Learning Biosphere Response to Climate Drivers Using Echo State Observers

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VEGETATION RESPONSE to climate drivers is challenging to model due to the **long term** trends, **nonlinear** response to weather stimuli, and **stochasticity**.

- Can a data driven algorithm trained only on atmospheric observables reproduce the biosphere dynamics?
- Can this model also replicate the vegetation response to extreme events?

ECHO STATE NETWORKS

ECHO STATE NETWORKS are machine learning models based on recurrent neural networks:

- Trained **without backpropagation**
- **Faster** and computationally **less expensive**
- No vanishing/exploding gradients
- Suited to model chaotic systems[1]

States equation[2]

$$\mathbf{x}(t+\Delta t) = (1-\alpha)\mathbf{x}(t) + \alpha f(\mathbf{W}\mathbf{x}(t) + \mathbf{W}_{\text{in}}\mathbf{u}(t))$$

Training with ridge **regression**.

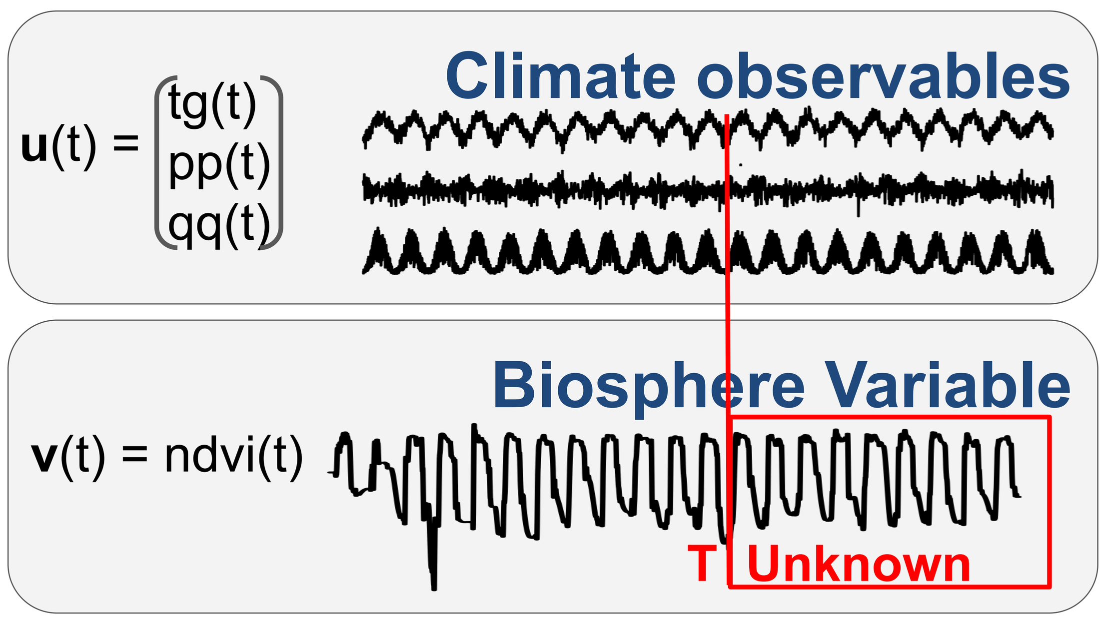
$$\mathbf{W}_{\text{out}} = \mathbf{Y}^{\text{target}}\mathbf{X}^{\mathsf{T}}(\mathbf{X}\mathbf{X}^{\mathsf{T}} + \beta\mathbf{I})^{-1}$$

Prediction: $\mathbf{v}(t) = g(\mathbf{W}_{\text{out}}\mathbf{x}(t))$

OBSERVERS

OBSERVERS are estimators of the state of a dynamical system:

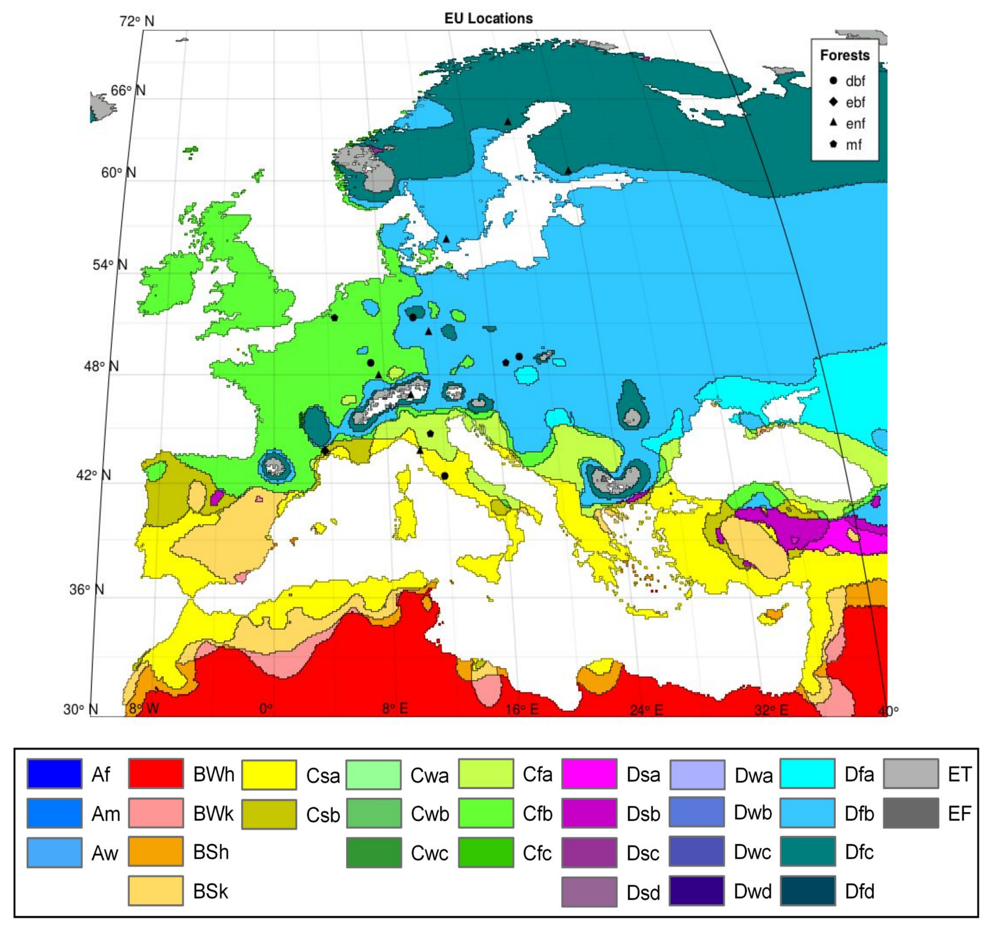
- Consider **u**(t) and **v**(t) from same system
- After time T we only observe to **u**(t)
- An observer returns a valid estimation of **v**(t) given **u**(t)



DATA

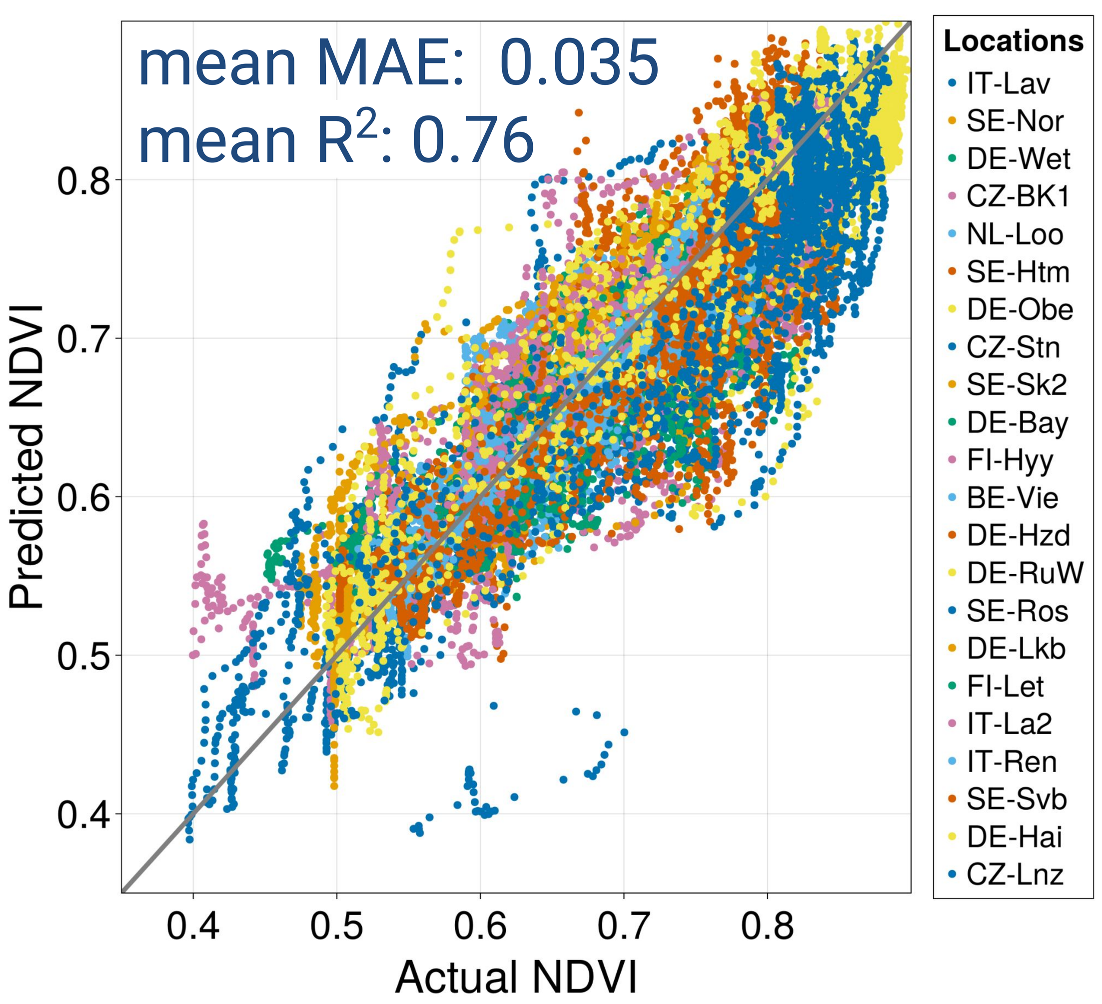
DATA taken from[3,4]

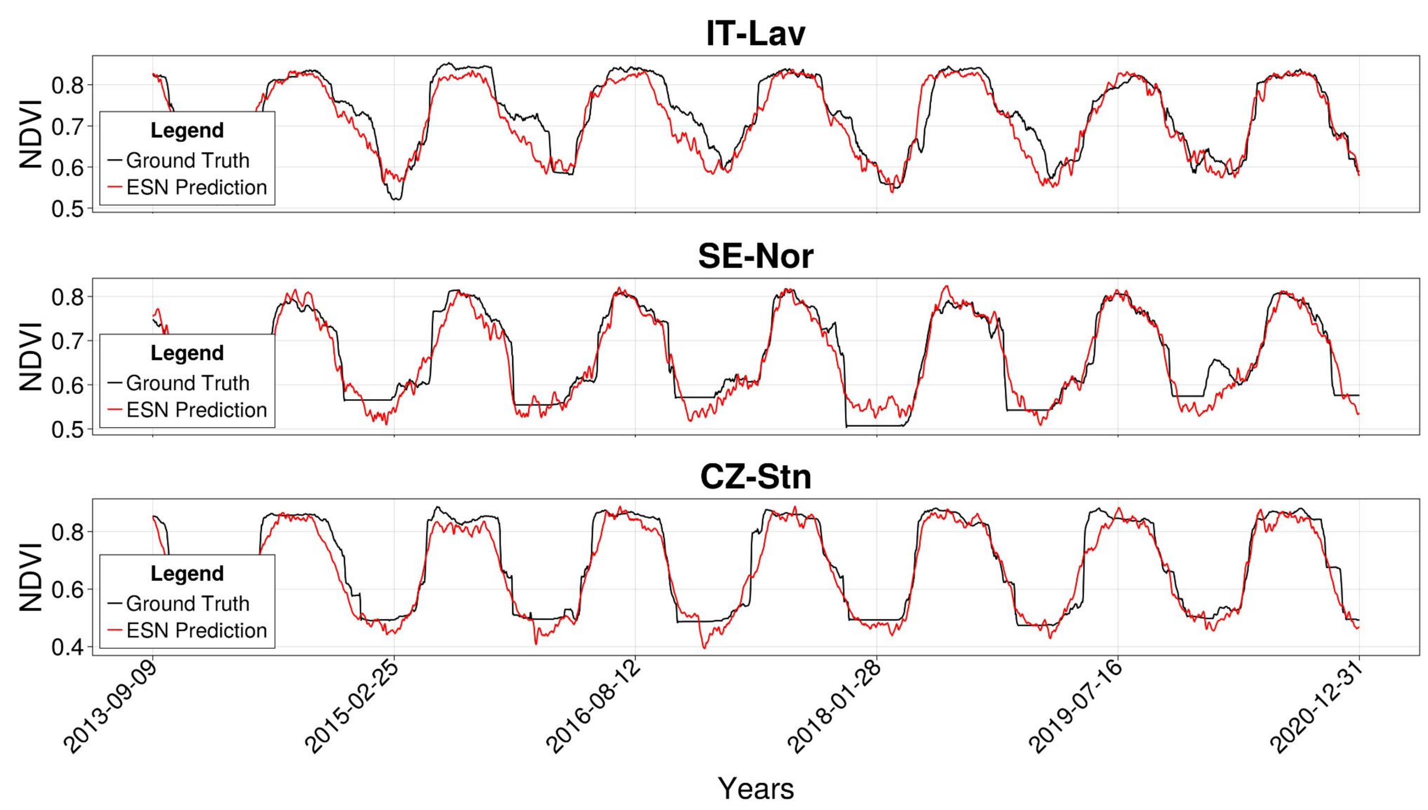
- Different **forest** types
- Different **climate** zones



RESULTS

- Overall good prediction values
- Some locations show irregular behaviour, harder to predict
- The majority has a strong seasonal component





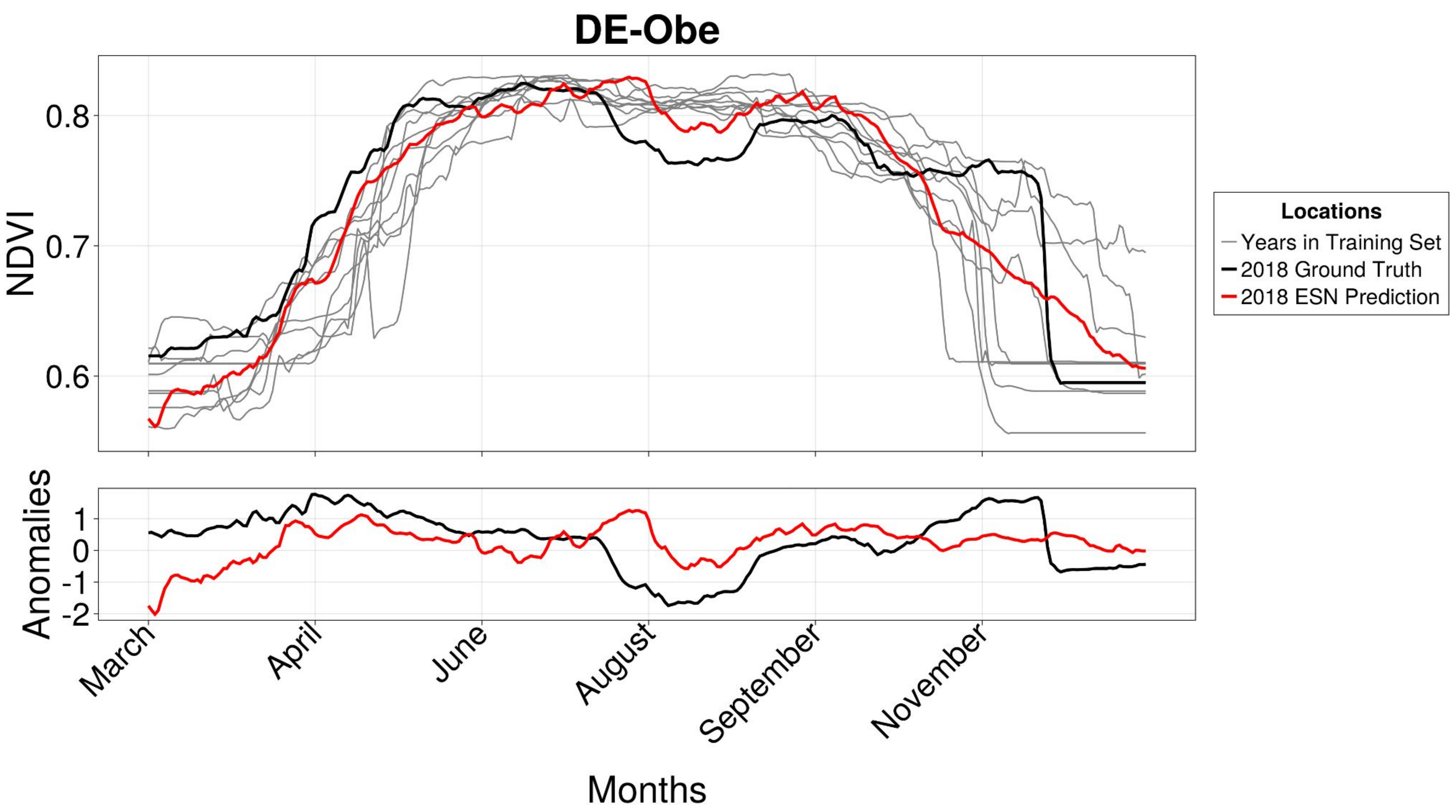
GREENNESS ANOMALIES

GREENNESS ANOMALIES can be defined using the following formula[5], and checking for values >1

$$A(i) = \frac{NDVI(i) - \overline{NDVI}}{\sigma(NDVI)}$$

Decrease in accuracy measures during anomalies

- MAE 30.7%
- R^2 34.8%
- RMSE 66.4%



CONCLUSIONS

- The ESNs are able to replicate vegetation dynamics
- Repercussions of extreme events, defined as anomalies in the NDVI signal, show a decrease in the accuracy of the prediction

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REFERENCES

1: Chattopadhyay, A et al. (2020)
2: Jaeger, H. (2001)
3: Walther, S. et al. (2022)
4: Cornes, R. C. .et al. (2018)
5: Lotsch, A. et al. (2005)

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