



# Learning-based tracking of below ground asparagus carbohydrates fusion of SAR and optical data

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# Outline

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Research aims

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Test site and datasets

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Asparagus crop

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Methods

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Results

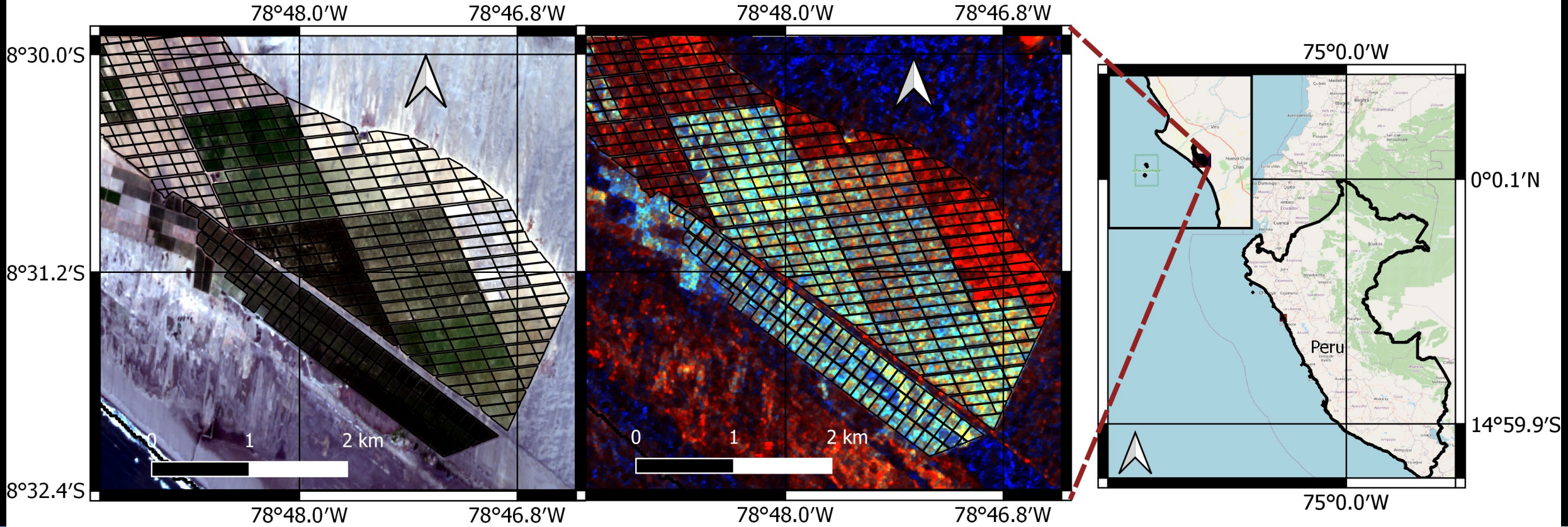
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# Research aims: Asparagus monitoring

- **Below ground carbohydrate estimation**
- **key dates estimation:**
  - Harvest or any crop stage (forecast).
  - Date when season started (hindcast).
- **Everything in near-real time**
- **Combining Sentinel-1 and Sentinel-2 data**
- **Resilient to noisy and/or missing observations**





Test site



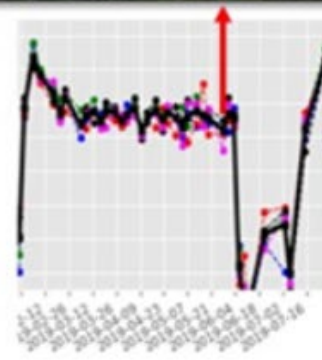
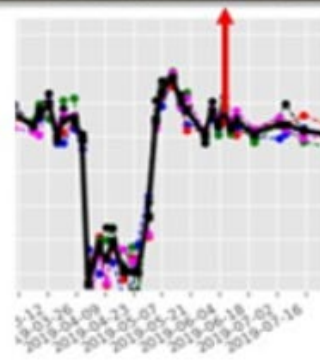
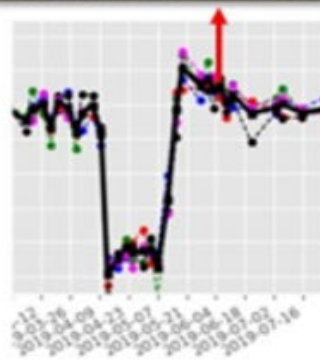
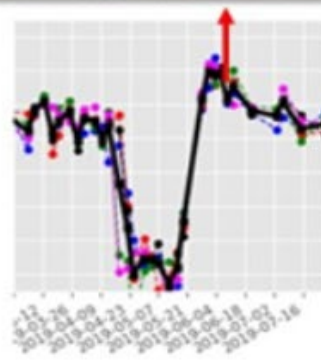
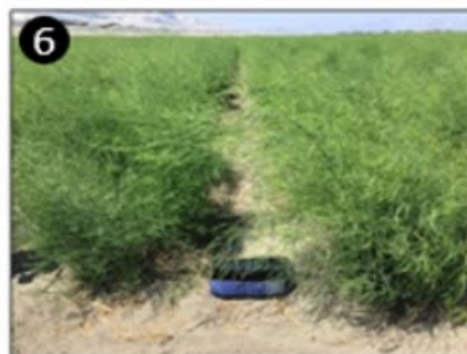
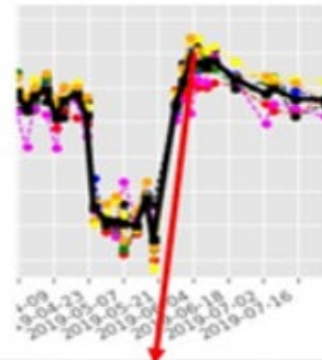
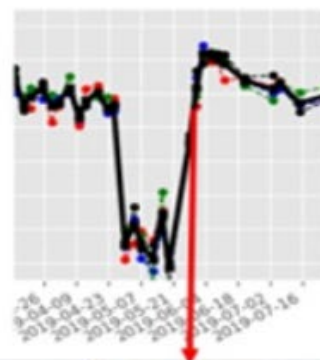
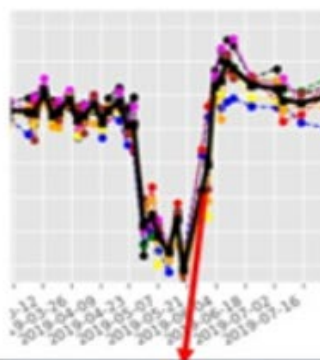
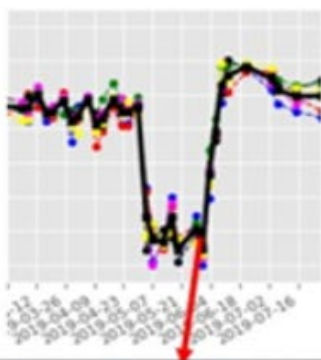
# Datasets

- Sentinel-1 GRD imagery from 2018 to 2020 – 210 images
- Sentinel-2 imagery from 2018 to 2020 – 71 images (cloud-free only in ‘summer’)
- Brix degrees (surrogate of carbohydrates) collected during the same period.
- Data from xx used for training, data from xx used for validation
- Features used: VH, VV, VH/VV, GNDVI, MCARI



Asparagus crop

Backscatter intensity  
(VH)



Asparagus  
growth

Methods:  
Unscented Kalman Filtering  
(Bayesian Filtering)





## State variables (Variables we are tracking)

- Below ground carbohydrates: Approximated as brix degrees.
- Cultivation Days: Also known as crop age. Tells us how many Days ago the season started

# Algorithm:

Sensor fusion: One model for each sensor type

Observation model:  
Expected remote sensing observation

$$x'_k = f(x_{k-1})$$

Dynamic model:  
Dynamics of crop evolution

$$y_{k'} = g_2(x_{k'})$$

$$y_{k'} = g(x_{k'})$$

New image today  
( $y_k$ )

Prior belief of state variable (s)  
( $x_{k-1}$ )

Prediction: state variable (s)  
( $x'_k$ )

Update: Update prediction based on observation

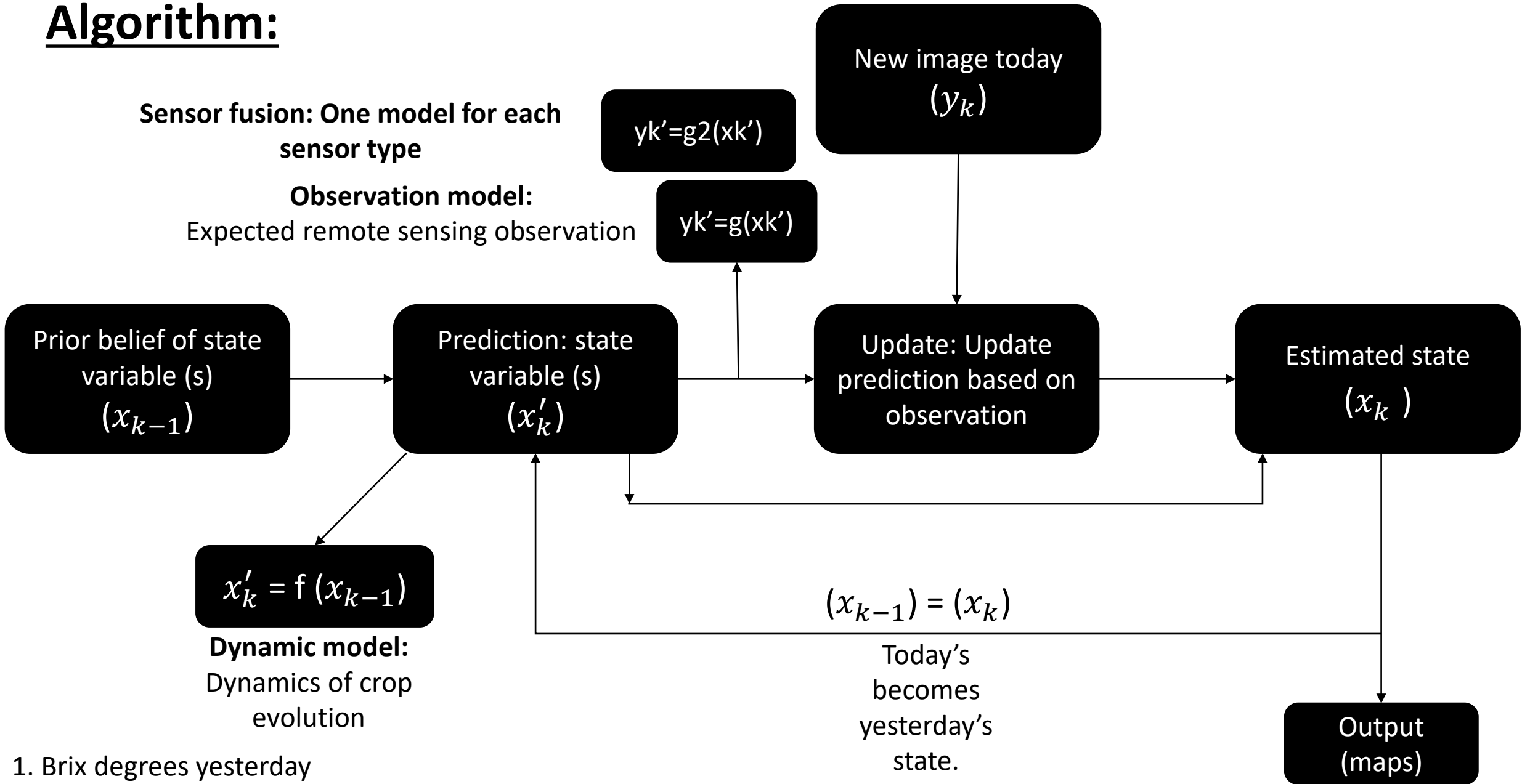
Estimated state  
( $x_k$ )

$$(x_{k-1}) = (x_k)$$

Today's becomes yesterday's state.

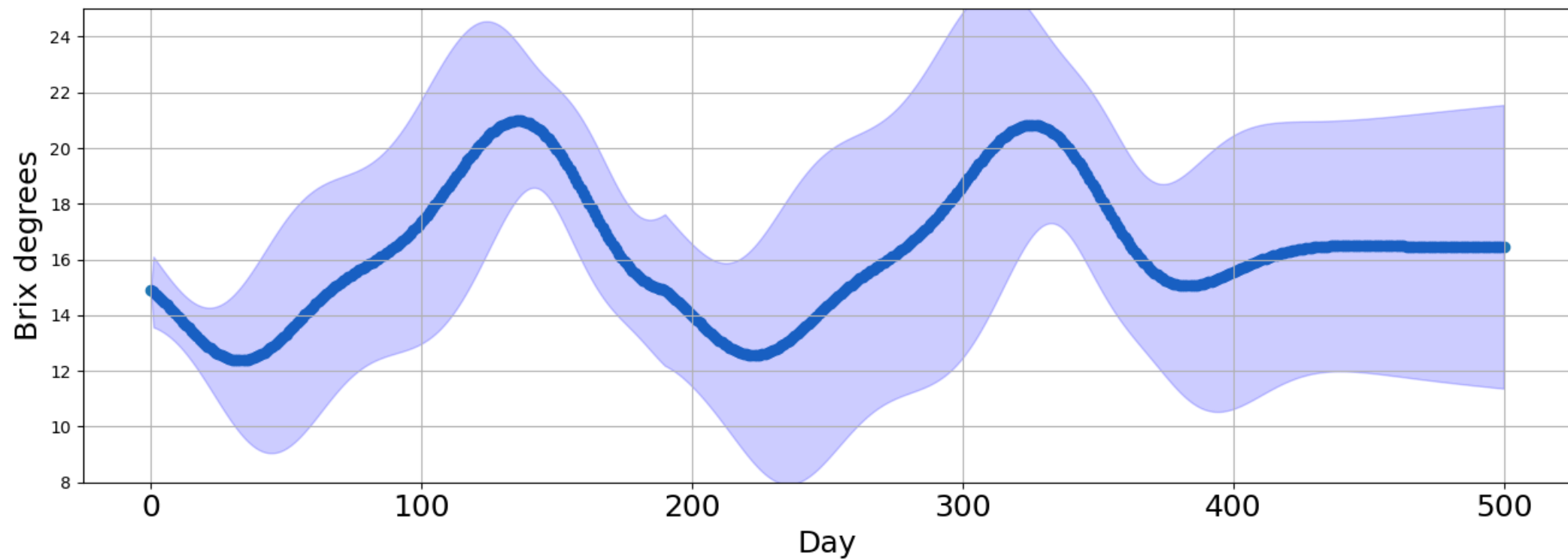
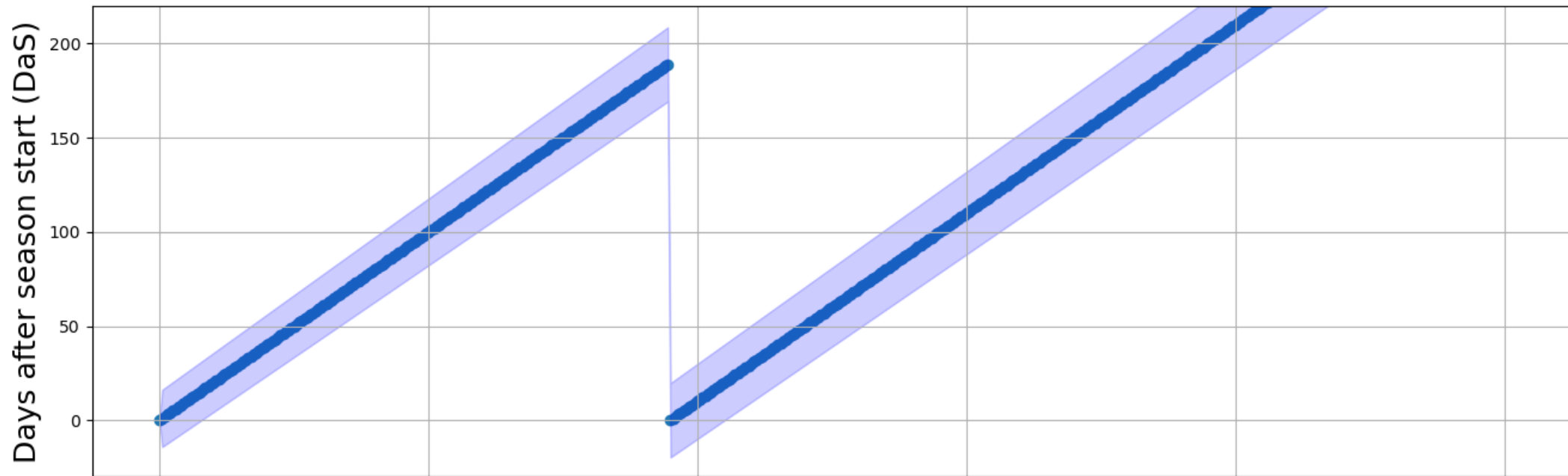
Output  
(maps)

1. Brix degrees yesterday
2. Expected brix degrees for today

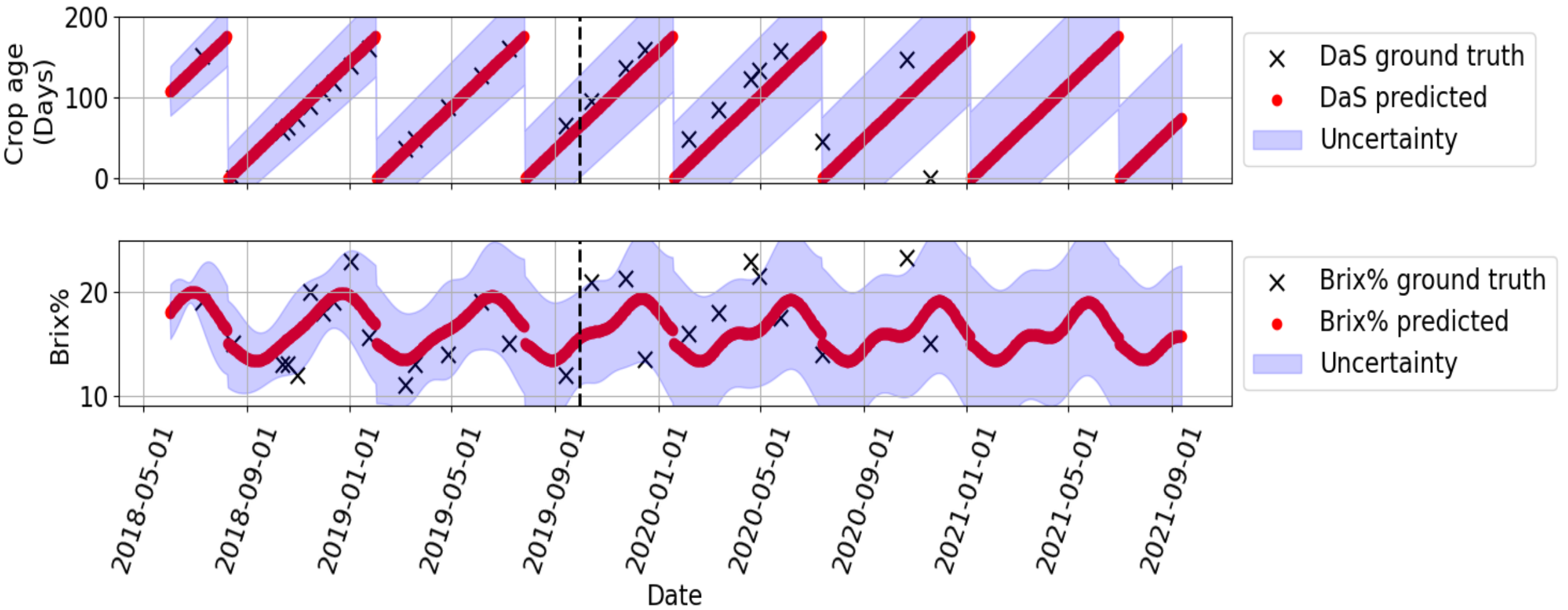


# Results

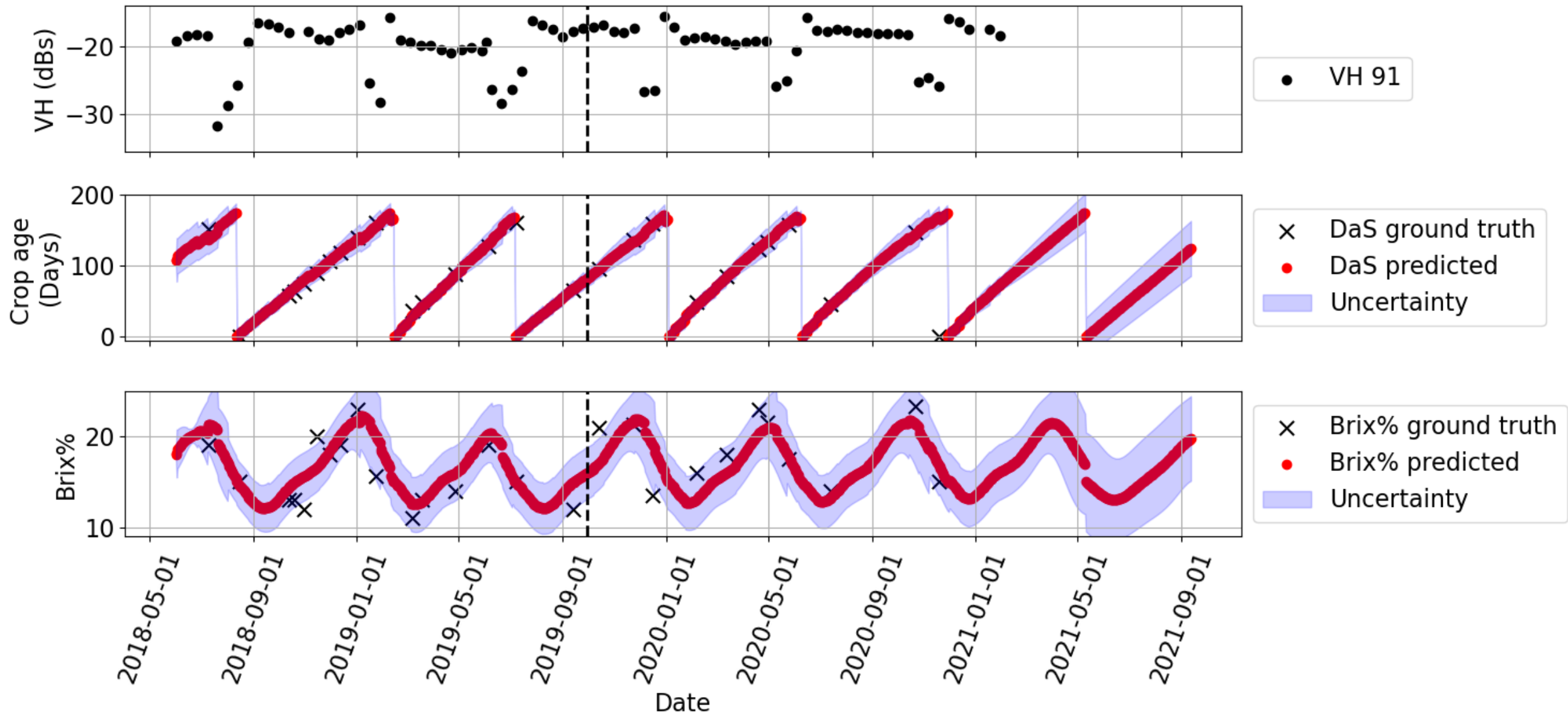




# Dynamic model only (No remote sensing)

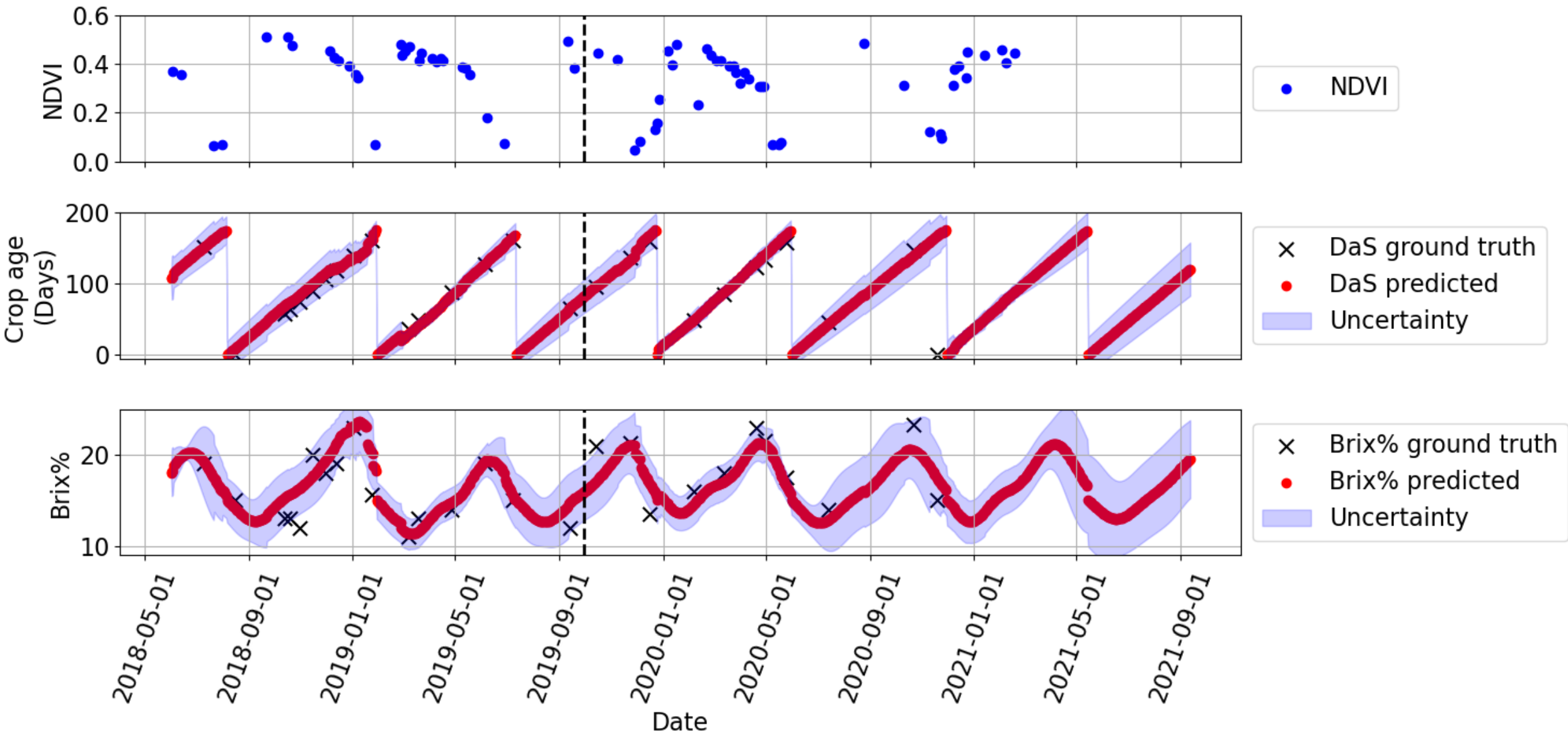


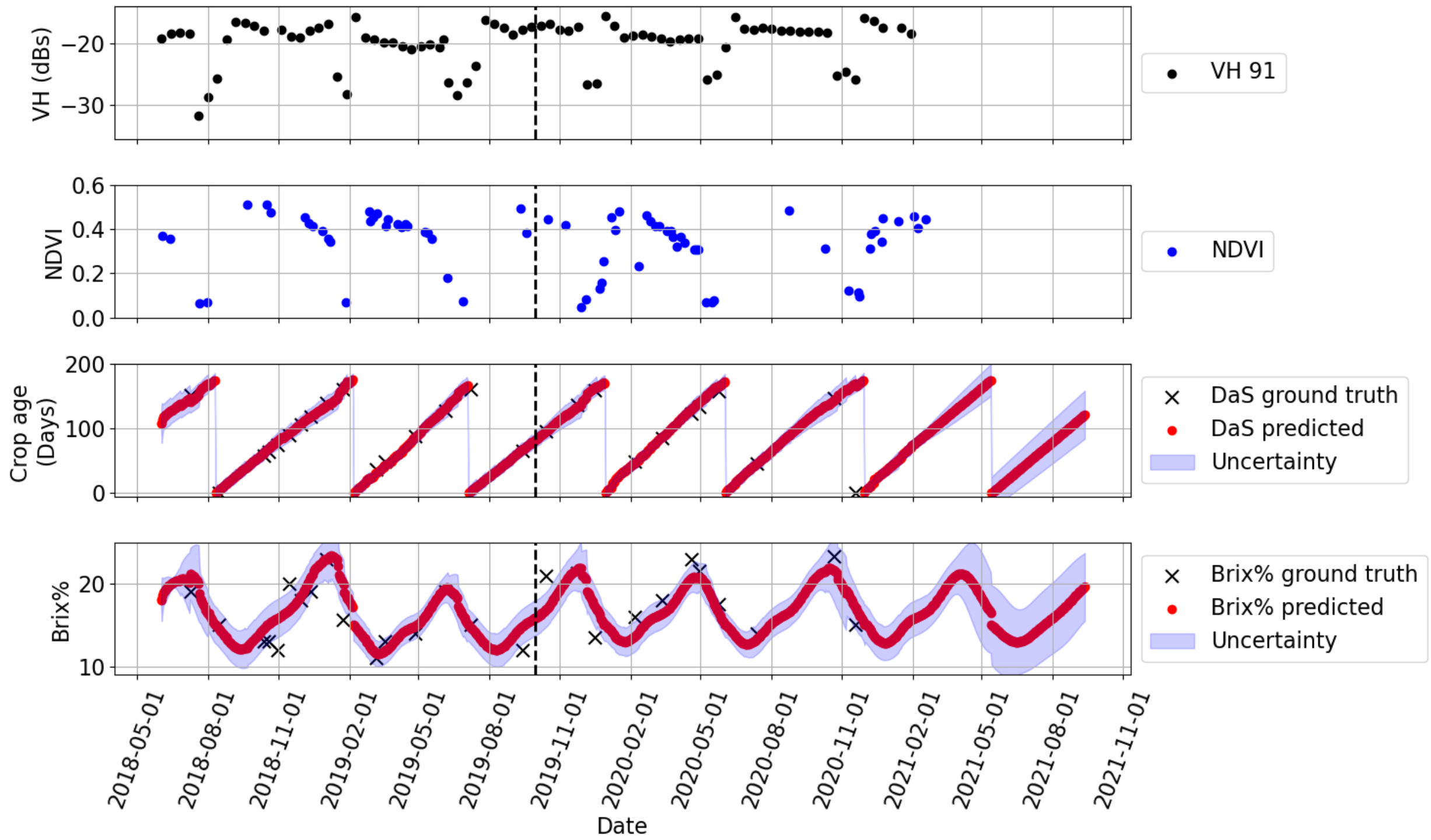
# Dynamic model and Sentinel-1 (1 orbit)

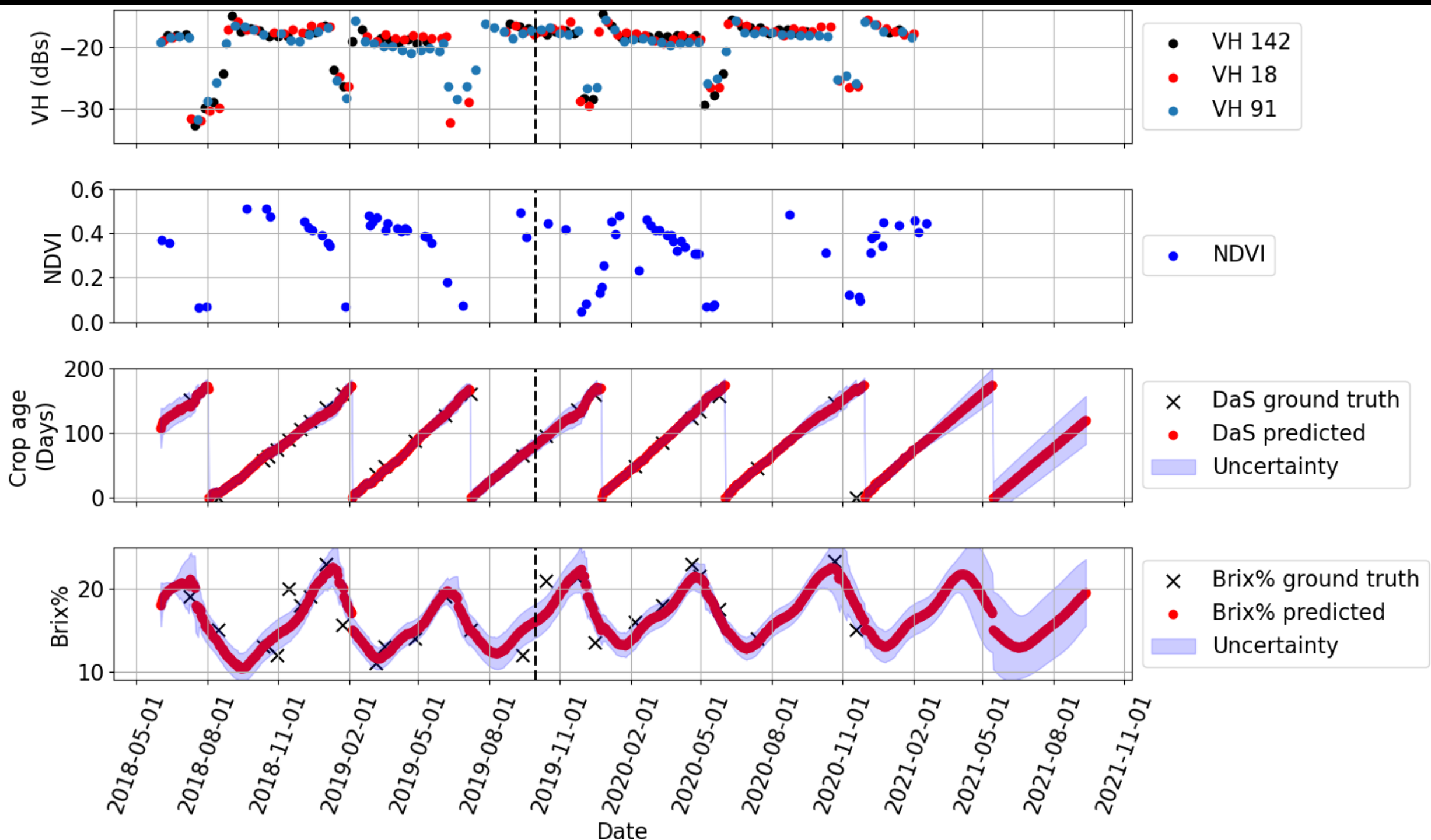




# Dynamic model and Sentinel-2

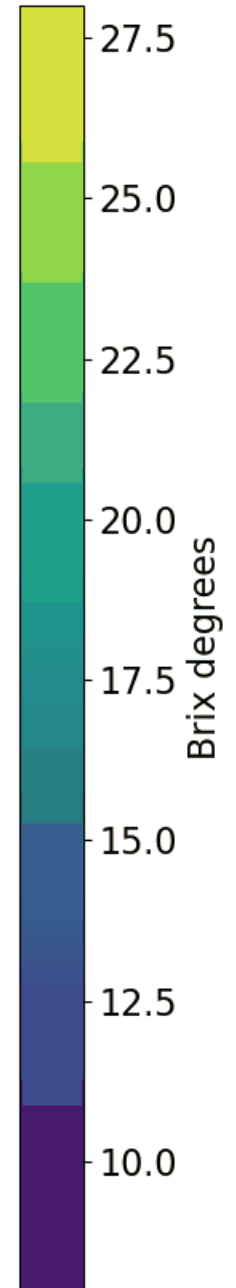
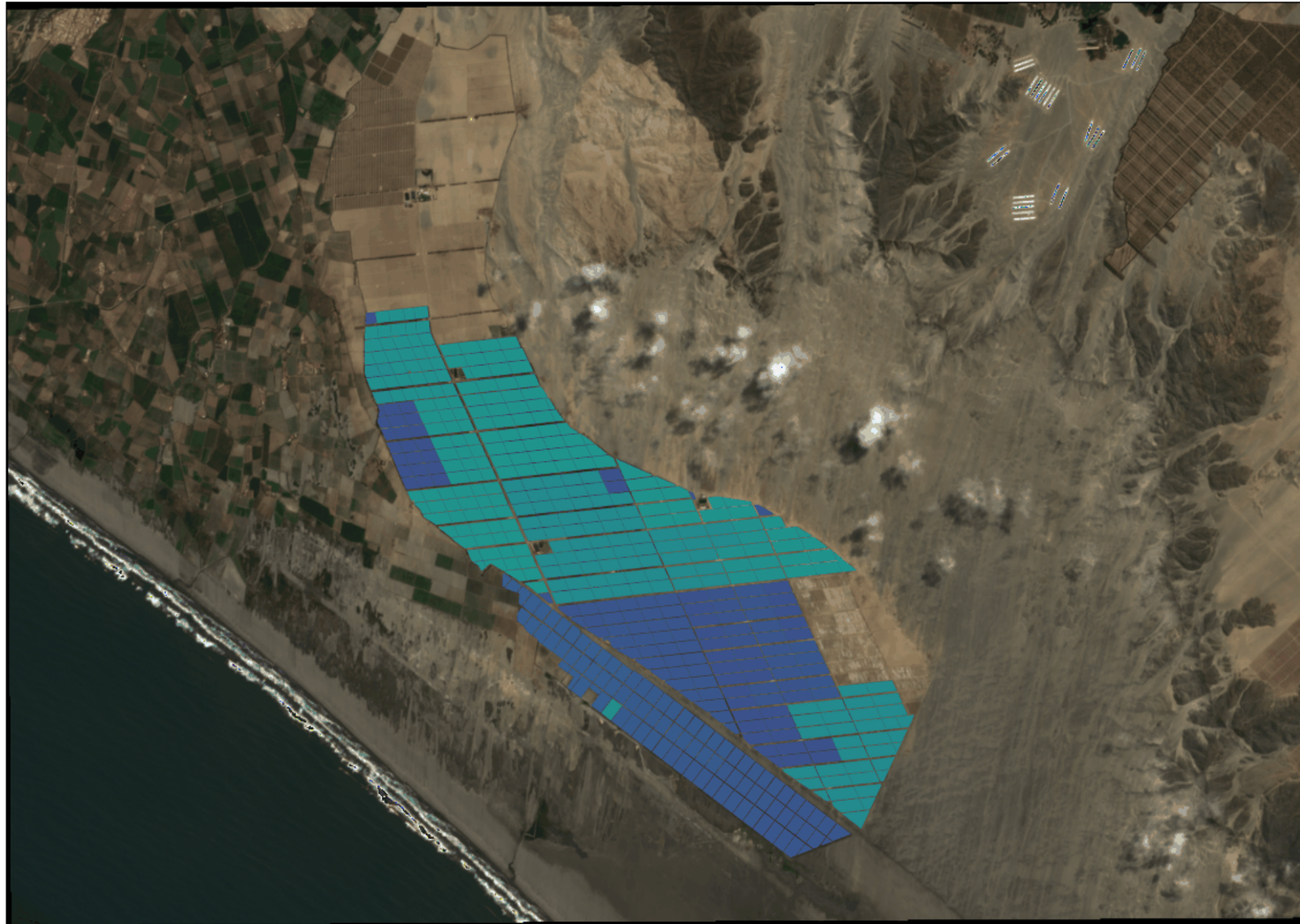








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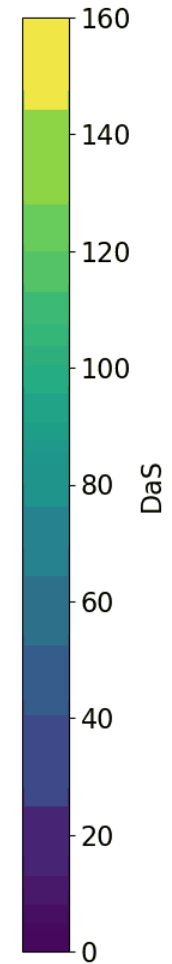
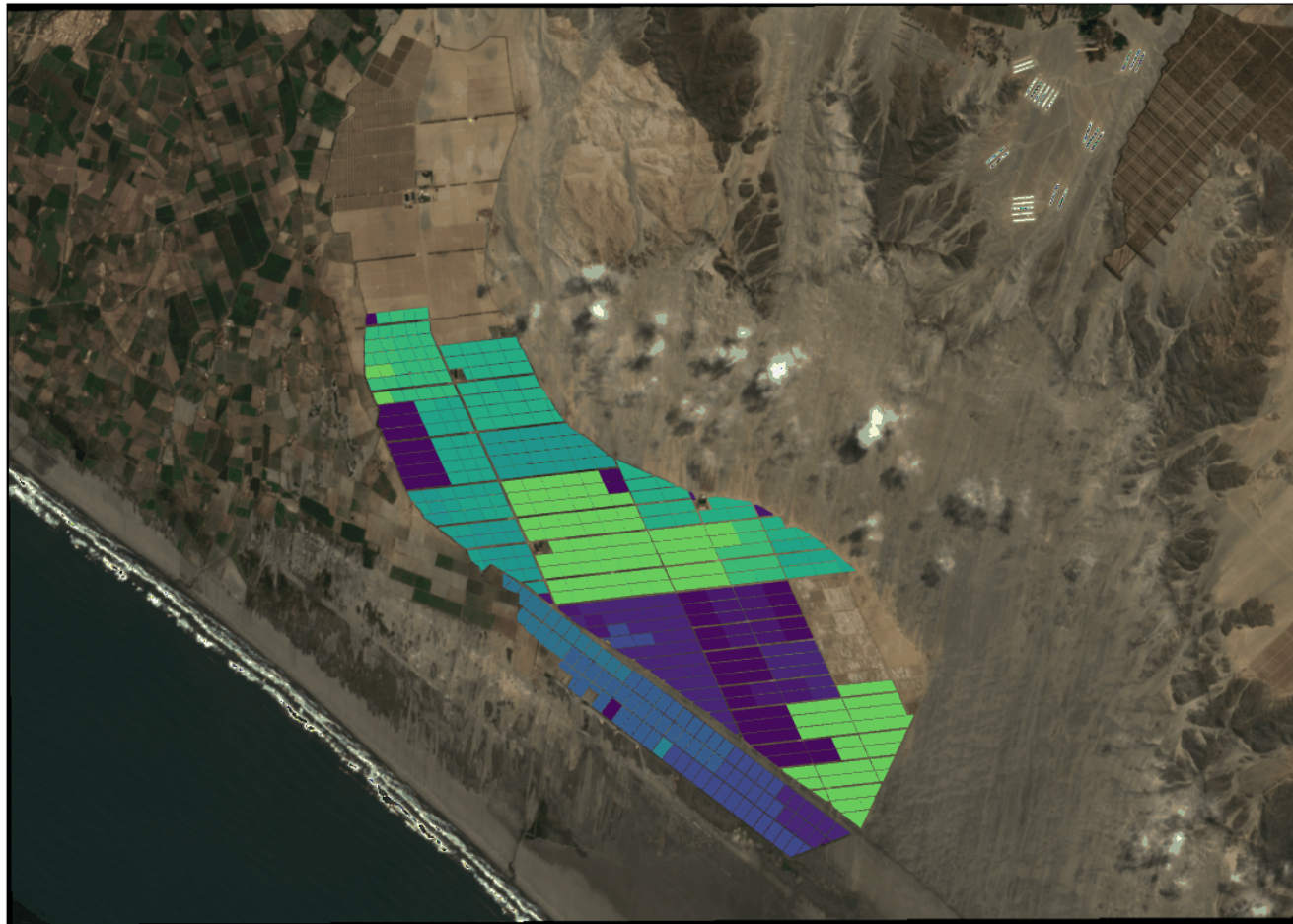


Validation

| Case            | MAE Brix | MAE DaS 1 | r2 Brix 2 | r2 DaS | RMSE Brix | RMSE DaS |
|-----------------|----------|-----------|-----------|--------|-----------|----------|
| S1_all + S2     | 1.802    | 6         | 0.58      | 0.97   | 2.287     | 8        |
| S1_18+S1_91+S2  | 1.805    | 6         | 0.59      | 0.97   | 2.278     | 8        |
| S1_91+S2        | 1.808    | 6         | 0.58      | 0.97   | 2.295     | 8        |
| S1_91+S1_142+S2 | 1.812    | 6         | 0.58      | 0.97   | 2.309     | 8        |
| S1_all          | 1.905    | 6         | 0.53      | 0.97   | 2.401     | 8        |
| S1_91           | 1.931    | 6         | 0.54      | 0.96   | 2.413     | 8        |
| S1_18+S2        | 1.944    | 7         | 0.5       | 0.94   | 2.472     | 10       |
| S1_18+S1_91     | 1.946    | 6         | 0.53      | 0.96   | 2.435     | 8        |
| S1_91+S1_142    | 1.953    | 5         | 0.51      | 0.97   | 2.46      | 7        |
| S1_18+S1_142+S2 | 1.989    | 7         | 0.45      | 0.91   | 2.548     | 11       |
| S2              | 2.083    | 8         | 0.43      | 0.91   | 2.649     | 12       |
| S1_142+S2       | 2.14     | 9         | 0.32      | 0.83   | 2.745     | 12       |
| S1_18+S1_142    | 2.243    | 8         | 0.33      | 0.83   | 2.862     | 13       |
| S1_18           | 2.508    | 12        | 0.17      | 0.74   | 3.166     | 17       |
| S1_142          | 2.531    | 15        | 0.07      | 0.52   | 3.278     | 22       |
| Dyn_model       | 3.109    | 31        | -0.27     | -0.01  | 3.964     | 39       |
| Line            | 16.88    | 44        | -22.52    | -0.34  | 17.252    | 52       |



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Thank you!

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