Mapping oak wilt using phenology-informed observations from space

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1. Background

- Oak wilt is a lethal disease that infects oak trees caused by the invasive fungal pathogen (*Bretziella fagacearum*) (Juzwik et al. 2011). The disease is the top threat to oak forests, killing thousands of oak trees every year and impacting the ecosystem services that they provide (Cavender-Bares et al. 2022).
- Detecting the presence of oak wilt at large scales is essential for active forest management, which can slow and potentially stop the spread of the disease.
- The disease causes wilting symptom in trees such that leaves show a decline in water content and concentration of green pigments (Fallon et al. 2020).
- Diseased oaks tend to show early and increasing wilting symptoms during phenological progression. These symptoms can be tracked using Chlorophyll/Carotenoid Index (CCI) (**Fig. 1**).

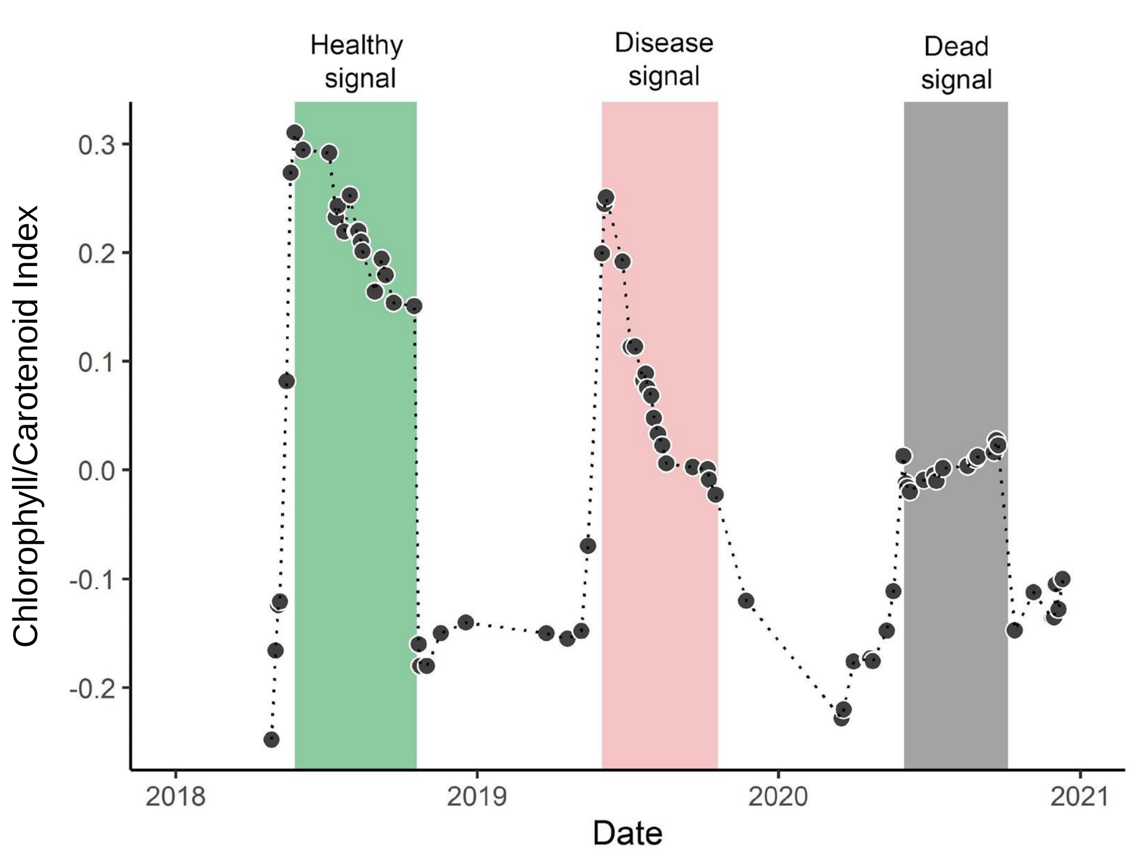

Fig. 1. Time series observations of the Chlorophyll/Carotenoid Index (CCI) for a single oak tree (e.g., pixel) that died from oak wilt.

2. Goal and hypothesis

Goal

- Our goal is to create a reproducible, scaled, and open-source workflow to map oak wilt and its impacts across Minnesota and Wisconsin (applicable to other regions) to enhance efficient management of forests by stakeholders (**Fig. 2**).

Hypothesis

- We hypothesize that phenological changes in pigments and photosynthetic activity of oak trees due to oak wilt can be tracked using phenological metrics of the Chlorophyll/Carotenoid Index (CCI) from satellite observations (**Fig. 3**).

3. Phenological metrics

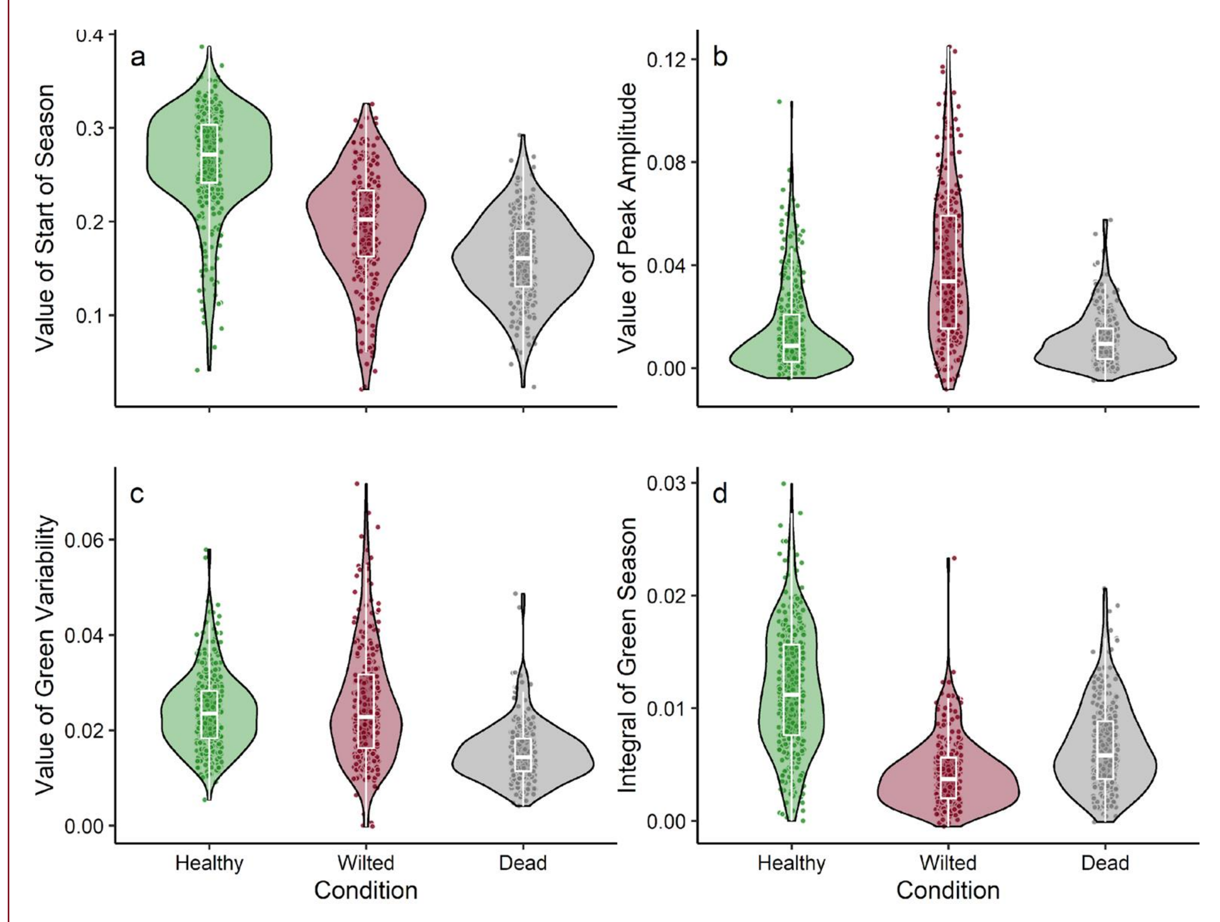

Fig. 3. Violin plot comparing phenological metrics of healthy, diseased, and dead oaks.

4. Algorithm training

- Pixels from healthy (n = 352), deceased (n = 261), and dead (n = 256) oak trees were used to train and test (60:40 ratio) a Linear Discrimination Analysis (LDA) (**Fig. 4**).
- Repeated 10-fold cross-validation was used to improve the model performance.
- The model was then evaluated looking at the accuracy, sensitivity, specificity, and the Receiver Operating Characteristic curves (**Table 1** and **Fig. 5**).

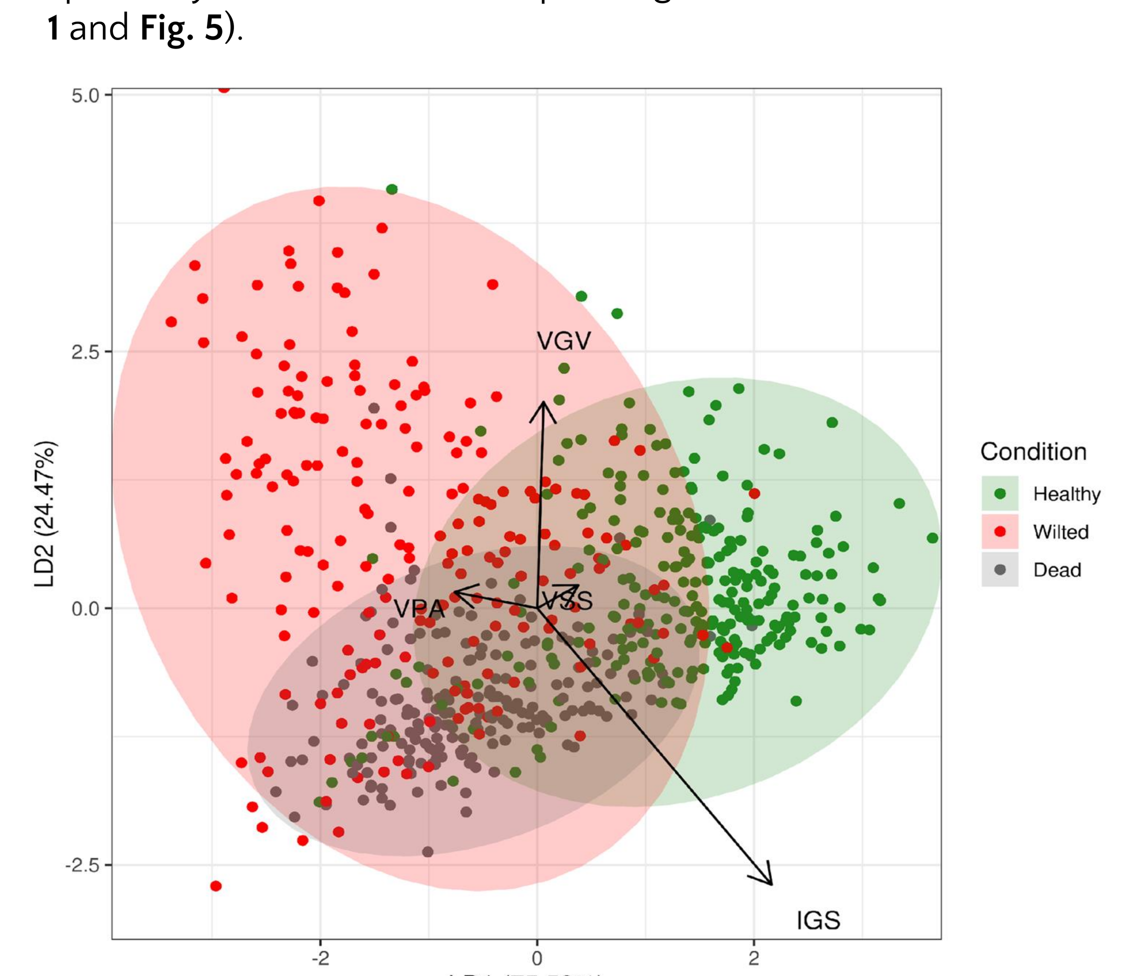

Fig. 4. Linear Discrimination Analysis on the training dataset as an algorithm to summarize the variability of the phenological signal between healthy, wilted, and dead oak trees.

5. Classification assessment

Table 1. Model performance on the testing dataset to discriminate the phenological signal between healthy, diseased, and dead oak trees.

Metric	Condition		
	Healthy	Wilted	Dead
Accuracy	0.86	0.85	0.78
Sensitivity	0.82	0.84	0.66
Specificity	0.91	0.85	0.90

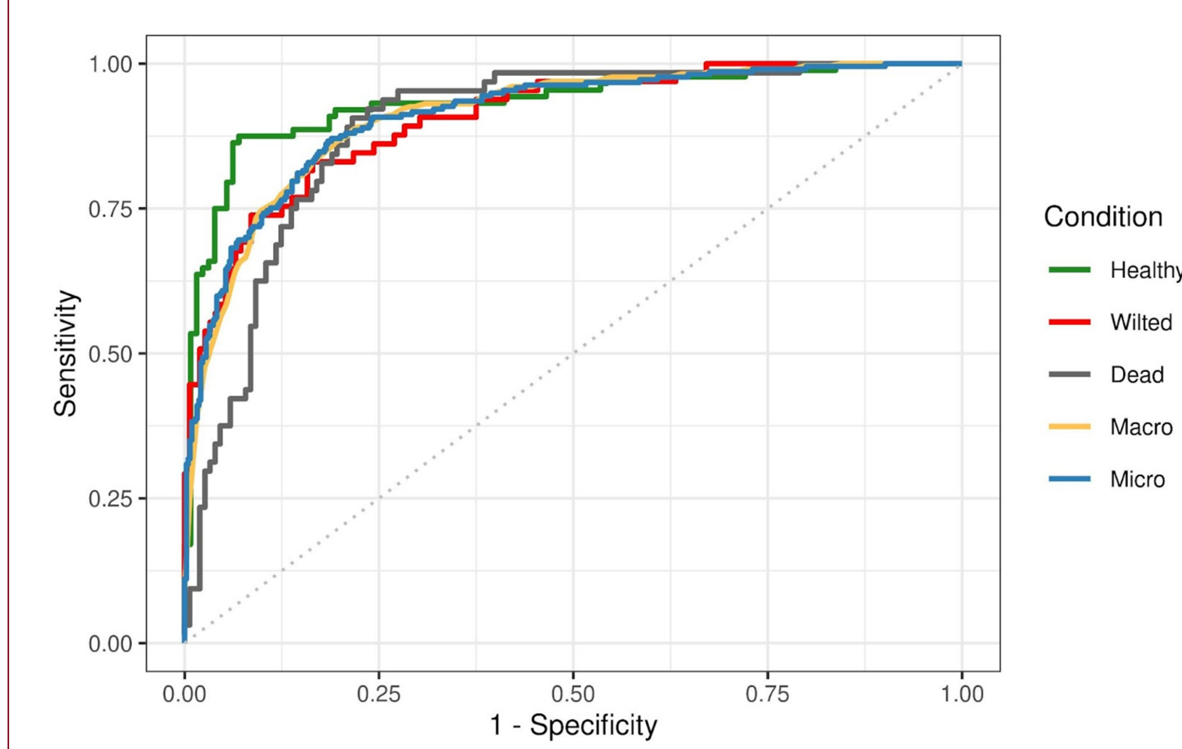

Fig. 5. Receiver Operating Characteristic curves that assesses the discrimination of the phenological signal between healthy, diseased, and dead oaks.

6. Mapping

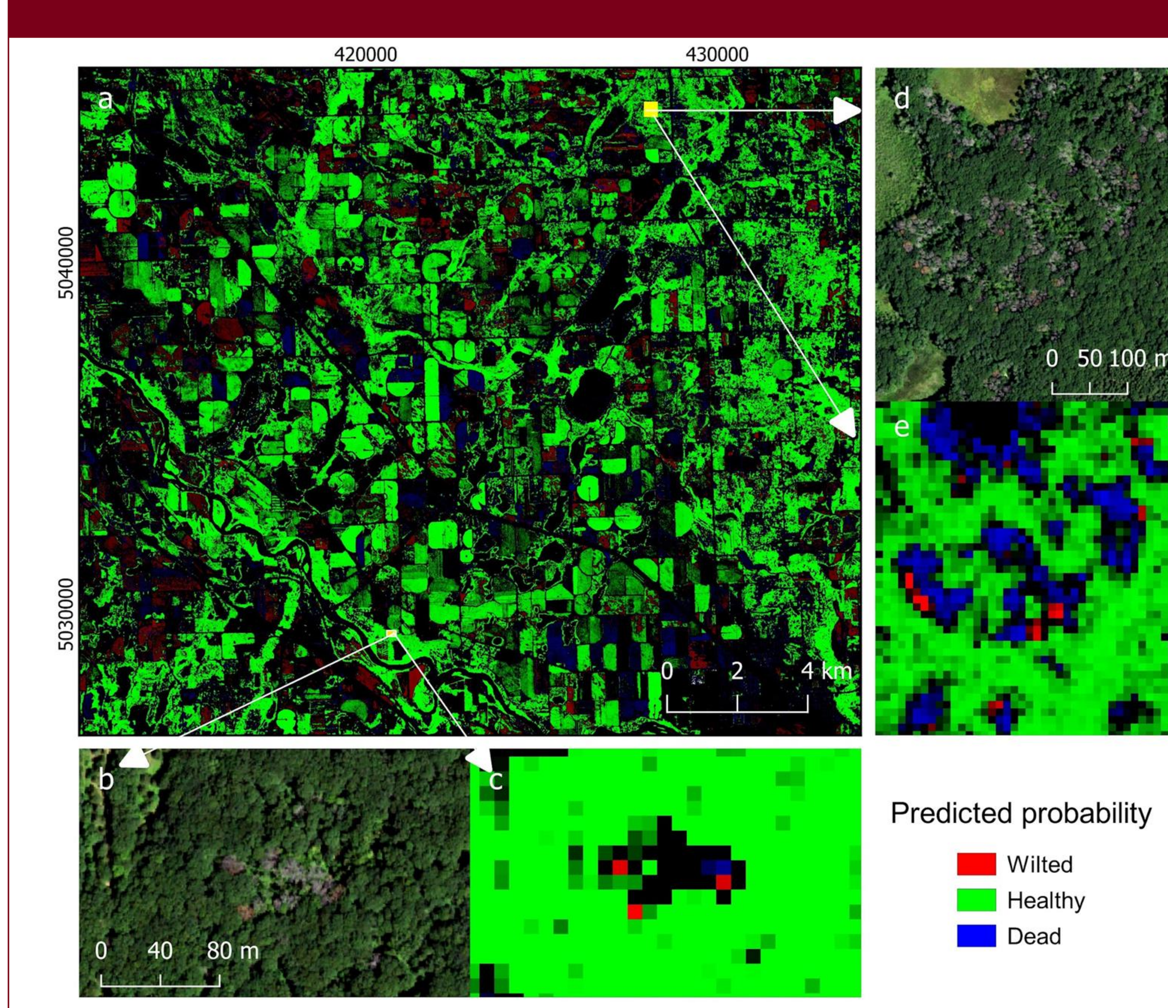

Fig. 6. Oak wilt detection for 2019 at Sherburne County, MN (a). Colors on panels a, c, and e represent the probability of a pixel of describing a signal of healthy, deceased, or dead tree.

3. Materials and Methods

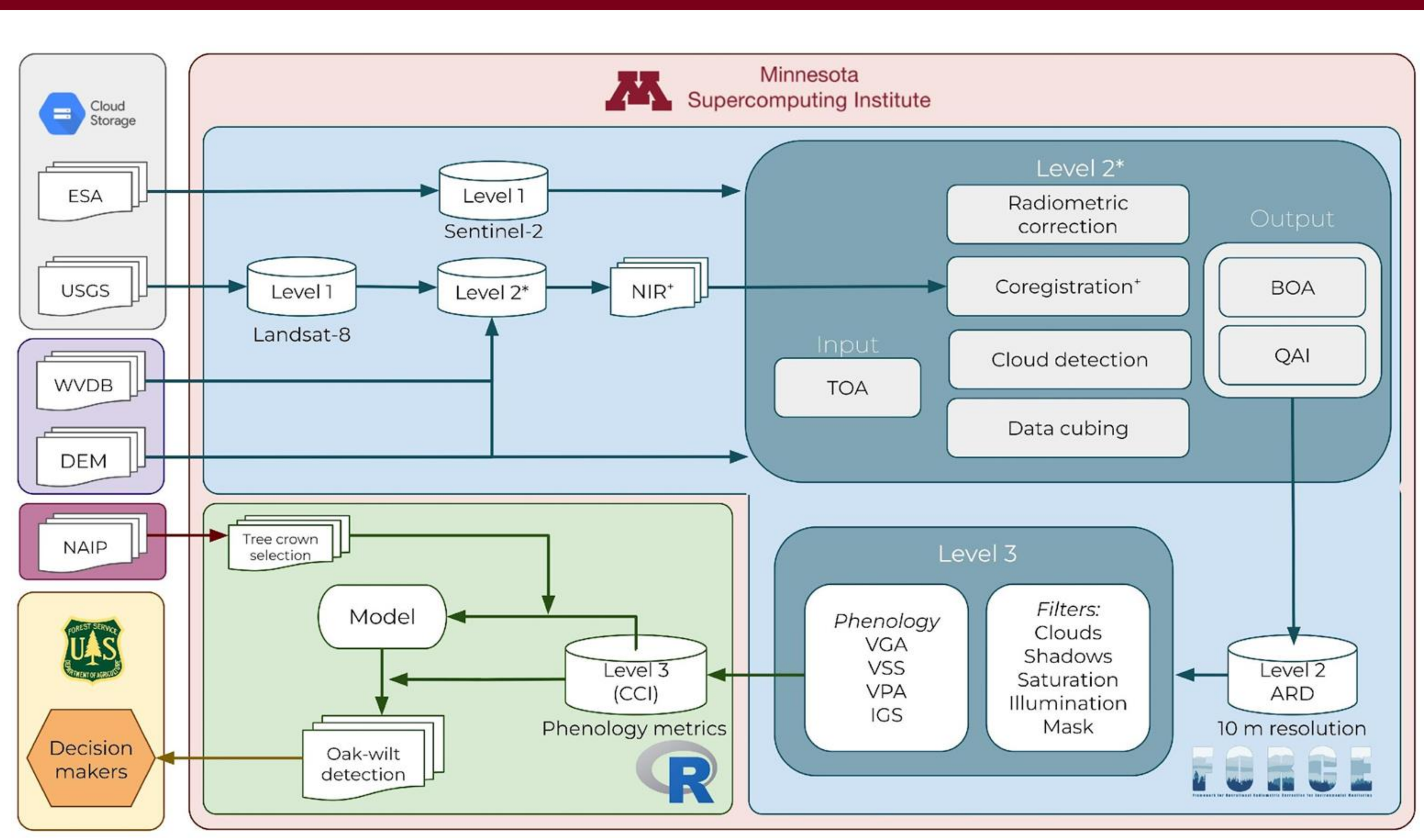

Fig 2. Workflow for acquiring, processing, and analyzing Landsat 8 and Sentinel-2 imagery for mapping of oak wilt.

7. Conclusions

- Our results indicate that detecting and mapping the phenological signal of oak wilt is feasible using observations of CCI from Sentinel-2 (**Fig. 6**).
- The mapping of oak wilt using the presented workflow can be scaled in space and time, providing a broad overview of the presence and spread of the disease on land.
- Potential biases of mapping are likely to be the product of the spectral mixing of pixels when symptoms appear in small tree crowns. Future work will be focused on producing bi-annual comparisons and differentiation from other stress factors to inform models.

8. References

Cavender-Bares, J.M., E. Nelson, J.E. Meireles, J.R. Lasky, D.A. Miteva, D.J. Nowak, et al. (2022) The hidden value of trees: Quantifying the ecosystem services of tree lineages and their major threats across the contiguous US. PLOS Sustain Transform 1(4): e0000010.

Fallon, B., Yang, A., Lapadat, C., Armour, I., Juzwik, J., Montgomery, R.A., Cavender-Bares, J.M. (2020) Spectral differentiation of oak wilt from foliar fungal disease and drought is correlated with physiological changes. Tree Physiology 40(3): 377–390,

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Acknowledgment

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