Disentangling the Spectra of Flowers to Map Landscape-Scale Blooming Dynamics

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Motivation

Shifts in flowering phenology are reported as an effect of climate change during the last decades. Therefore, quantifying flowering traits, such as color, floral density, and flower-background color relationships, is relevant for identifying pollinators habitat degradation, monitoring floral adaptations to environmental changes, and species competition based on flower color signaling.

Flower pigments absorb light along the spectral range between the ultraviolet and shortwave infrared (~300-800 nm), depending on their chemical structures. Image spectroscopy can measure the amount of light reflected, absorbed, and transmitted by such pigments across different spatio-temporal scales. We explore how flowers contribute to canopy spectral signals by using airborne remote sensing for monitoring and detecting blooming dynamics at high spatial, spectral, and temporal resolution:

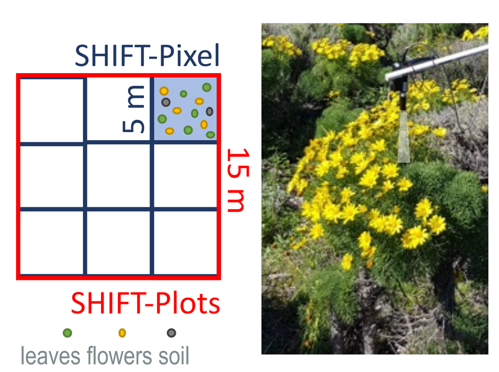
- Characterizing the spectral variability within a pixel.
- Mapping flowering areas.
- Revealing specific phenophases across species.

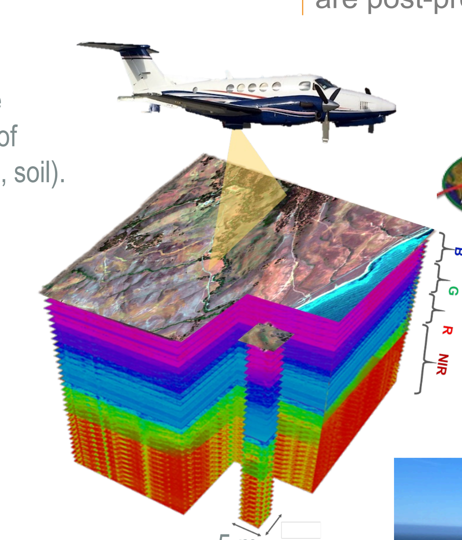
Data collection and processing

1. **Data collection**: Weekly time series imagery from the airborne imaging spectrometer AVIRIS-NG and field spectra were collected in the study site as part of the SBG High-Frequency Time Series (SHIFT) campaign.

2. **Processing**: Raw radiance swaths are atmospherically corrected with ISOFIT and translated into reflectance. Ground spectra (leaves, flowers, soil) from flowering sampled plots are post-processed.

Each pixel represents an individual reflectance spectrum comprising the spectral contribution of several surface elements (e.g., leaves, flowers, soil).

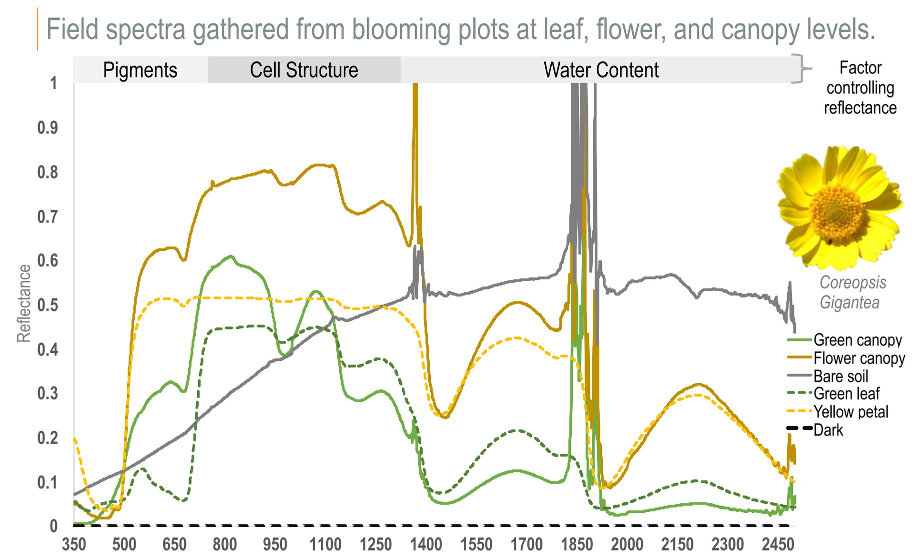




Imaging spectroscopy involves dividing light into thousands of narrow bands to gain detailed information.

A diversity of native shrubs is associated with sandy soils in the chaparral habitat, including *Coreopsis Gigantea* and *California Sagebrush*, the two most extensive species observed in the sampled plots.

Field spectra gathered from blooming plots at leaf, flower, and canopy levels.

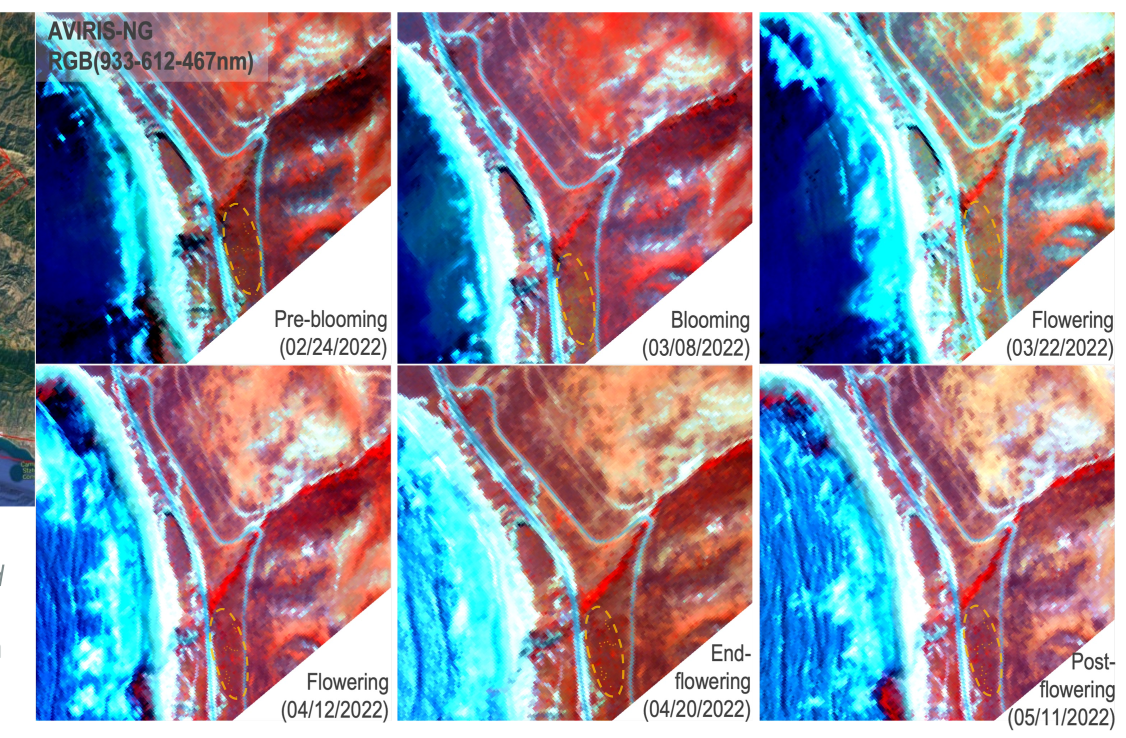


3. **Modeling**: Field spectra and processed reflectance images are used to investigate the spectro-temporal variation and spatial distribution of flowering species using spectral unmixing and Bayesian clustering techniques.

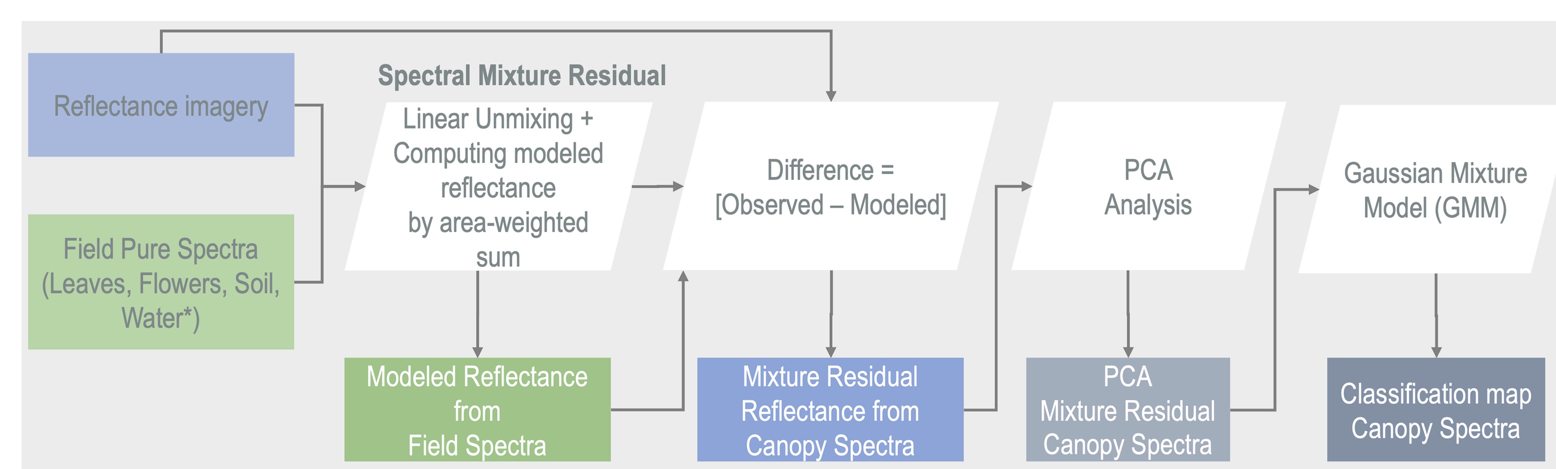
4. **Analysis**: Mapping flowering events from modeling spectro-temporal dynamics over the course of the season, from pre-blooming to post-flowering stages. Greenness and flowering analysis based on hyperspectral vegetation indices.

Mapping flowering areas

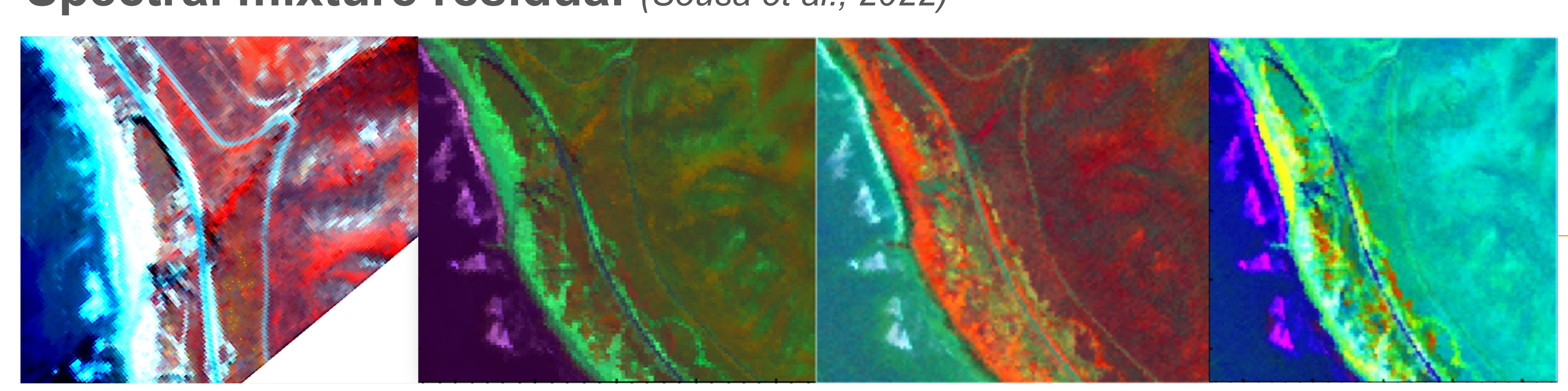
Data were acquired from February to May 2022, in the Nature Conservancy's *Jack and Laura Dangermond Preserve* over the north coastline of the Point Conception and 70 km northwest of Santa Barbara, California.



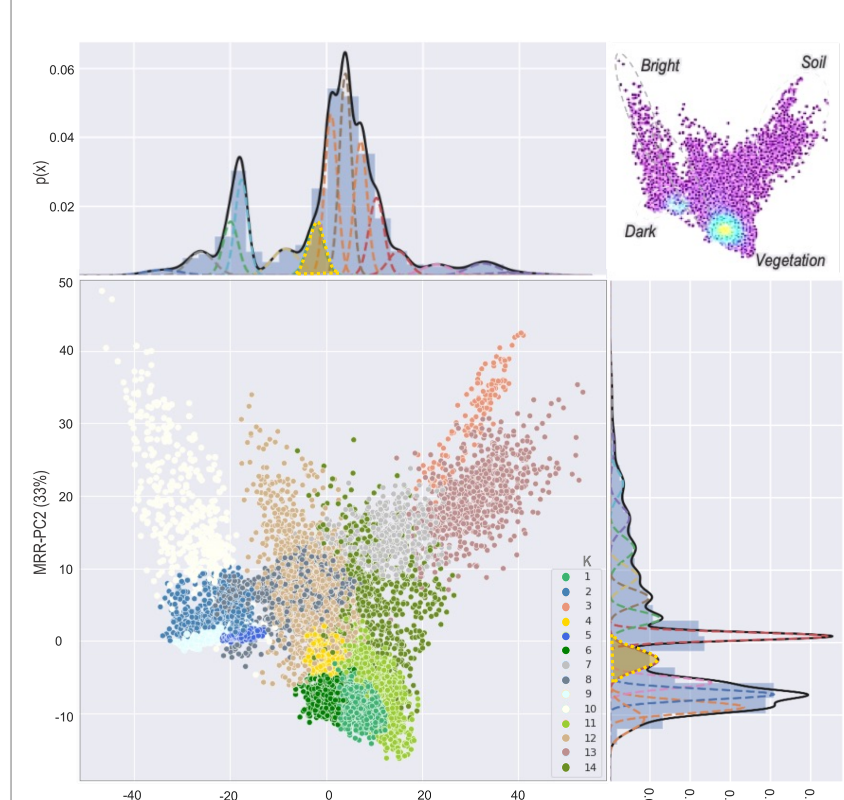
Mapping workflow



Spectral mixture residual *(Sousa et al., 2022)*



Reflectance | RGB-composite from reflectance's PC | Mixture residual reflectance (MRR) | RGB-composite from MRR's PC



A typical 5 m pixel may contain several individual plants of different species, flowers, soil, and shadows with highly variable fractional coverage of the canopy area. A mixed pixel's reflectance spectrum is considered the sum of a linear combination of four low-variance endmembers (leaves, flowers, soil, dark water pixel) and a misfit (high-variance signal + noise):

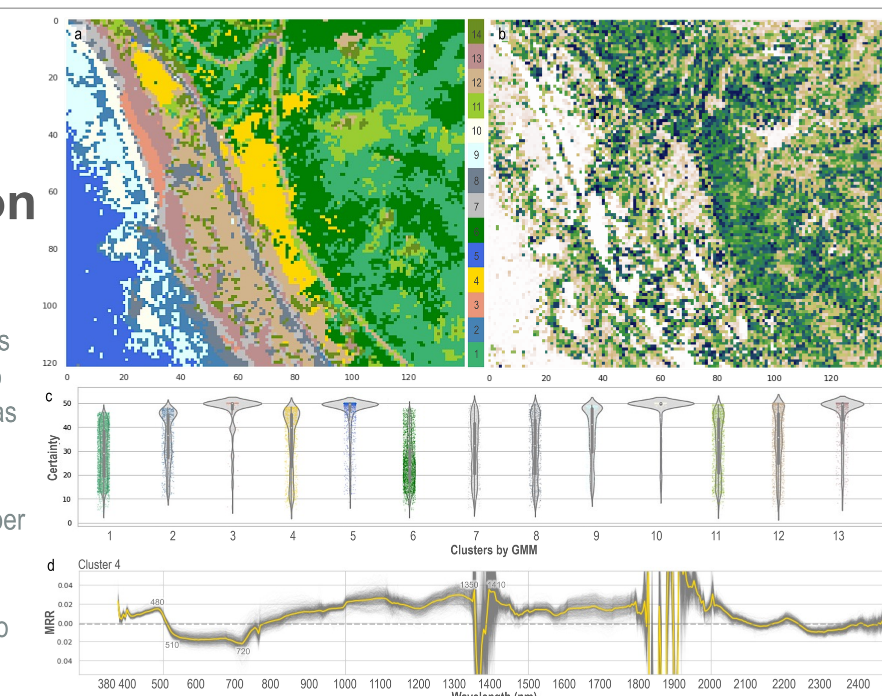
1. Linear spectral unmixing using field spectra endmembers.
2. Computing modeled reflectance by a weighted sum of components.
3. Subtracting (observed – modeled) reflectance spectra to obtain the residual spectrum (mixture residual).

Principal Components (PC) analysis

The first three Principal Components (PC) of a hyperspectral reflectance image capture broad mixtures of vegetation, soil, and dark components; in contrast, PC1 and PC2 of a mixture residual image comprise the main spectral differences between the mixed endmembers.

Gaussian Mixture classification

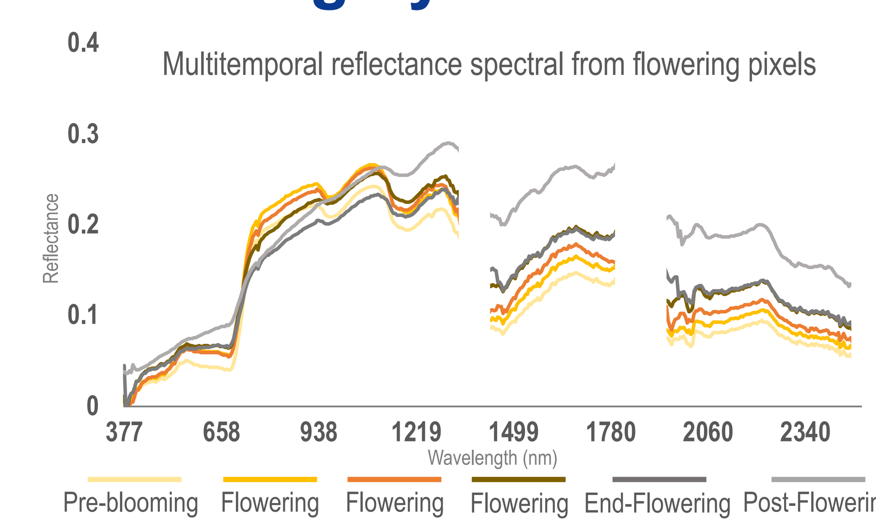
Gaussian Mixture Model (GMM) is an unsupervised clustering approach that fits K Gaussian distributions to the data. Each K cluster has a mean and variance. A maximum likelihood condition defines the number of clusters. For each pixel, GMM calculates the probabilities of belonging to each cluster.



The spatial distribution of the classes over the study domain (a) closely matches the location of flowering plots (K=4). Clusters in blue and white colors (e.g., K=2, 5, 8-10) contain dark pixels associated with ocean cover, while earth tones and green colors represent soil and vegetated areas, respectively.

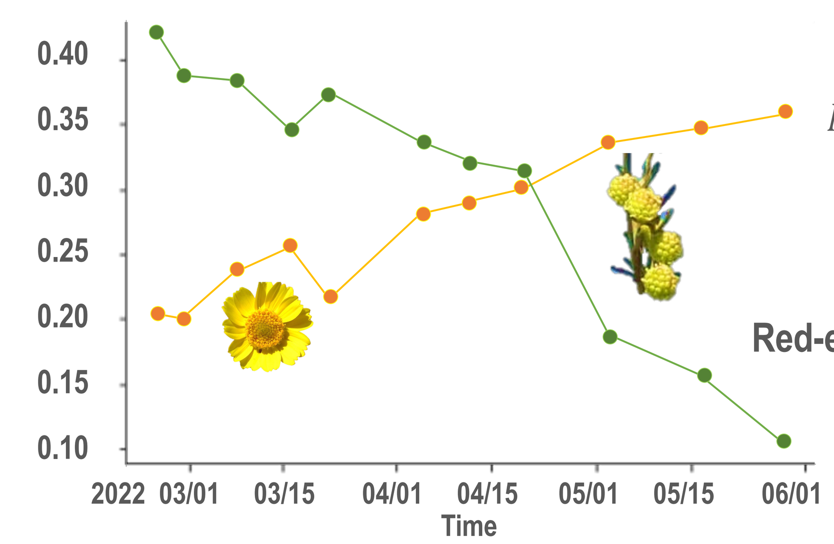
Certainty map (probability %) of the results (b) allow to assess the spatial distribution across clusters (c). Also, the spectral distribution of the MRR is shown for flowering areas (d), comparing the average residual reflectance (yellow line) against the population of flowering pixels (gray profiles).

Flowering dynamics



Flowering spectral features are characterized by weak blue absorptions and gradient temporal variations within the green and red spectral range.

Hyperspectral vegetation indices (HVIs) are mathematical formulations of spectral narrow bands that quantify plant functional traits. HVIs often combine many continuous bands to capture spectral profile features, such as slopes, curvatures, and absorption depths.



Modified enhanced blooming index

$$MEBI = \frac{\bar{R}_{yellow} + \bar{R}_{nir}}{\left(\frac{\bar{R}_{green}}{\bar{R}_{blue}}\right) * (\bar{R}_{red} - \bar{R}_{blue} + \varepsilon)}$$

Red-edge normalized difference vegetation index

$$RENDVI = \frac{\bar{R}_{750} - \bar{R}_{705}}{\bar{R}_{750} - \bar{R}_{705}}$$

The MEBI time series reveals specific flowering cycles, and the RENDVI leaf shows emergence/senesce sequence phenophases across the two main species (e.g., *Coreopsis Gigantea* and *California Sagebrush*) in the flowering areas.

Future directions

- Mapping flowering events from modeling spectro-temporal dynamics opens opportunities for future satellite (e.g., SBG, EMIT, CHIME) monitoring of floral cycles at broader scales.
- Advancing physical-based models that parametrize flower pigment contents (e.g., chlorophylls, carotenoids, and anthocyanins) for a quantitative understanding of flower coloration and its relative contribution to canopy spectral signals.
- Modeling flowering dynamics at the landscape scale and its connection with ecological processes, diversity of plants and pollinators, and phenological adaptations to environmental changes.

Angel, Y.; Shiklomanov, A. Remote Detection and Monitoring of Plant Traits: Theory and Practice. Annual Plant Reviews. 2022, 5, 3. DOI: 10.1002/9781119312994.apr0778
NASA. (2022). California Field Campaign Is Helping Scientists Protect Diverse Ecosystems. Climate Change: Vital Signs of the Planet. https://climate.nasa.gov/news/3157/california-field-campaign-is-helping-scientists-protect-diverse-ecosystems
Sousa, D., Brodrick, P., Cawse-Nicholson, K., Fisher, J. B., Pavlick, R., Small, C., & Thompson, D. R. (2022). The Spectral Mixture Residual: A Source of Low-Variance Information to Enhance the Explainability and Accuracy of Surface Biology and Geology Retrievals. Journal of Geophysical Research: Biogeosciences, 127(2), e2021JG006672. https://doi.org/10.1029/2021JG006672