Functional ecology in the SBG Era:
An assessment of the state of plant trait retrieval from imaging spectroscopy

Alexey N. Shiklomanov[1], Yoseline Angel[1,2], Dhruva Kathuria[1,3], Evan Lang[1,4]

[1] NASA Goddard Space Flight Center; [2] University of Maryland – ESSIC; [3] Morgan State University – GESTAR II; [4] Science Systems and Applications, Inc. (SSAI)

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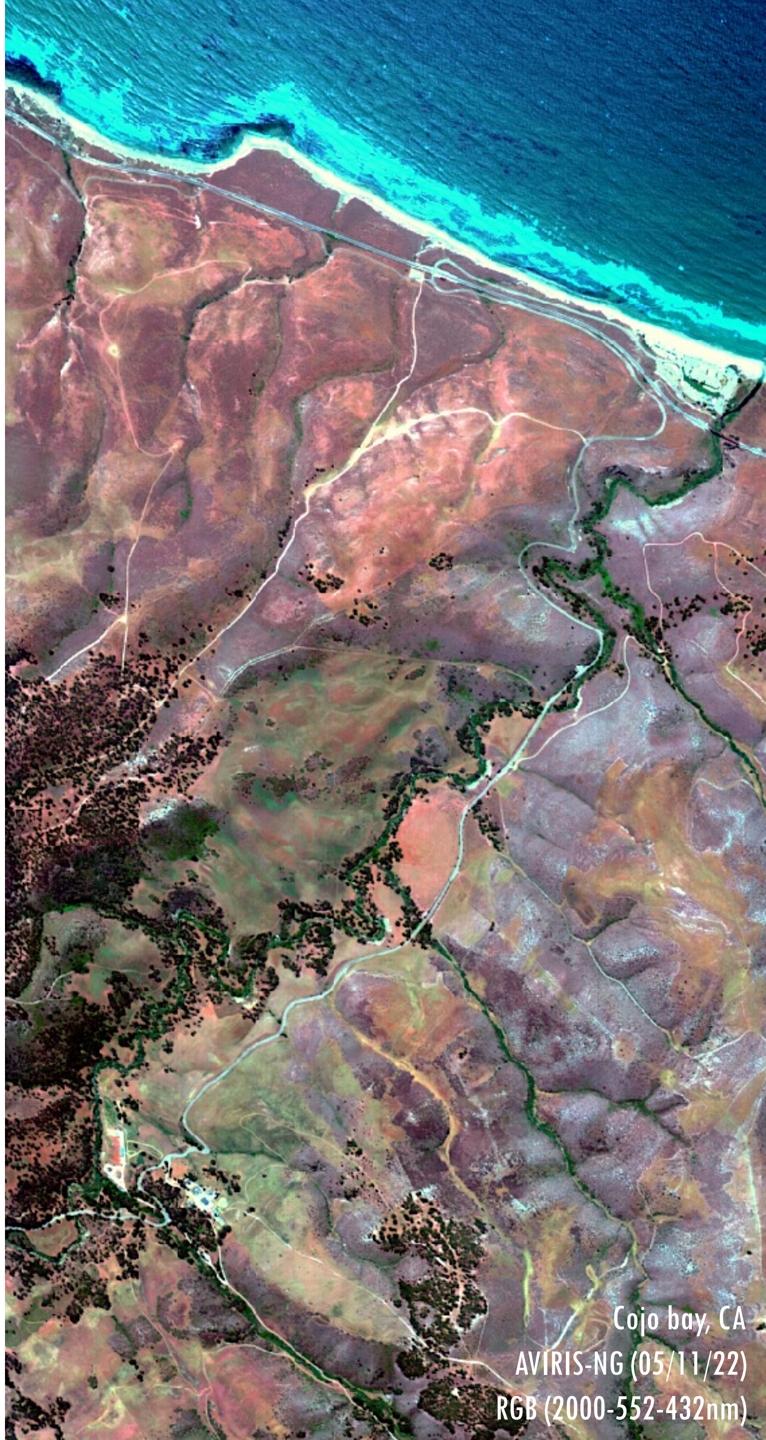
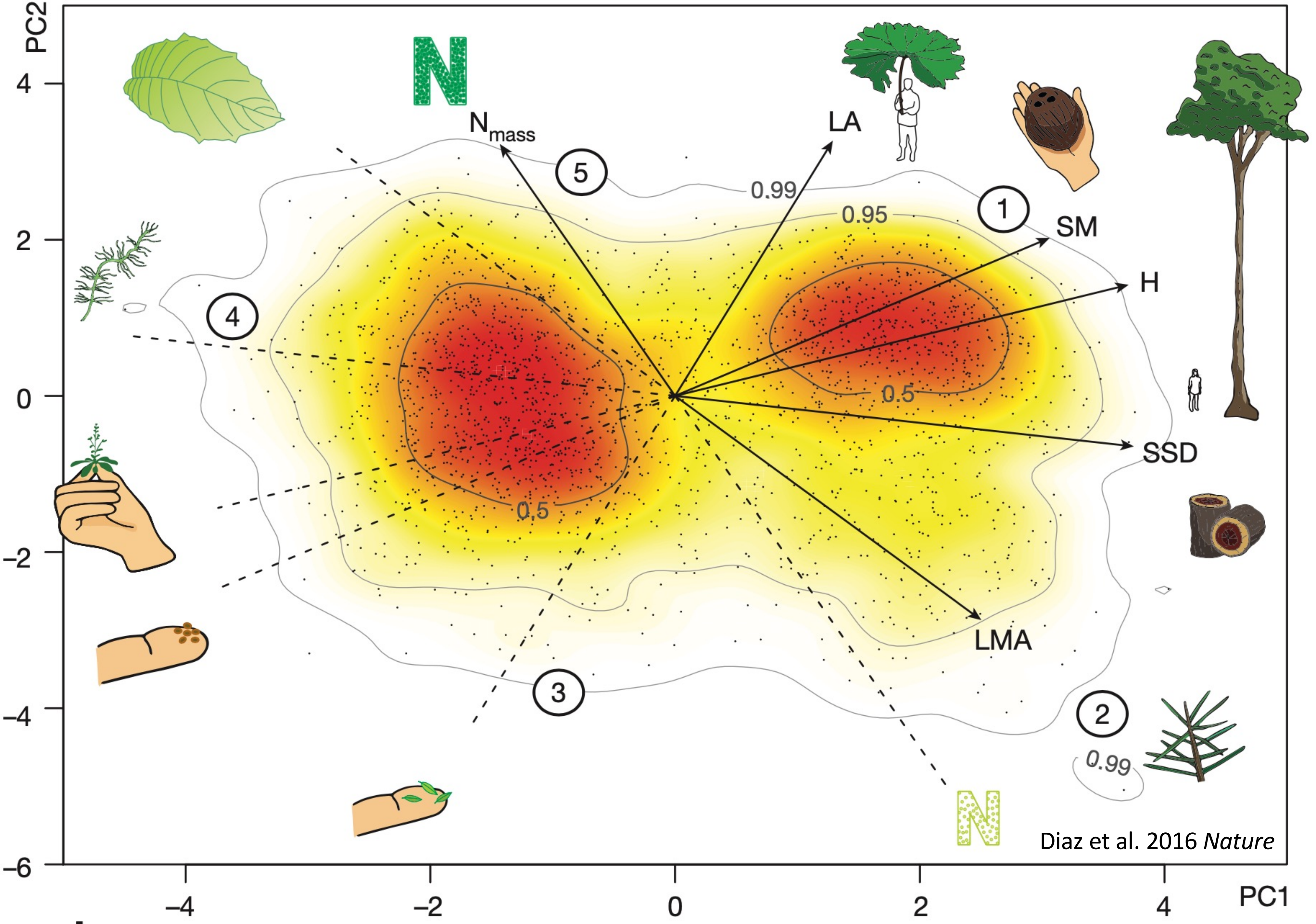


Plant functional traits

Measurable characteristics of plants that are closely related to function and fitness.

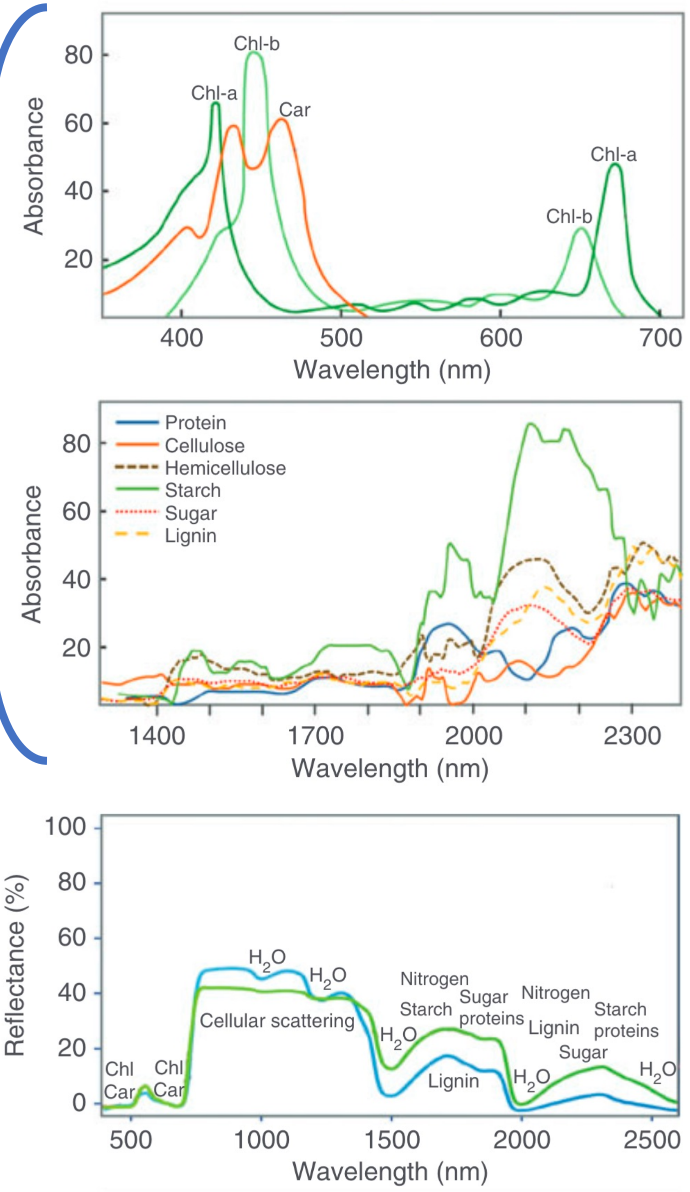


Diaz et al. 2016 *Nature*

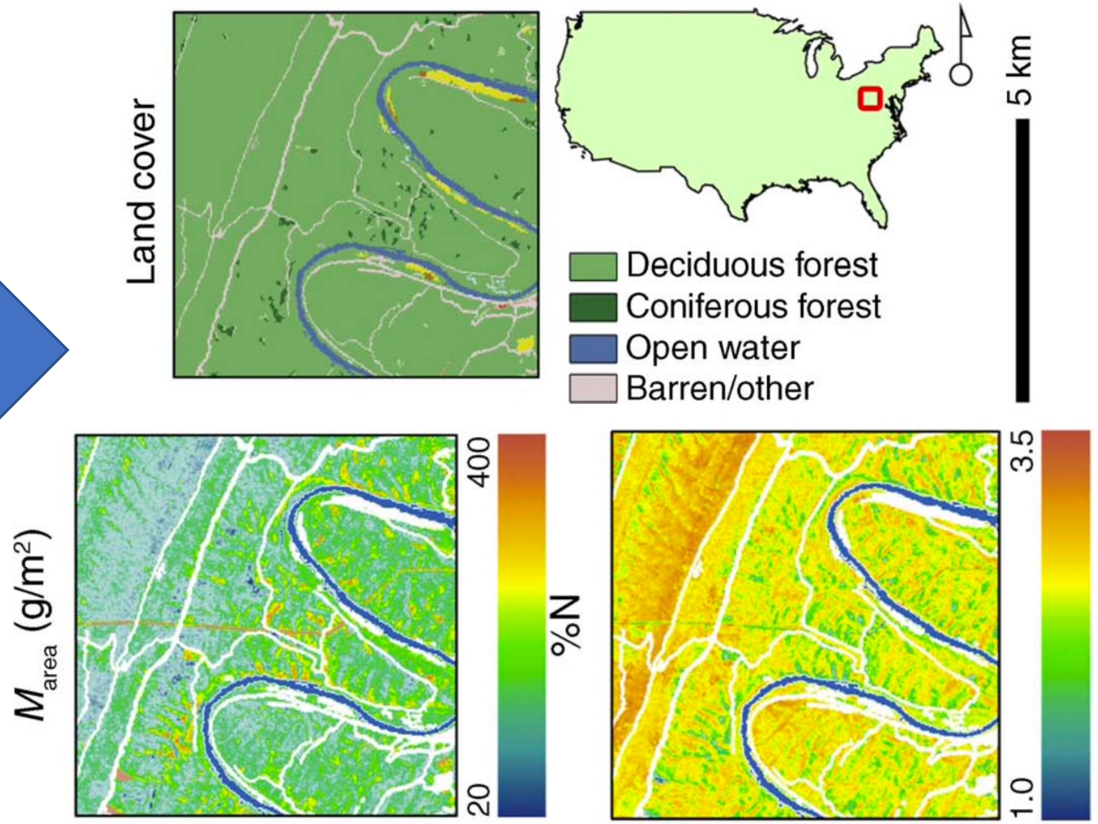
Leaf traits affect leaf optical properties, allowing us to estimate leaf traits from remote measurements of reflectance ("imaging spectroscopy").

Optical properties of specific traits

Leaf reflectance



Trait retrieval algorithm



Singh et al. 2015 *Ecological Applications*

~~(1) What are the "best" algorithms, at both leaf and canopy scales?~~

"Boring! Make new algorithms!"
- NASA review panel

Fine, we'll make new algorithms!
- Shiklomanov et al.

(2) Why do these algorithms succeed (or fail), and under what conditions?

~~(3) How should we measure spectra to get the best trait estimates?~~

"Too late -- nobody cares!"
- NASA review panel

Fine, we'll look at flowers instead!
- Shiklomanov et al.

New algorithms: Bayesian alternative to PLSR

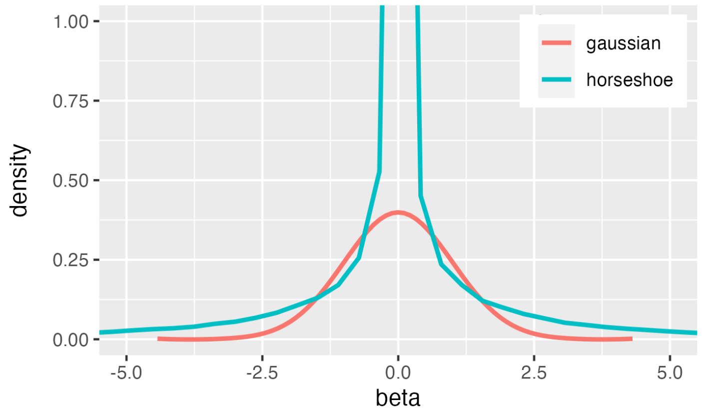
Traditional approach:
Partial Least Squares Regression (PLSR)

$$trait = \beta_1 PLSR_1 + \ldots \beta_p PLSR_p$$

$$w_1^1 x_{400} + \ldots w_{2400}^1 x_{2400} \qquad w_1^P x_{400} + \ldots w_{2400}^P x_{2400}$$

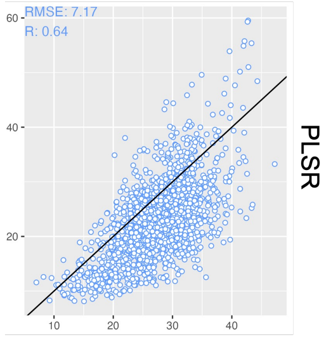
Alternative approach:
Bayesian Regression

$$trait \sim N(\theta, \sigma)$$
$$\theta = \beta_0 + \beta_1 x_{400} + \ldots + \beta_{2001} x_{2400}$$
$$\beta_i \sim horseshoe()$$
$$\sigma \sim halfCauchy(0, \alpha)$$

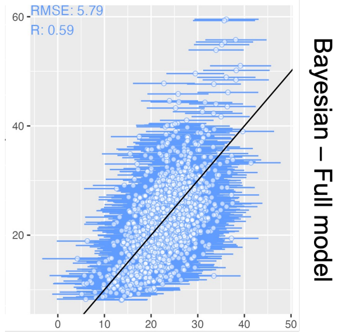


Comparable performance to PLSR for estimating leaf %N (and other traits) from field spectroscopy.

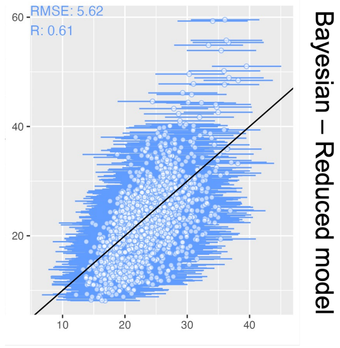
RMSE: 7.17, R: 0.64



RMSE: 5.79, R: 0.59



RMSE: 5.62, R: 0.61



Additional advantages

- Propagate uncertainty
- Leverage prior information
- Conceptually simple
- Extensible (e.g., multivariate)

Why do these algorithms succeed (or fail), and under what conditions?

"Visible"
Clear physical basis

"Invisible"
No direct physical basis

Water

Chlorophyll

Cellulose

Protein

Starch

Phenols

LMA

%N

%C

Mg

Ca

P

K

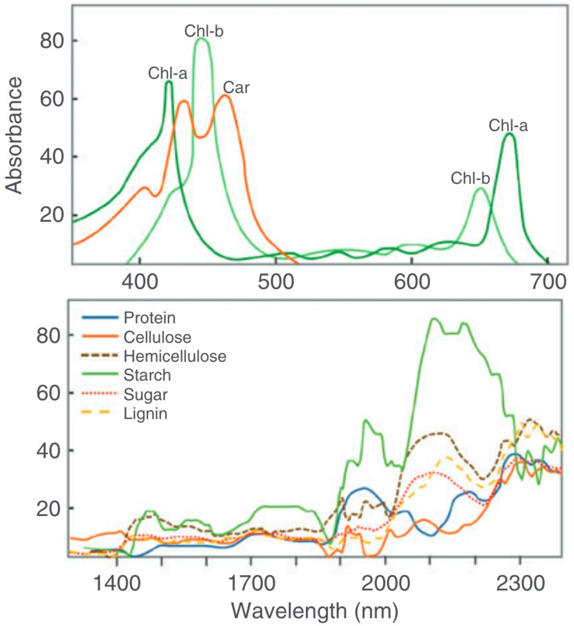
B

Fe

∂13C

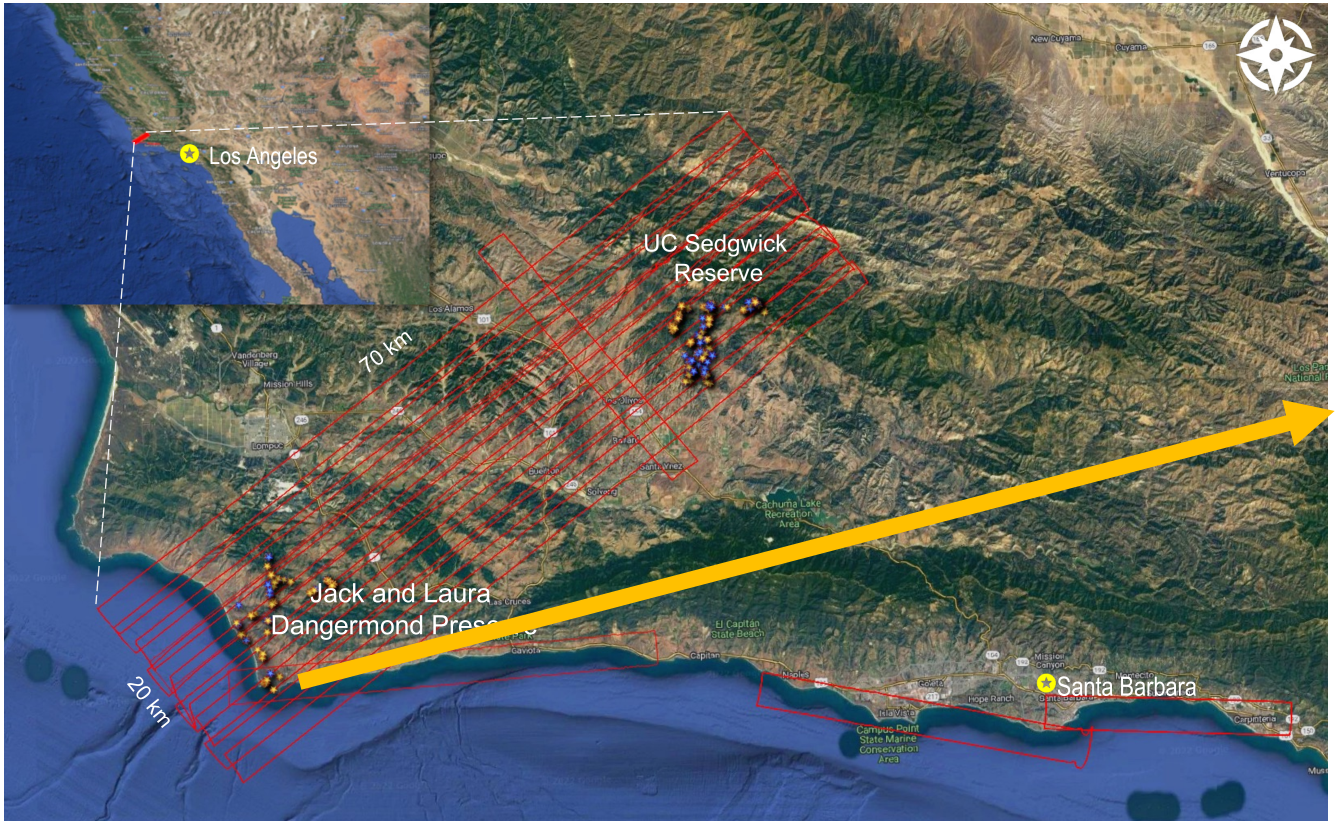
Vcmax

Jmax



All these traits have been successfully mapped using imaging spectroscopy. **Why does this work? What are we *really* seeing** when we see "invisible" traits, in terms of correlations with other traits, structure, etc.

(3) Flowers!



SHIFT
SBG High Frequency Timeseries

SBG High-Frequency Time series (SHIFT) — Weekly AVIRIS-NG flights during spring/summer 2021, with coordinated field sampling.

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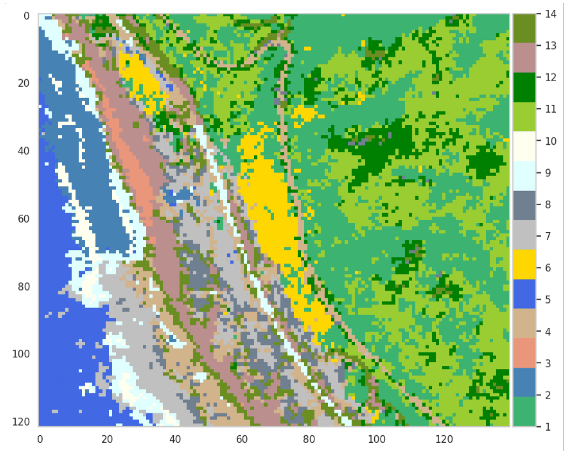
Mapping flowers and their phenology

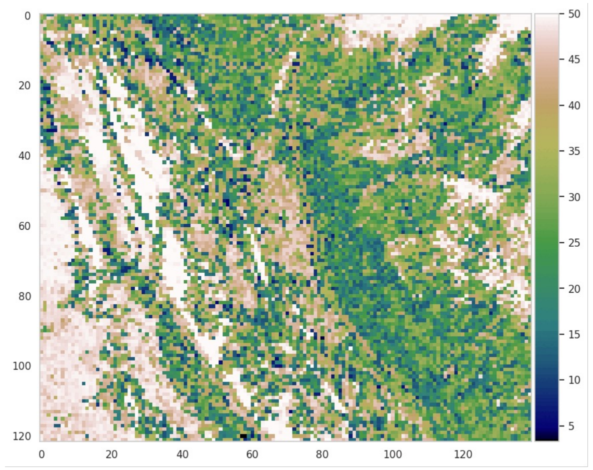
Mapping flowers using Gaussian mixture model (GMM)

Probability of Occurrence

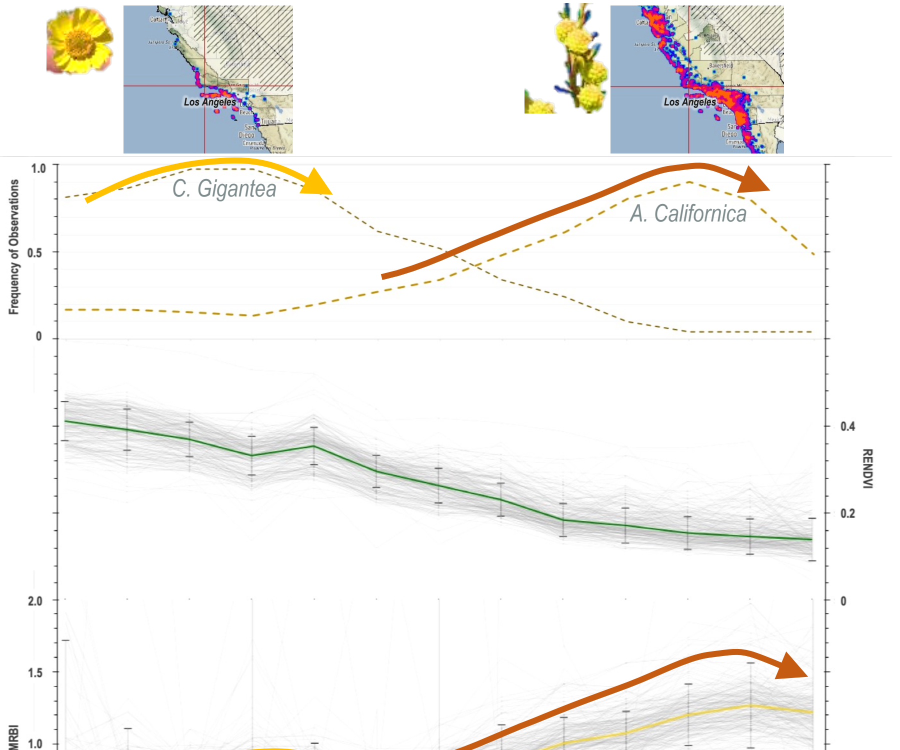


Spectral clusters $p(\theta)$ maps + uncertainties

Certainty



Species reported by **Wildflower Search*** shows the phenological dynamics of *C. Gigantea* and *A. Californica*, observed during their flowering phase



Red-edge normalized difference vegetation index

(Gitelson & Merzlyak, 1994)

$$RENDVI = \frac{R_{750} - R_{705}}{R_{750} + R_{705}}$$

Mixture residual blooming index

$$MRBI = \frac{\bar{R}_{557}}{\bar{R}_{672}} + \frac{\bar{R}_{1209} + \bar{R}_{1108}}{(\bar{R}_{1209} - \bar{R}_{1108})}$$

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Enabling large-scale SHIFT data analysis with cloud computing

SHIFT SMCE User Guide
latest

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Reading in Data

Data can be read in using two function calls: read and read_chunked. The read method will pull all the data in the dataset into memory. It is highly recommended to use the read_chunked method unless you are sure your data can fit into memory.

```
data = cat.aviris_v1_gridded.read_chunked()
data
```

xarray.Dataset

► Dimensions: (**time**: 13, **y**: 12023, **wavelength**: 425, **x**: 13739)

▼ Coordinates:

time	(time)	datetime64[us]	2022-02-24 ... 2022-05-29
wavelength	(wavelength)	float32	377.2 382.2 ... 2.496e+03 2.501e+03
x	(x)	float64	7.177e+05 7.177e+05 ... 7.864e+05
y	(y)	float64	3.866e+06 3.866e+06 ... 3.806e+06

▼ Data variables:

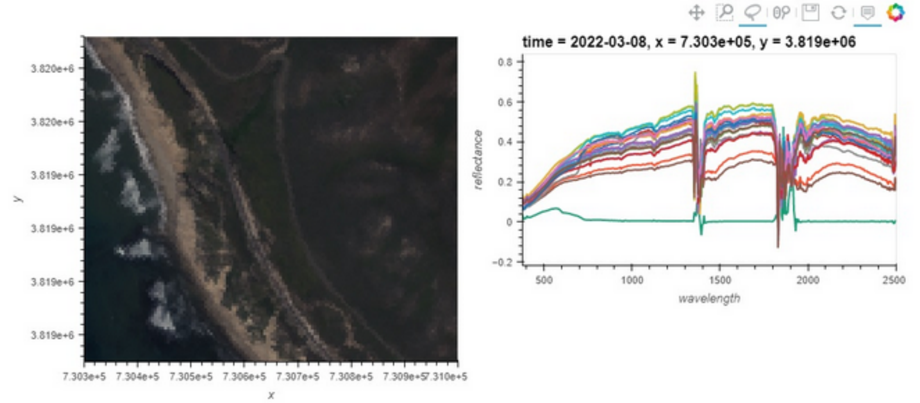
reflectance	(time, y, wavelength, x)	float32	dask.array<chunksize=(1, 1, 425, 1373...
spatial_ref	()	int64	...

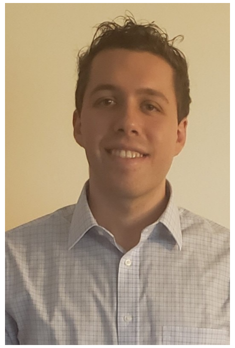
► Attributes: (13)

https://shift-smce-user-guide.readthedocs.io

Spectra Selection

```
# Create the RGB image plot
rgb_image = ds_rgb.hvplot.rgb(
    x='x', y='y', bands='wavelength', aspect = 'equal', frame_width=400).opts(
    tools=["hover", 'lasso_select'])

# Create streams
posxy = hv.streams.PointerXY(source=rgb_image, x=730302.5, y=-3819657.5)
sel = hv.streams.Lasso(source=rgb_image, geometry=np.array([[730302.5, 3819657.5]]))

# Function to build a new spectral plot based on mouse hover positional
# Information retrieved from the RGB image using our full reflectance dataset
def point_spectra(x,y):
    return aoi.sel(x=x,y=y,method='nearest').hvplot.line(
        y='reflectance',x='wavelength', color='#1b9e77', frame_width=400)

def selected_info(geometry):
    x = find_nearest(aoi.x, geometry[:, 0])
    y = find_nearest(aoi.y, geometry[:, 1])
    points = set(list(zip(x, y)))

    list_of_lines = [aoi.sel(x=x, y=y, method='nearest').hvplot.line(
        y='reflectance',x='wavelength', frame_width=400) for x, y in points]
    return hv.Overlay(list_of_lines)

# Define the Dynamic Maps
point_dmap = hv.DynamicMap(point_spectra, streams=[posxy])
lasso_dmap = hv.DynamicMap(selected_info, streams=[sel])

# Plot the RGB image and Dynamic Maps side by side
(rgb_image + point_dmap*lasso_dmap)
```





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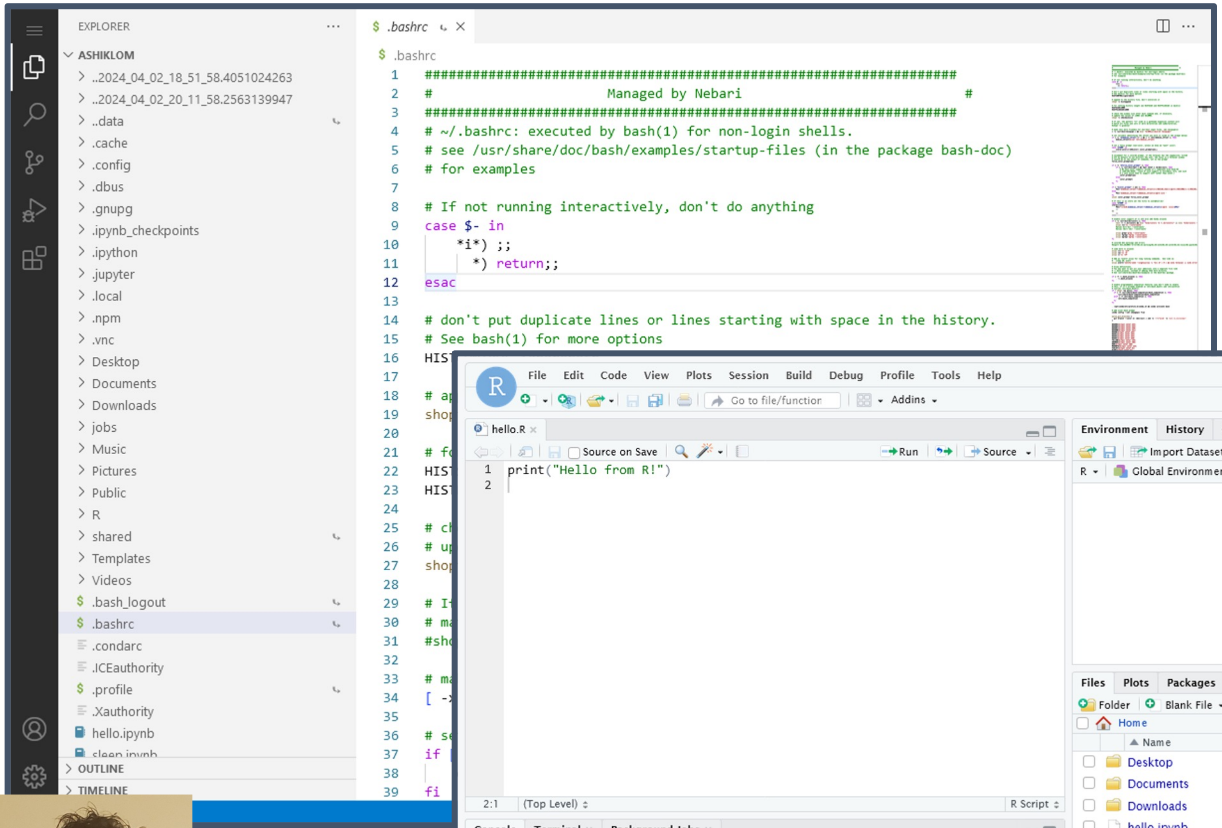
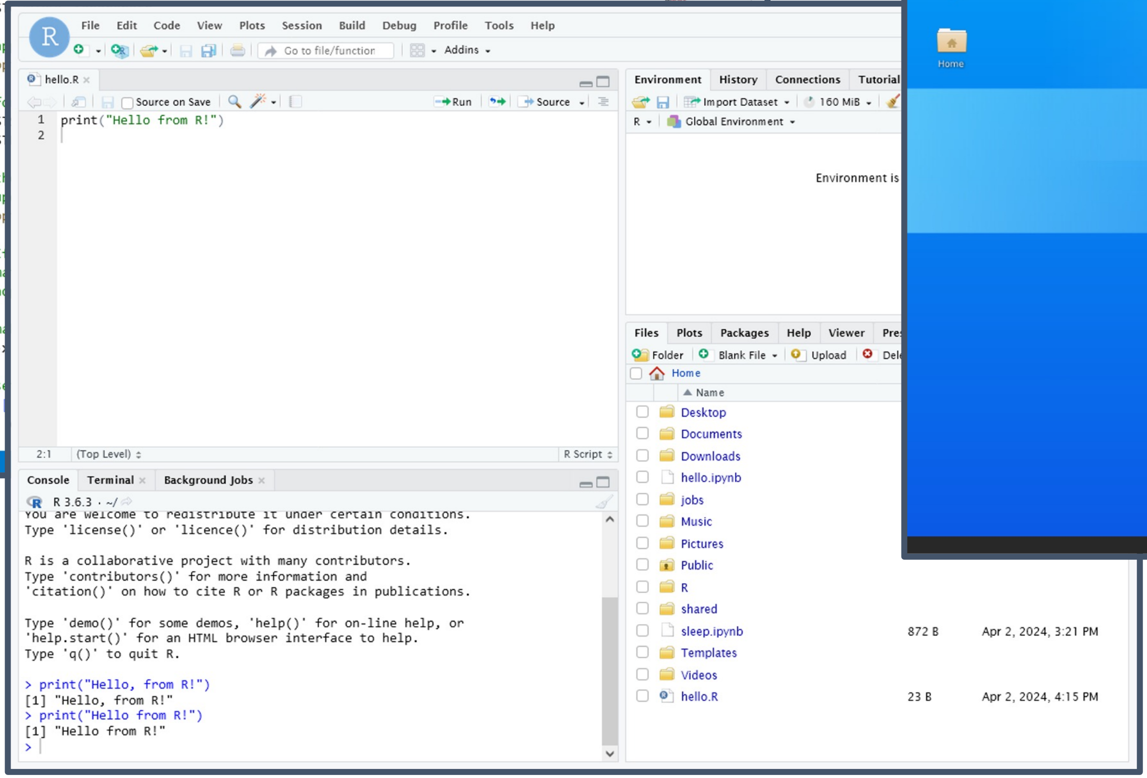
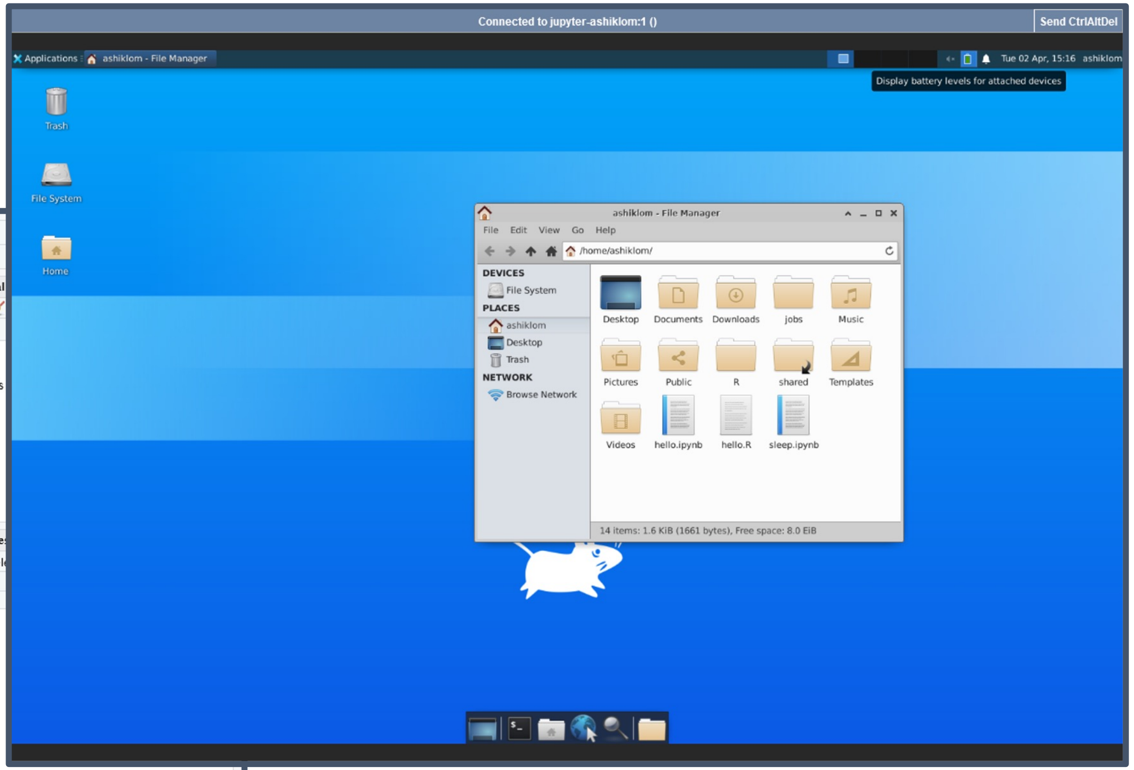
SHIFT project on NASA Science Managed Cloud Environment (SMCE) provides cloud-based interactive analysis capabilities (JupyterLab), scalable compute (SLURM) next to the SHIFT airborne data, and tools and documentation to make all of this easier!

Extensions to cloud platforms to support new use cases

New features to support the BioSCape field campaign

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Based on Nebari, an open-source infrastructure-as-code project.

Nebari

New algorithms for trait retrieval

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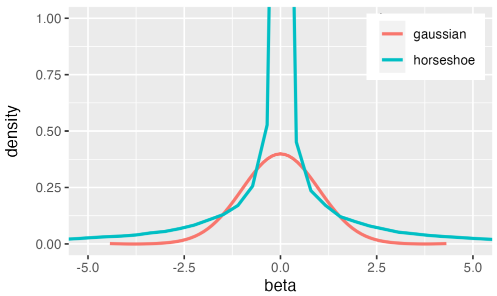

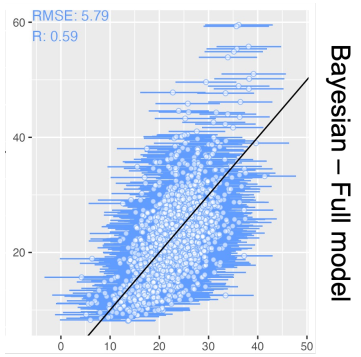

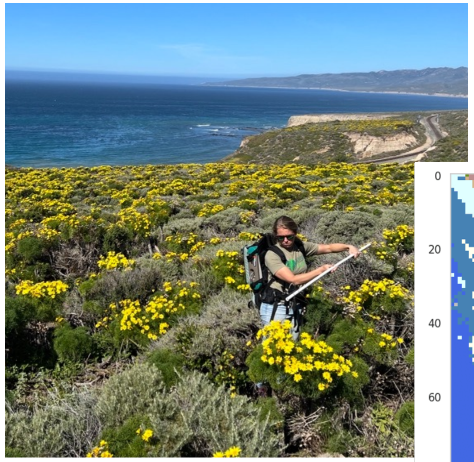

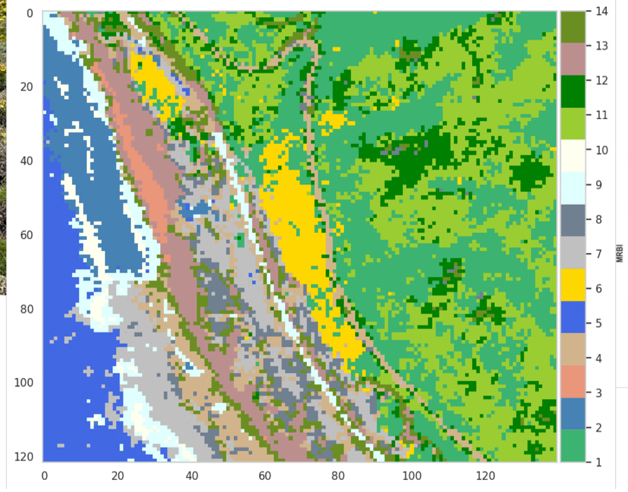

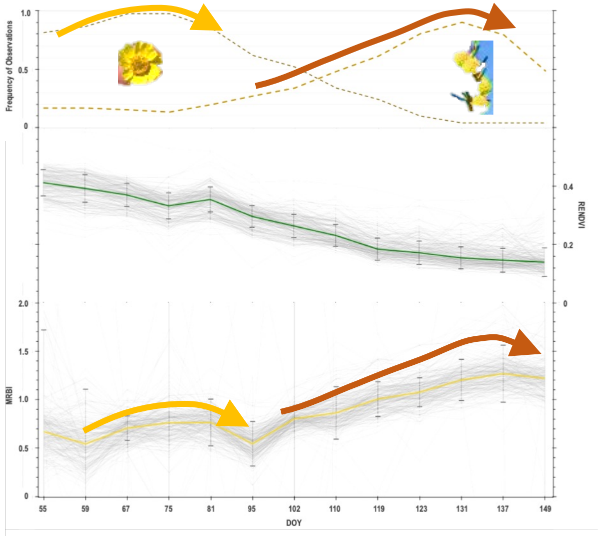

Mapping flowers and their phenology

Cyberinfrastructure to support spectroscopy