Ecosystem Structure, Composition, and Function: Ecological Responses to Environmental Perturbations in Mammoth Mountain, California

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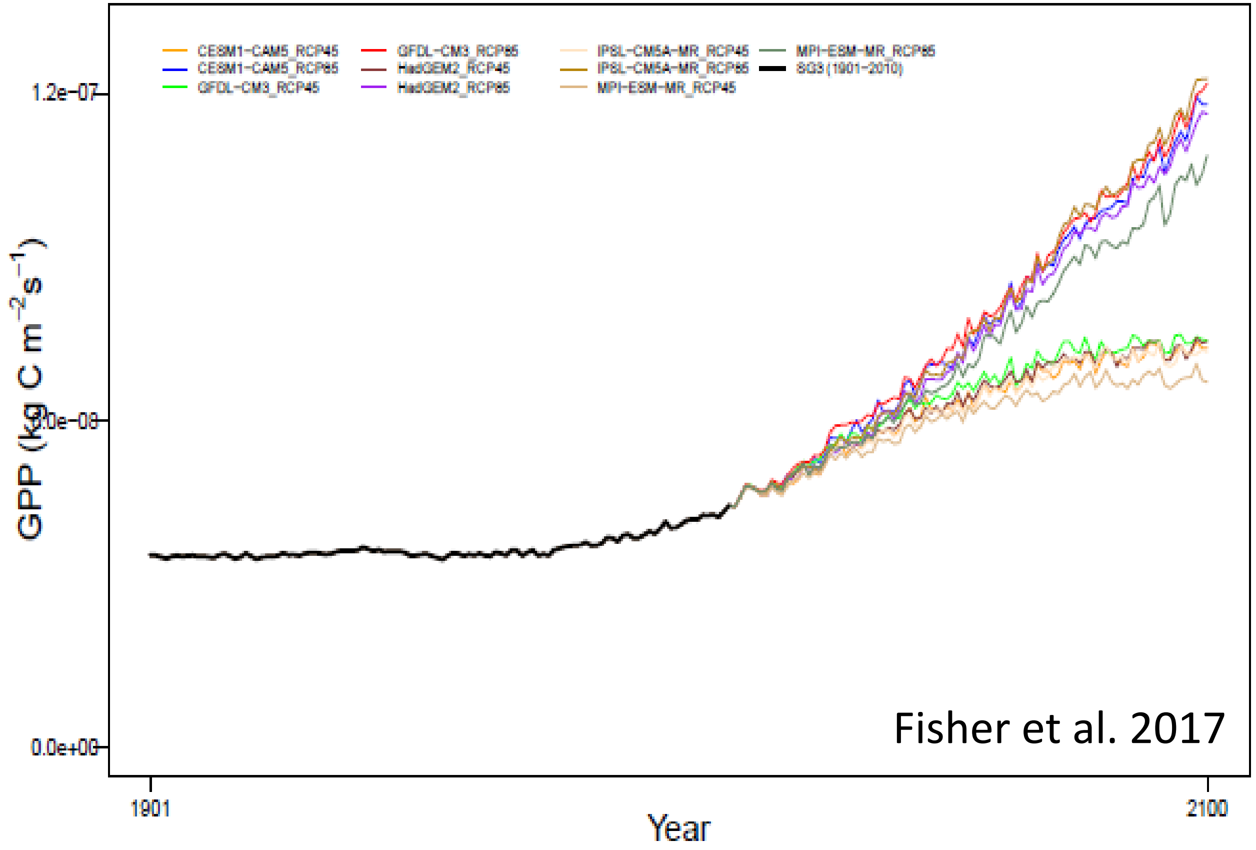
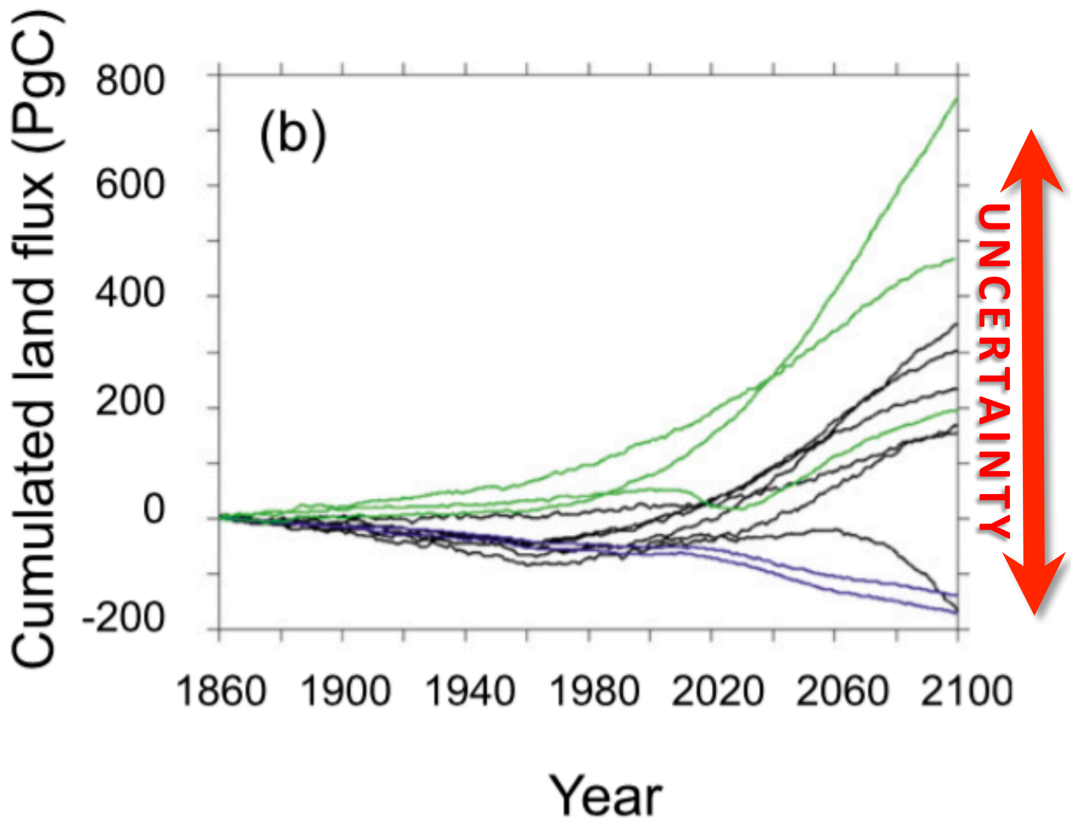




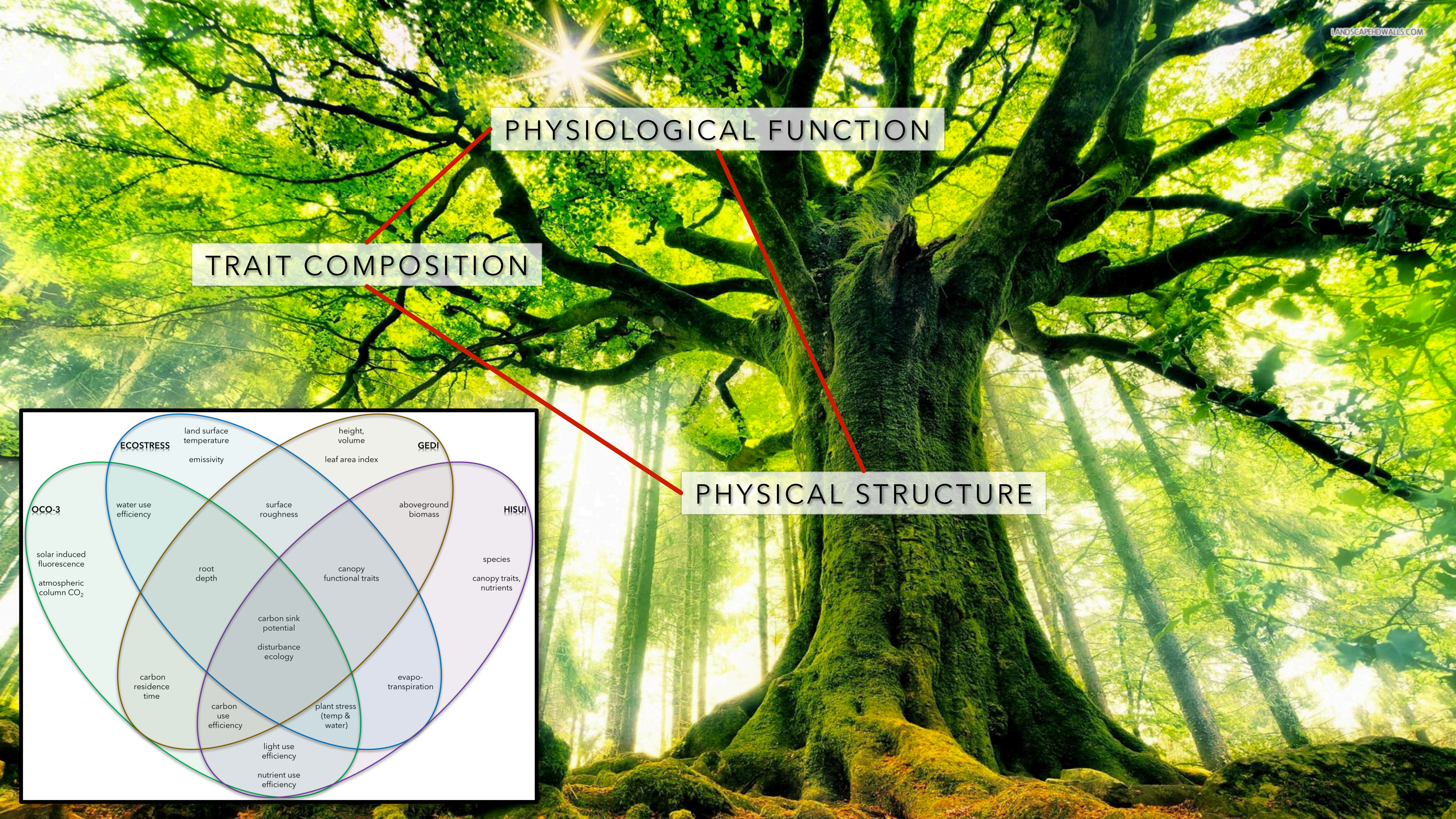
Two primary sources of uncertainty:

1) **Climate** (γ-response); versus, 2) **CO_2 fertilization** (β-response).

By far the largest sensitivity is in the β-response, with projected differences due to CO_2 fertilization in net carbon uptake up to 145% [*Piao et al.*, 2013; *Smith et al.*, 2016].

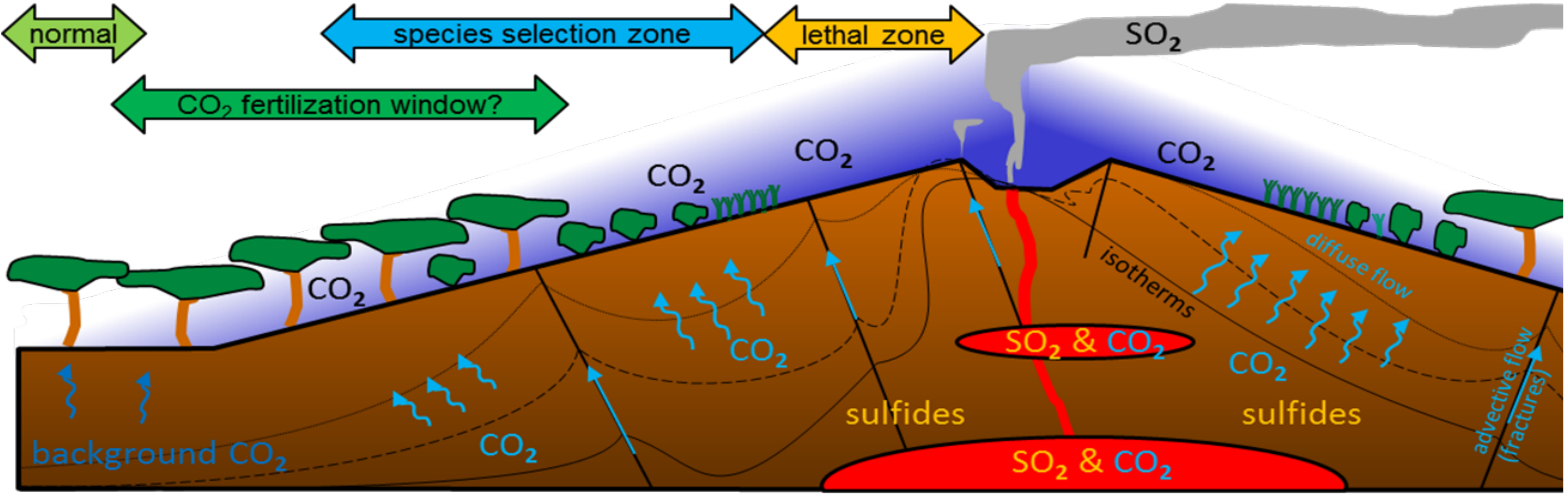
Plants and Elevated CO_2

- Tree responses to high CO_2 have been extensively studied in field experiments (Norby et al., 1999)
- Optimum-growth phase followed by a water-stressed phase eventually severe enough to cause death
- Threshold CO_2 concentration?

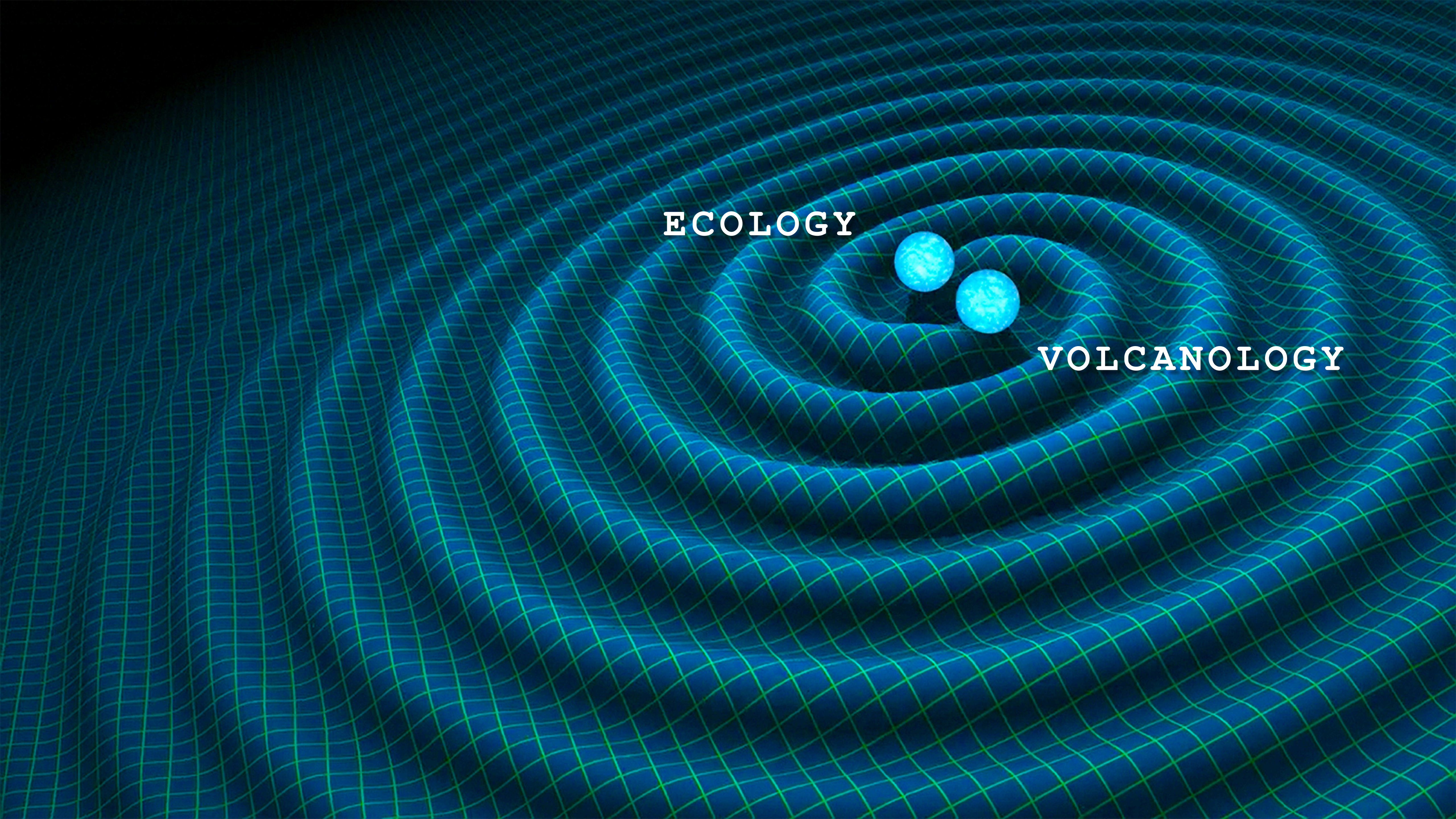

LANDSCAPEHDWALLS.COM
PHYSIOLOGICAL FUNCTION
TRAIT COMPOSITION
PHYSICAL STRUCTURE
ECOSTRESS
land surface temperature
emissivity
height, volume
leaf area index
GEDI
OCO-3
water use efficiency
surface roughness
aboveground biomass
HISUI
solar induced fluorescence
atmospheric column CO_2
root depth
canopy functional traits
species
canopy traits, nutrients
carbon sink potential
disturbance ecology
carbon residence time
evapo-transpiration
carbon use efficiency
plant stress (temp & water)
light use efficiency
nutrient use efficiency

Science questions

- **How do plants respond to rising CO_2**, in terms of ecosystem structure, composition, and function?
  - *Structure*: Does biomass increase with elevated CO_2?
  - *Composition*: Do canopy trait shifts occur in changing CO_2 environments?
  - *Function*: Does photosynthetic efficiency increase with increasing CO_2?



normal
species selection zone
lethal zone
CO_2 fertilization window?
SO_2
CO_2
CO_2
CO_2
CO_2
isotherms
diffuse flow
CO_2
SO_2 & CO_2
CO_2
sulfides
sulfides
advective flow (fractures)
background CO_2
CO_2
SO_2 & CO_2


ECOLOGY
VOLCANOLOGY

Mammoth Mountain, CA

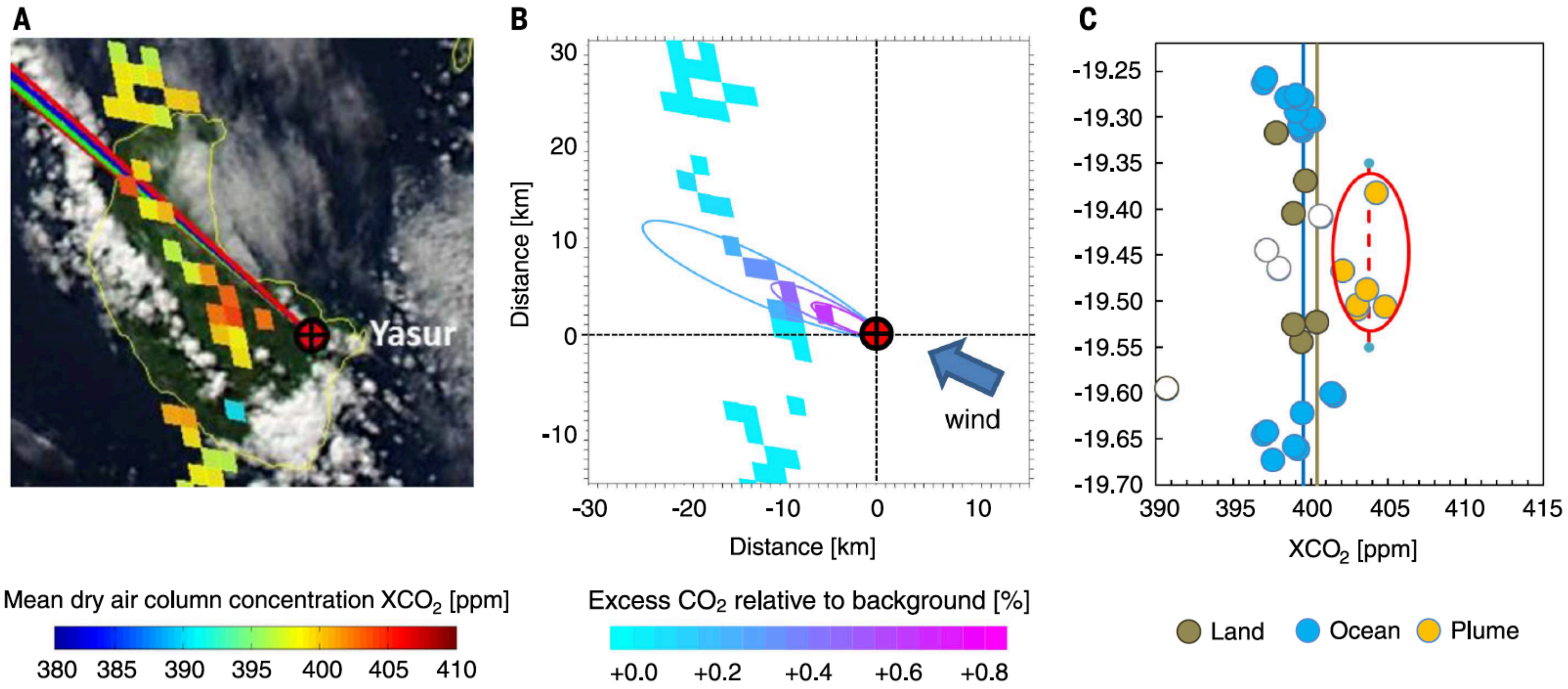
- A 1989 earthquake swarm and associated geologic deformation have drastically altered gas discharge at the land surface
- Magmatically CO_2 escapes through faults and fissures on the flanks of the mountain
- Soil CO_2 flux has created unlivable conditions for much vegetation

Mammoth Mountain, CA

- Five main tree-kill areas exist, all characterized by extreme root zone CO_2 concentrations
- Rate and spatial distribution of soil CO_2 flux: well-understood (Werner et al., Gerlach et al., Sorey et al.)
- Abundance of airborne data available in the region
- Gradient-like nature of response by Mammoth vegetation as a case study for ecological responses to future environmental perturbations, especially in vulnerable regions

Airborne

- Schwandner et al. (2017) demonstrated the potential for spaceborne detection of individual CO_2 plumes using OCO-2.
- However, greater resolution is needed to see the effect on individual trees.



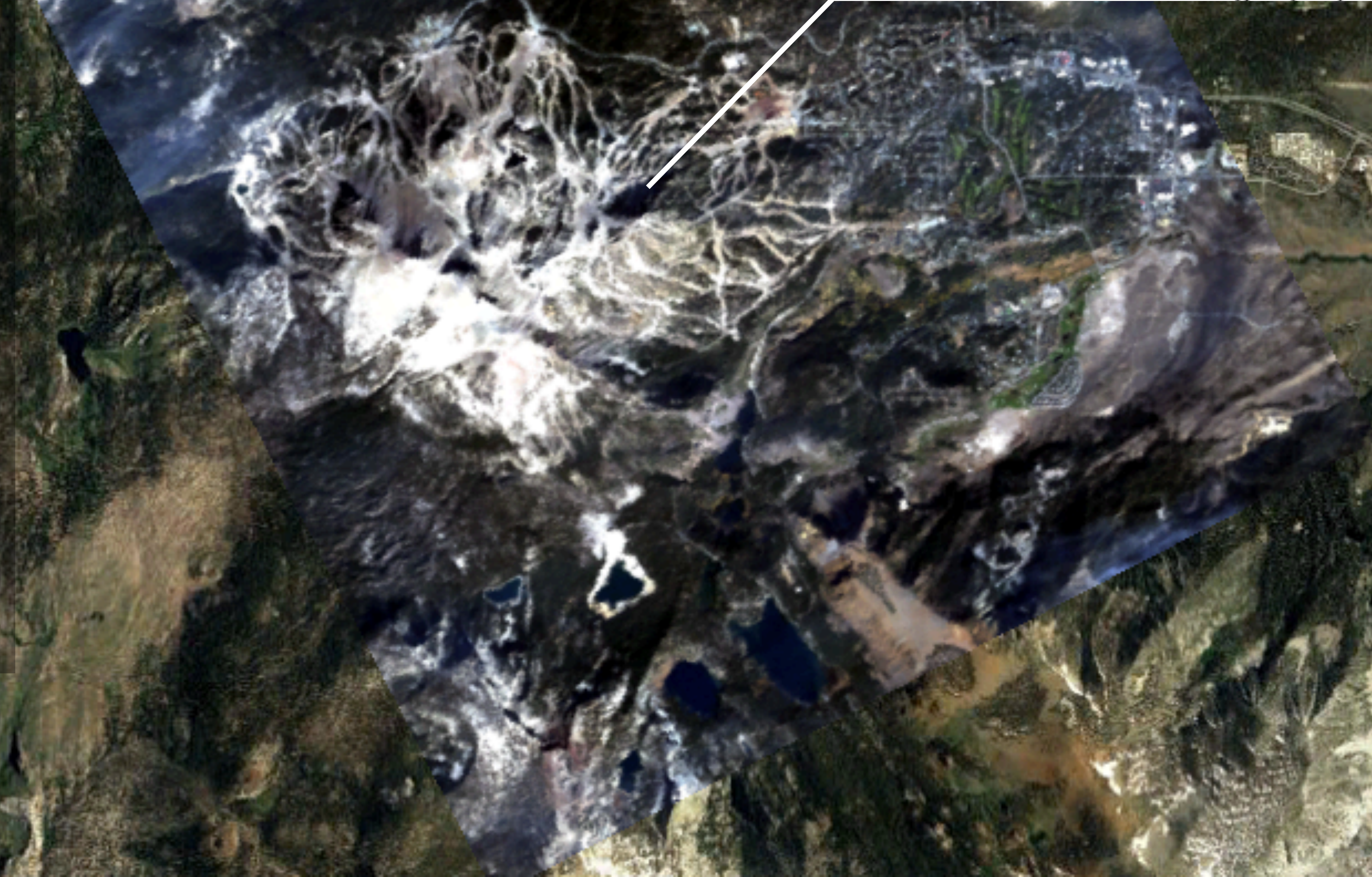
Data

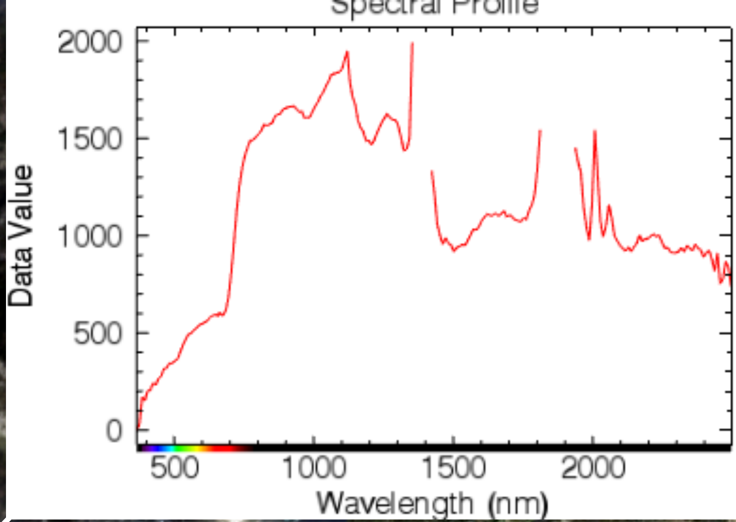
A wealth of information has been acquired over Mammoth mountain, including:

- **Field CO_2** measurements
- **Airborne spectrometer data**, from which we can derive various indicators of vegetation health, type, and traits
- **Thermal infrared imagery**, from which we can derive land surface temperature and evapotranspiration
- **Lidar data**, from which we can derive slope, aspect, elevation, and vegetation height
- **Fluorescence data**

AVIRIS

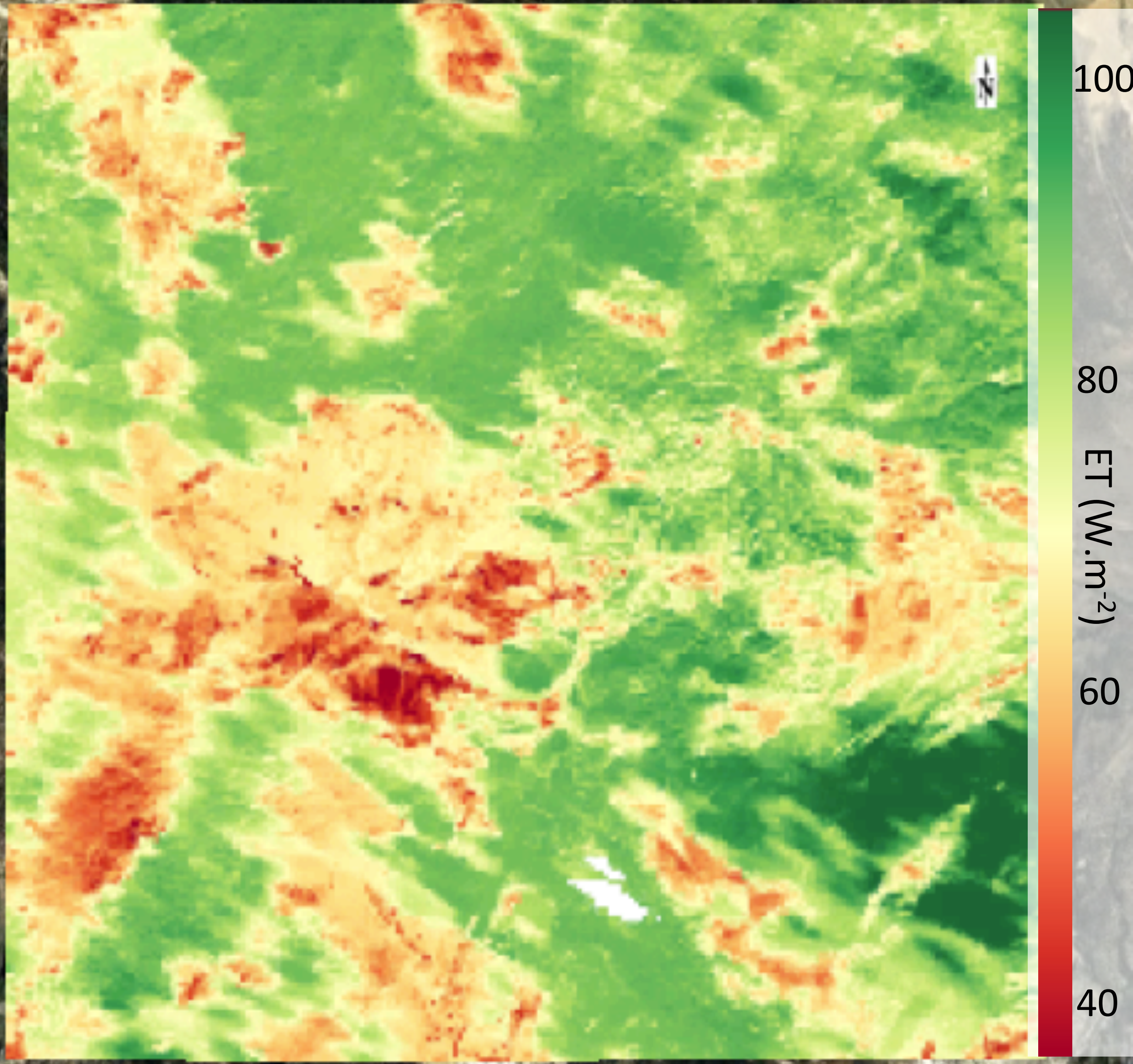
- AVIRIS Classic imagery was acquired in October 2014.
- L2 reflectance data was used.
- Spatial resolution is 13m.
- This scene was chosen to minimize snow cover.





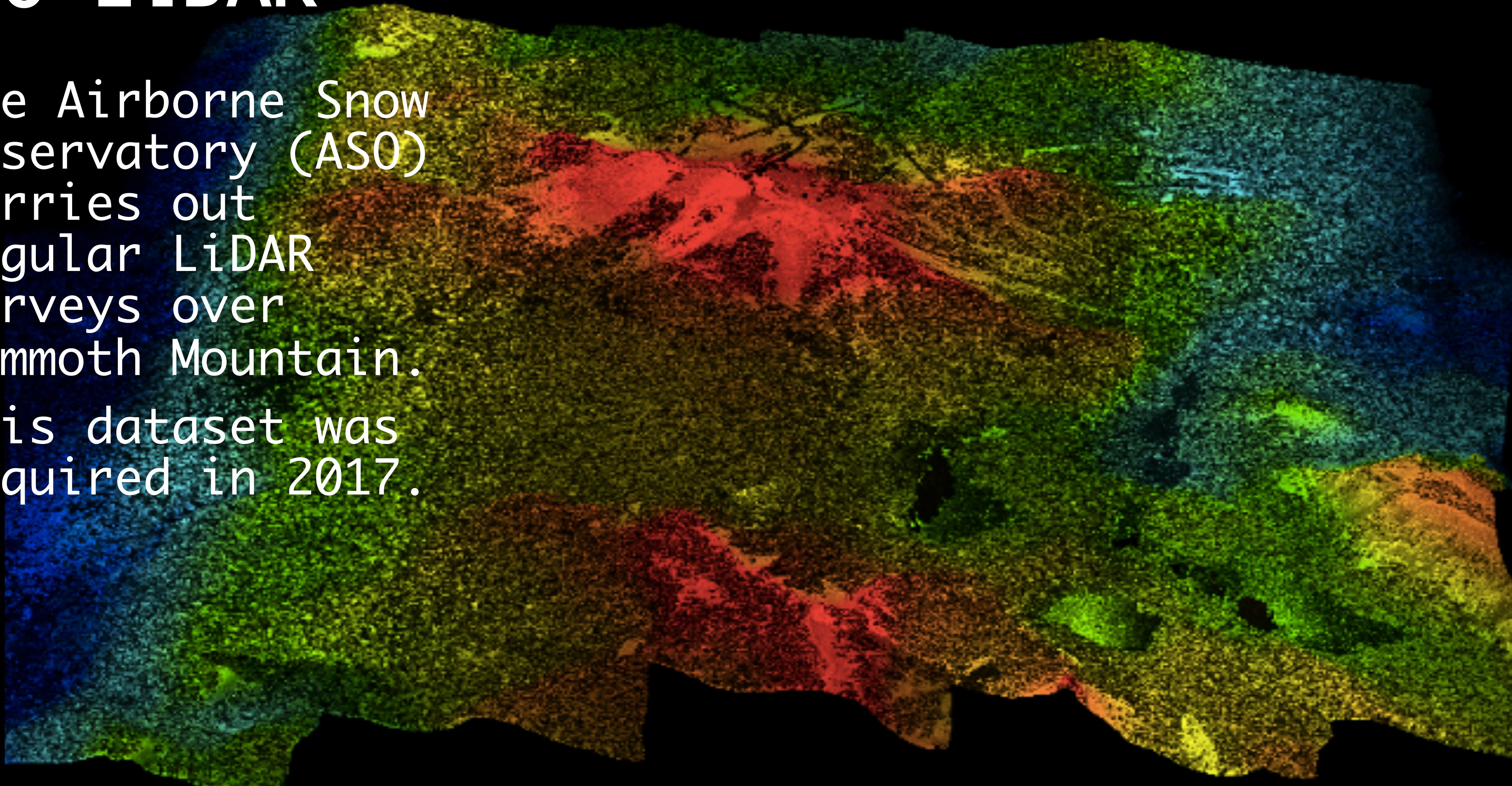
MASTER

- Two MASTER datasets were obtained: one in 2013 and one in 2017.
- From the MASTER data, we derived:
  - Emissivity
  - Land surface temperature
  - Evapotranspiration
- Spatial resolution is 35m.



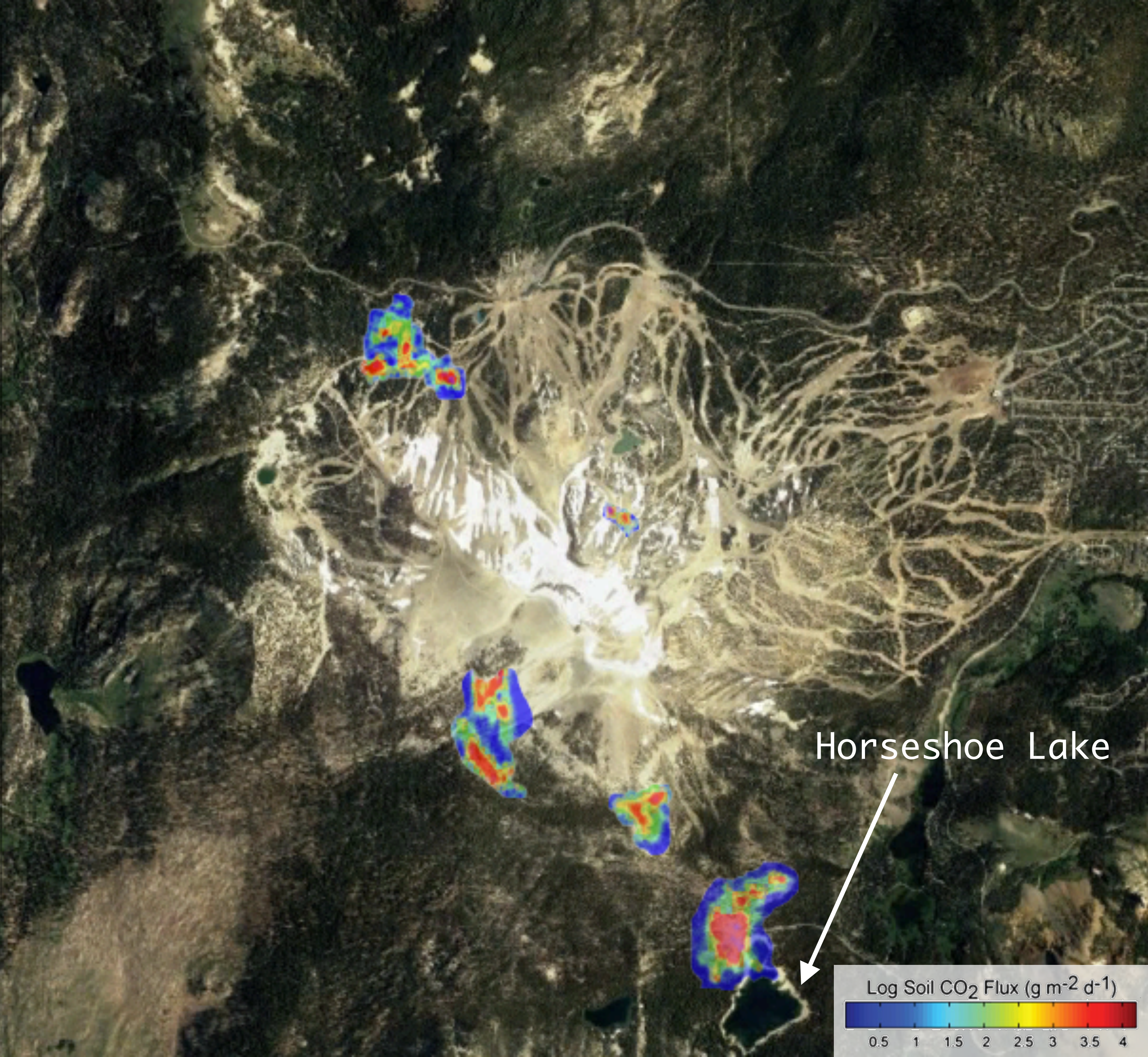
ASO LiDAR

- The Airborne Snow Observatory (ASO) carries out regular LiDAR surveys over Mammoth Mountain.
- This dataset was acquired in 2017.

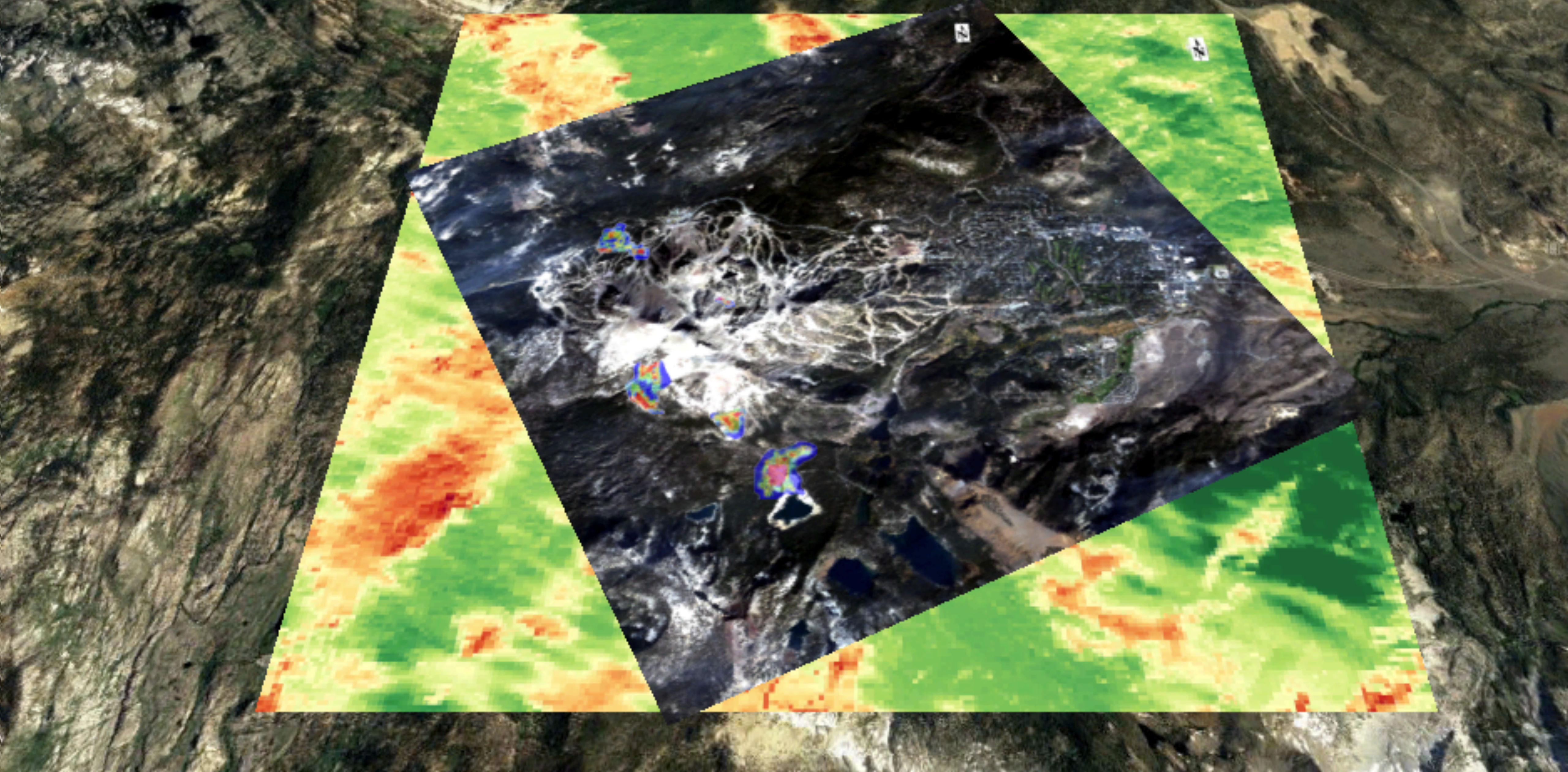


Field CO_2

- Field CO_2 measurements were made by Werner et al. in 2013, during a larger project that has been ongoing since 1991.
- Five degassing and tree-kill areas were measured using a LI-COR ® infrared gas analyzer.
- Data have been Kriged to a 1m grid.



Carbon dioxide measurements



Dataset summary

Dataset	Dates	Product	Derived Products	Resolution
AVIRIS	Oct 2014	Reflectance	Spectral features Foliar traits*	13m
MASTER	Nov 2013 Jun 2017	Thermal Reflectance	Land Surface Temperature Evapotranspiration	35m
LiDAR	Jun 2017	Point cloud	Elevation Slope, Aspect	*
Fluorescence	2017	Chlorophyll fluorescence	-	*
Carbon dioxide	Jun-Oct 2013	LiCOR soil CO2 flux	-	1m

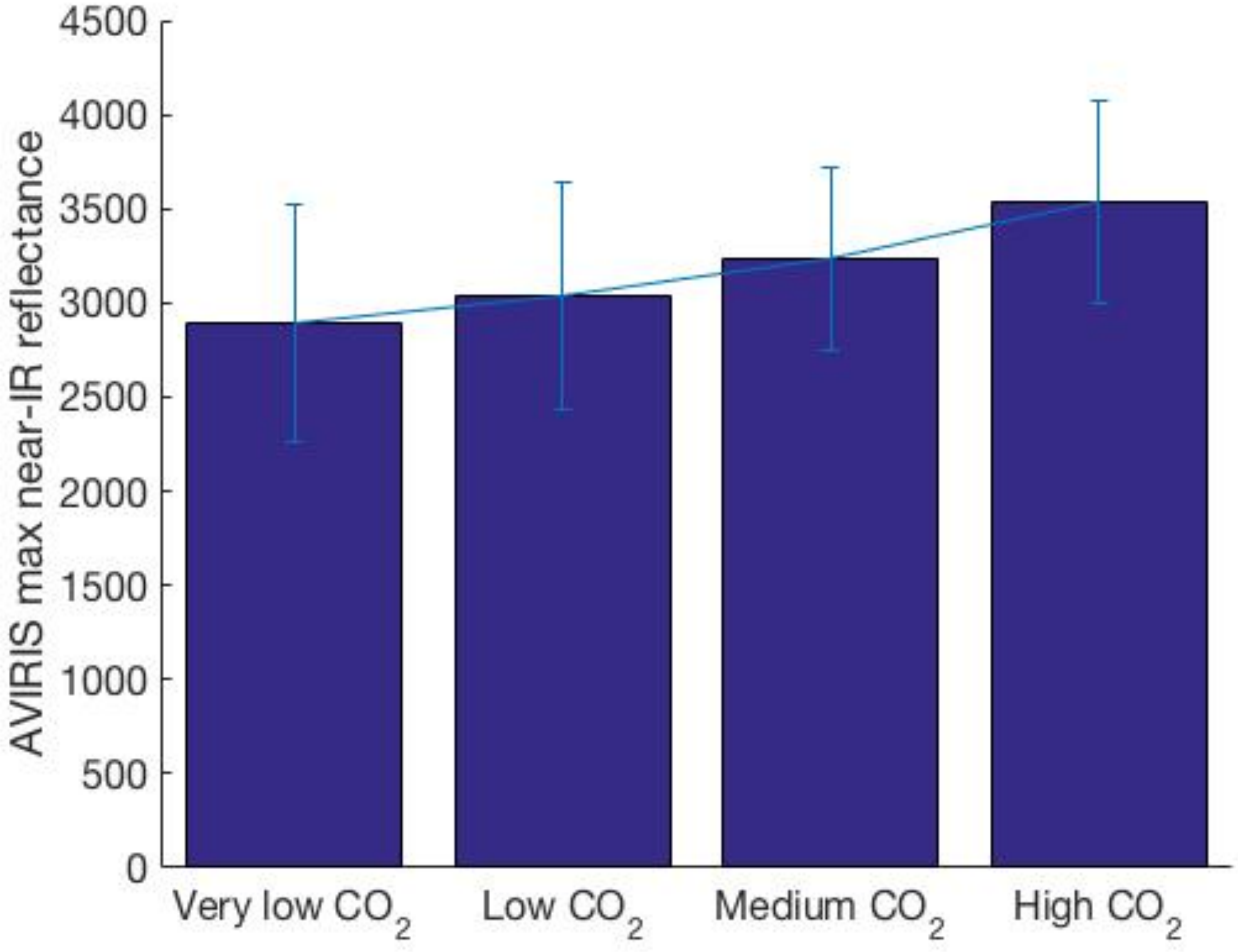
* Data still being processed.

Hypothesis Testing Framework

- Covariate Balancing Propensity Scores stratify the data and control for confounding variables, such as rain, air temperature, and downwelling shortwave radiation.
- Exploratory data analysis on the strata, by evaluating the ability of CO_2 to predict dependent variables within each strata (i.e. removing the confounding effect) individually, in pairs, etc.

*Ma, P., Kang, E.L. Spatial Statistical Downscaling for Constructing High-Resolution Nature Runs in Global Observing System Simulation Experiments, Technometrics, In Review.

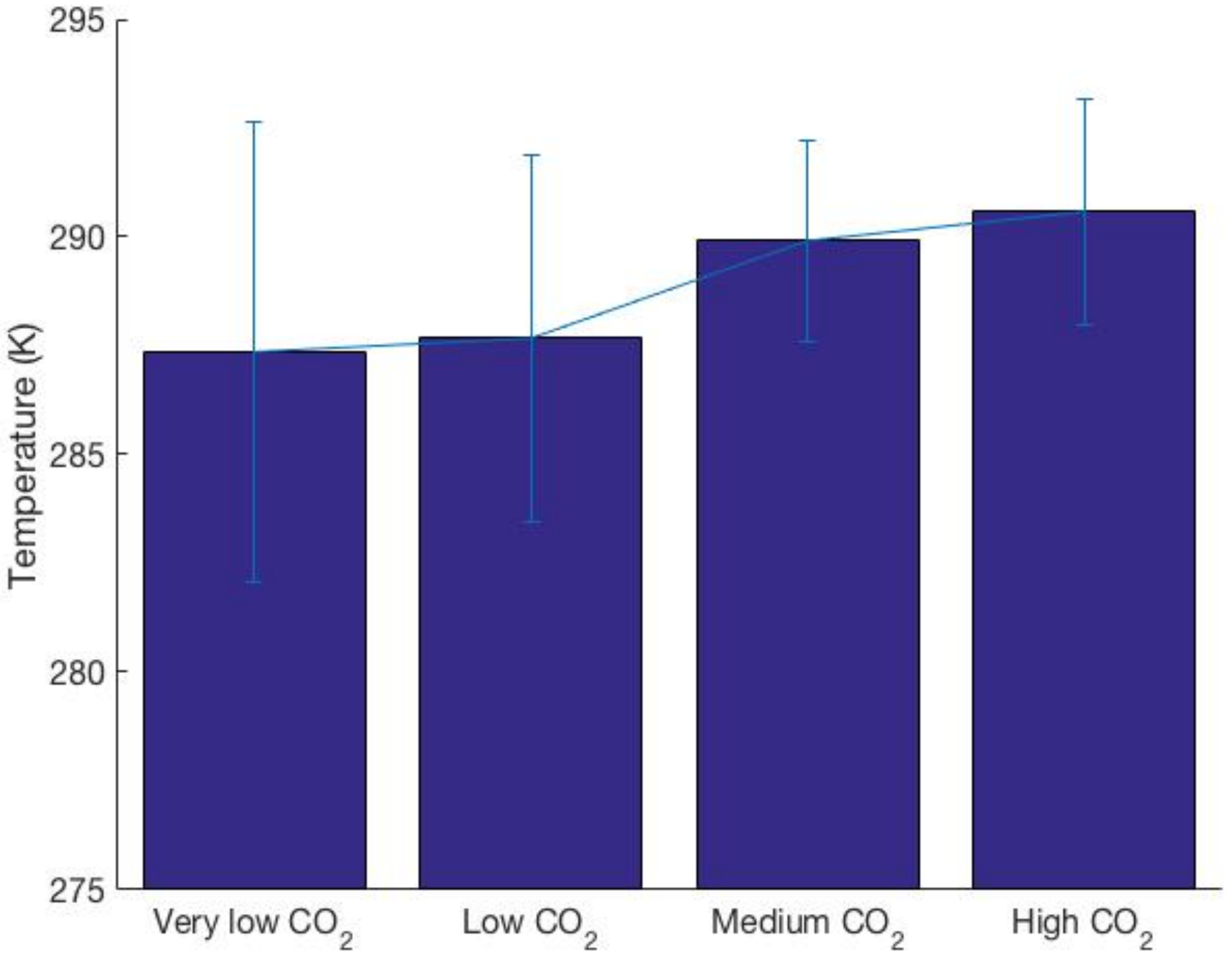
CO_2 versus AVIRIS NIR



- Preliminary results; effects of confounding variables still to be addressed

$p<0.01$

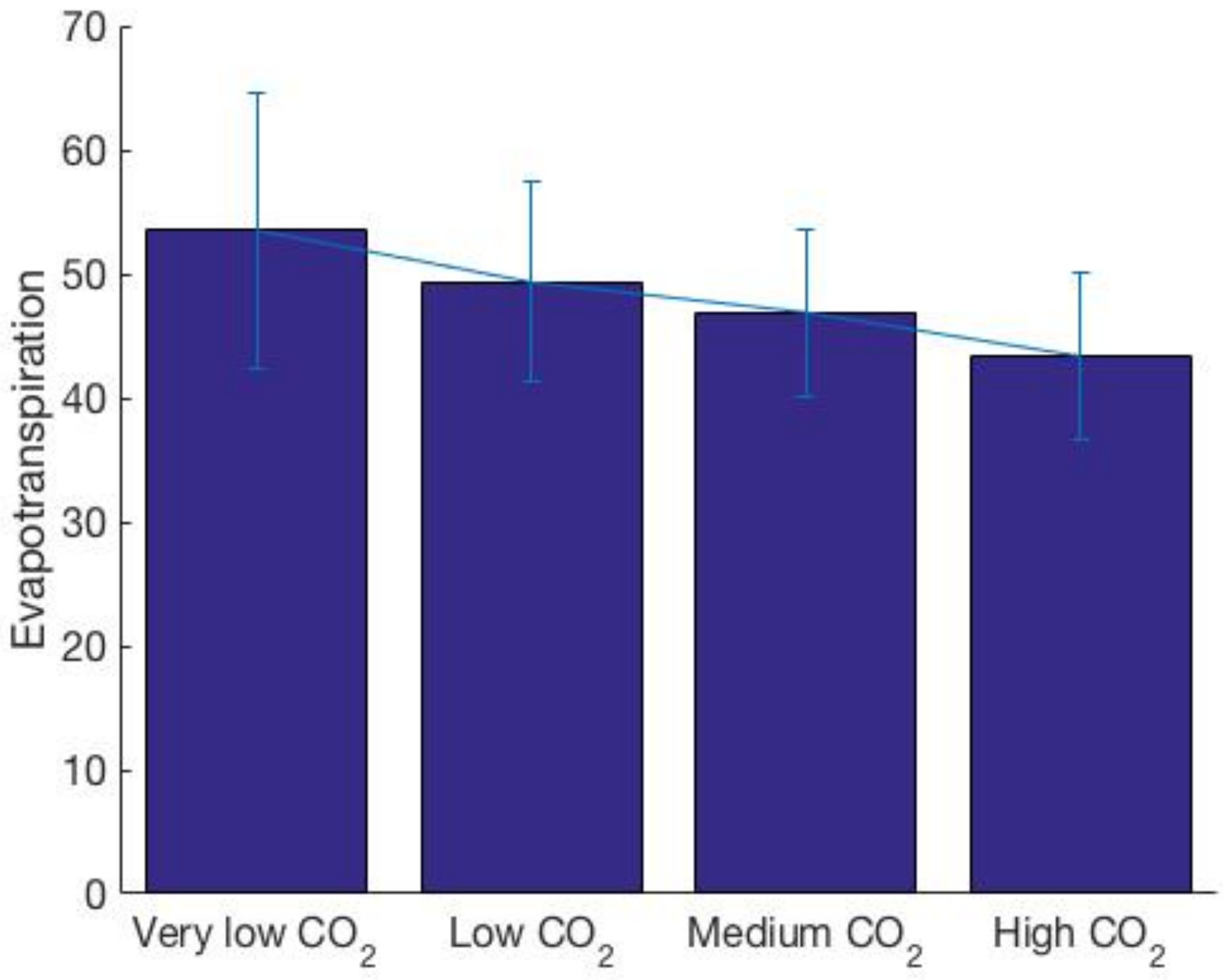
CO_2 versus Land Surface Temperature



* Preliminary results; effects of confounding variables still to be addressed

$p<0.01$

CO_2 versus Evapotranspiration



* Preliminary results; effects of confounding variables still to be addressed

$p<0.01$

CO_2 versus remotely sensed ecosystem properties (total data cube)

	R^2 (all data)	R^2 (NDVI>0.1)	R^2 (NDVI>0.3)	% remaining at 0.3
Horseshoe Lake	0.70	0.70	**0.59**	42%
South Side Fumarole	0.67	0.67	**0.95**	16%
Mammoth Fumarole	0.81	0.83	**0.84**	5%
Chair 12	0.55	0.57	**0.57**	56%
Reds Creek	0.57	0.66	**0.73**	16%

* Non-vegetation areas were masked.

Conclusions

- There is a **strong relationship** between CO_2 flux and our remote sensing datasets
  - R^2 high across all 5 ground data locations
  - Trends: as CO_2 flux increases, land surface temperature decreases and evapotranspiration increases
- Our results will have strong implications for ecological responses to elevated CO_2 in **other parts of the world**
  - This extension illustrates the need for consistent airborne data retrieval in regions where we have the most to learn, like the tropics

Ongoing work

- Once lidar data have been processed, we will use them to remove the confounding effects of slope, aspect, and elevation.

- A concurrent study is investigating the correlation between modelled ground CO_2 and parameters that may be remotely sensed.