dimartinot.github.io

@DimartinotFR



Thomas
Di Martino

SCAN ME