Improvements to ECOSTRESS Algorithms and Products in Collection 2

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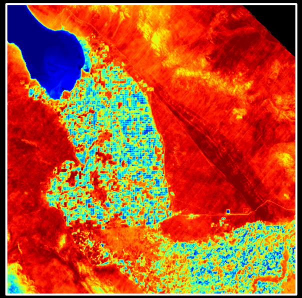
Jet Propulsion Laboratory
California Institute of Technology

L2T_RAD

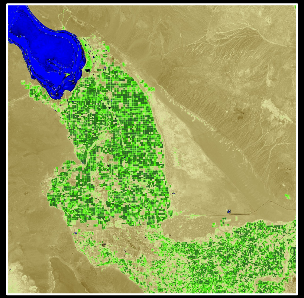
radiance_2
radiance_4
radiance_5

L2T_LSTE



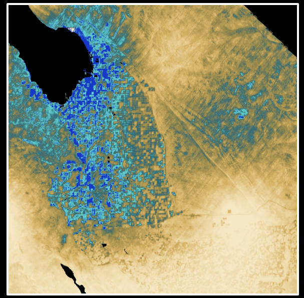
LST
LSTuncertainty
EmisWB

L2T_STARS



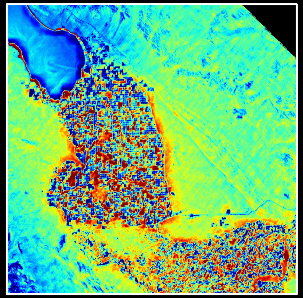
NDVI
NDVIuncertainty
albedo
albedoUncertainty

L3T_SM



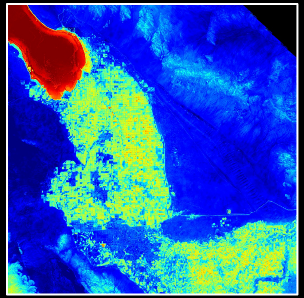
SM

L3T_MET



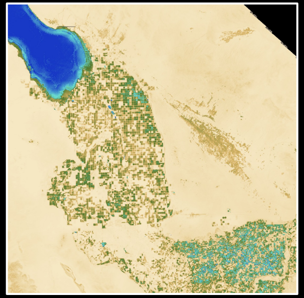
Ta
RH

L3T_SEB



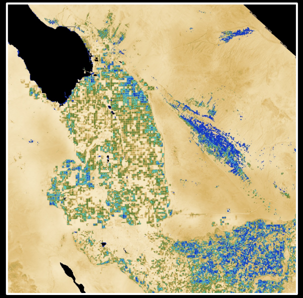
Rn

L3T_ET_PTJPL



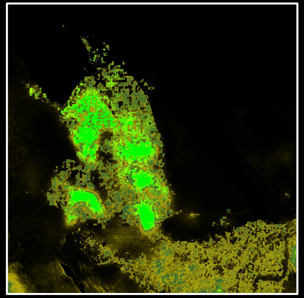
ETinst
ETinstUncertainty
ETcanopy
ETsoil
ETinterception
ETdaily

L4T_ESI_PTJPL



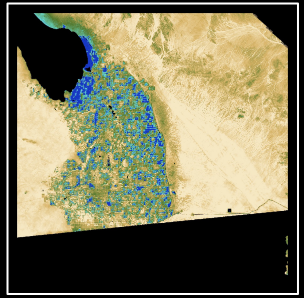
ESI
PET

L4T_WUE



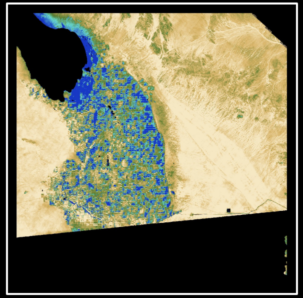
WUE
GPP

L3T_ET_ALEXI



ETdaily
ETdailyUncertainty

L4T_ESI_ALEXI

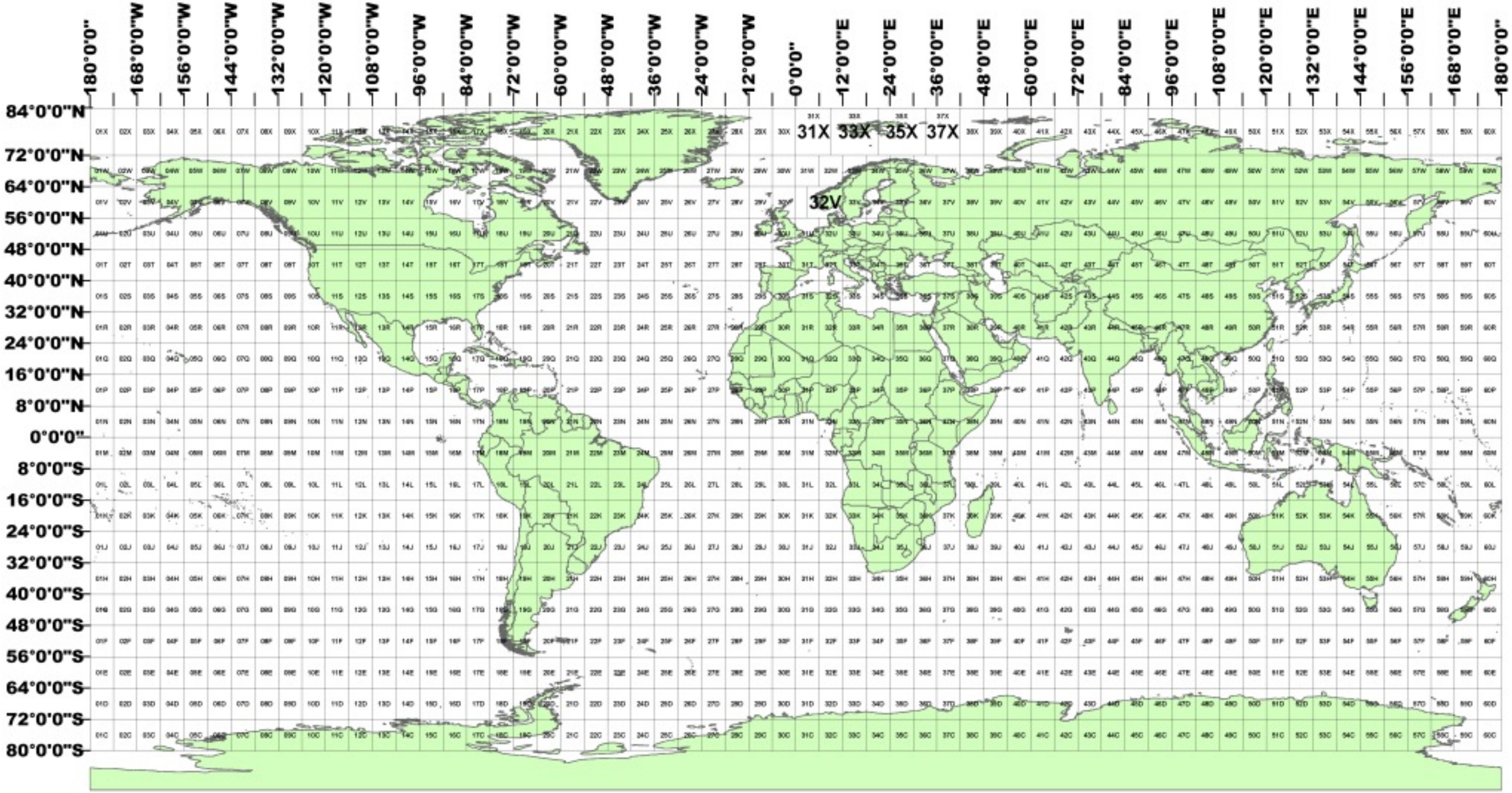


ESIdaily
ESIdailyUncertainty

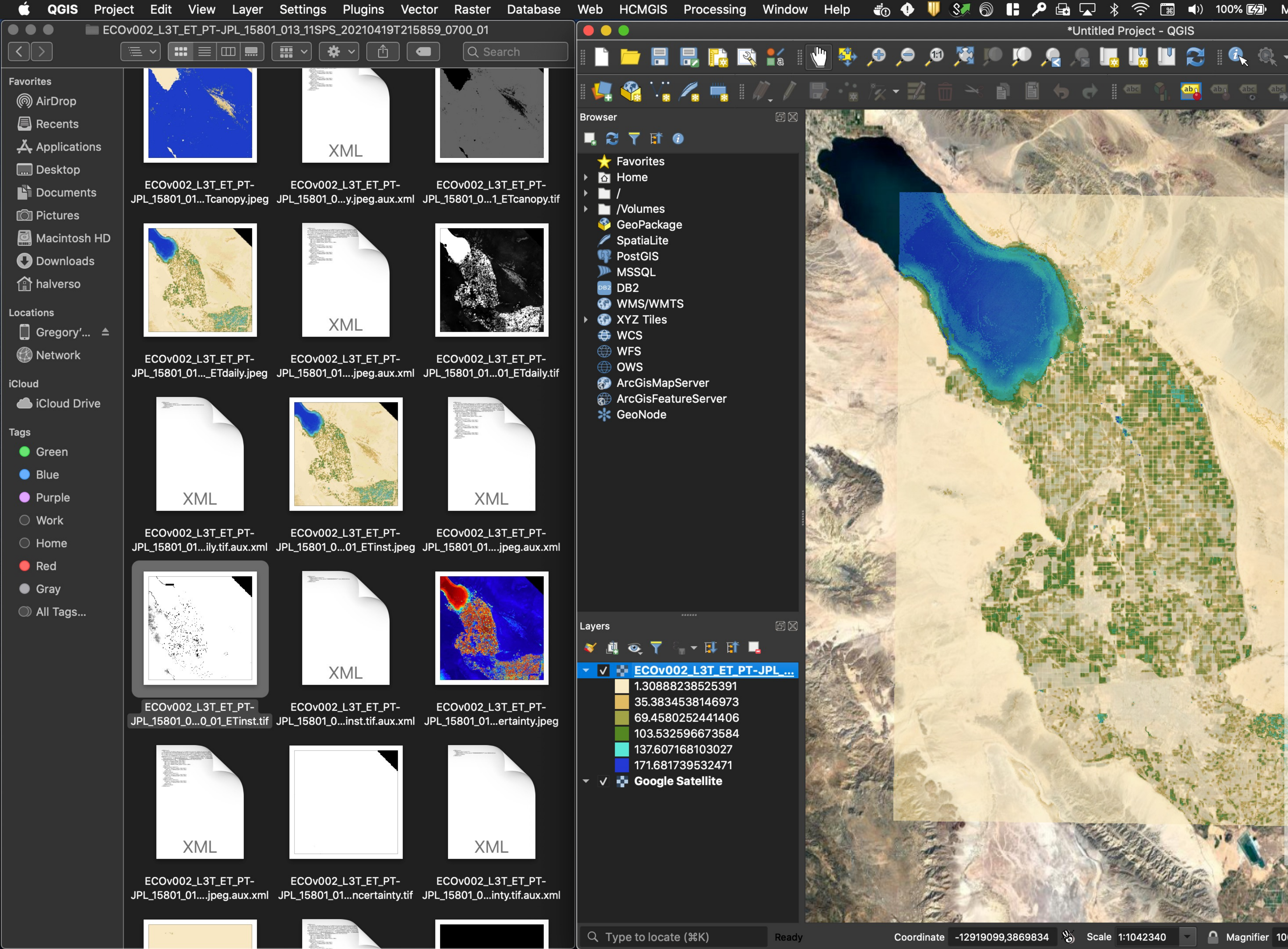
We have comprehensively revised the ECOSTRESS data products with improved algorithms and a new more accessible data format.

These products will contain additional key data layers required for modeling surface energy balance, including NDVI, albedo, soil moisture, air temperature, humidity, and net radiation.

The Collection 2 products use the Sentinel tile grid, following Harmonized Landsat Sentinel. This tile grid is a modification of the Military Grid Reference System, with each tile covering 100 km by 100 km with an additional 4.9 km overlapping edge (109.8 km x 109.8 km total). The Collection 2 products use a 70 m grid in local UTM projection for each tile.

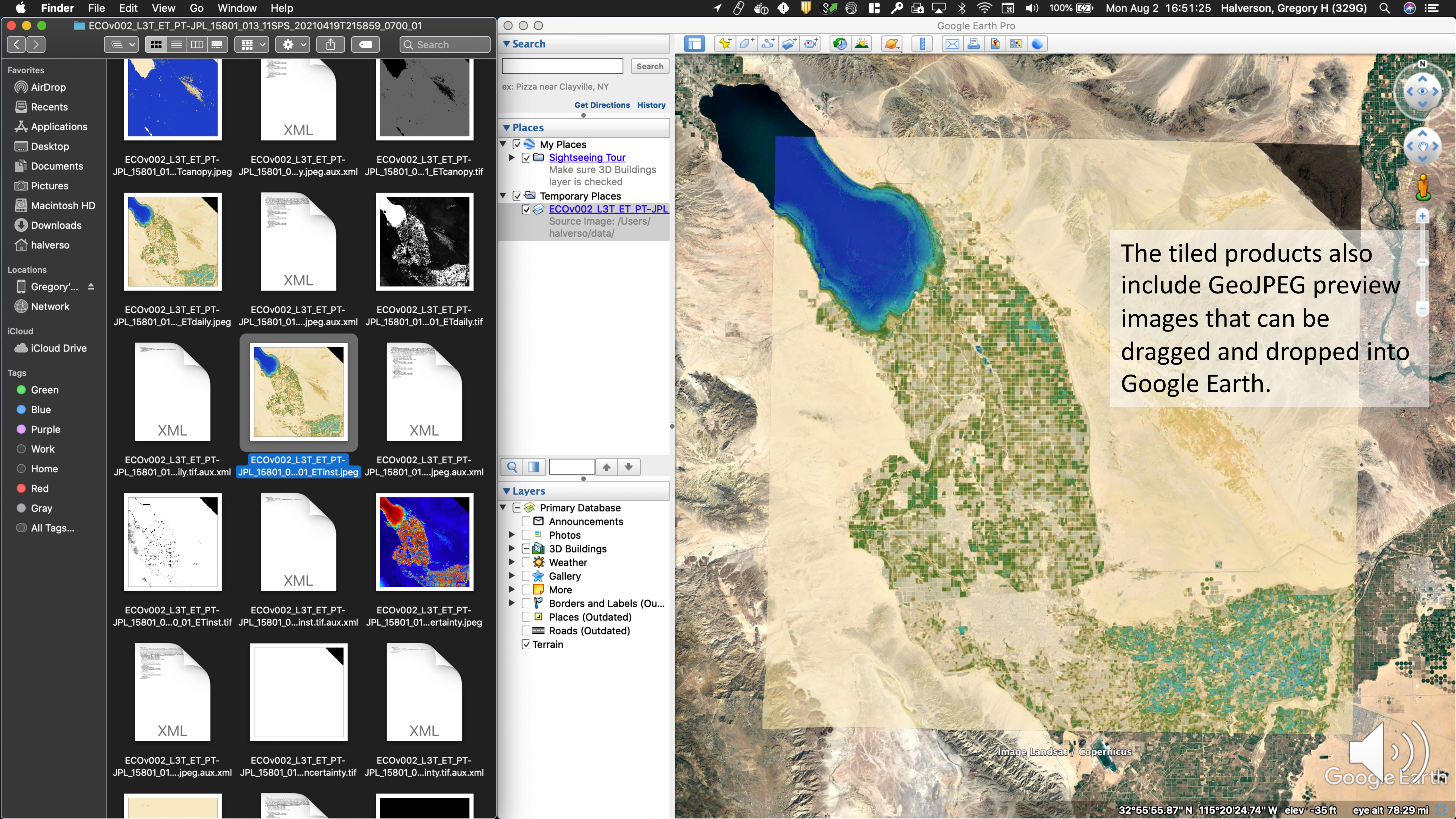


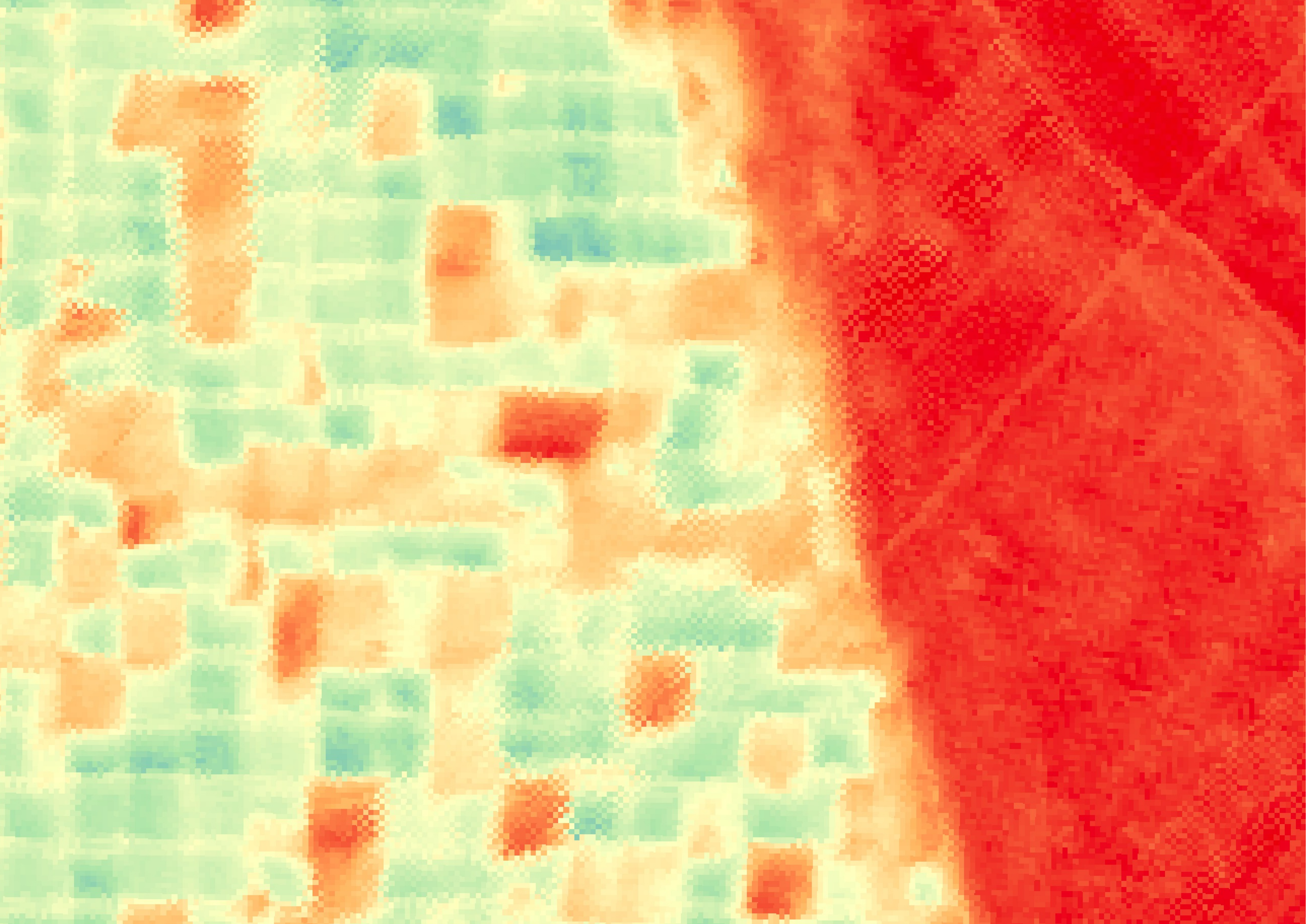
https://hls.gsfc.nasa.gov/products-description/tiling-system/



The ECOSTRESS Collection 2 products will be distributed using the Cloud Optimized GeoTIFF file format, following the standard established by Landsat Collection 2 and Harmonized Landsat Sentinel version 2. These GeoTIFF files can be dragged and dropped into GIS software, like ArcGIS and QGIS, as well as open source data analysis platoforms, like Python, R, and Julia, to become interactive map layers for exploration, analysis, and mapping.

The tiled products also include GeoJPEG preview images that can be dragged and dropped into Google Earth.

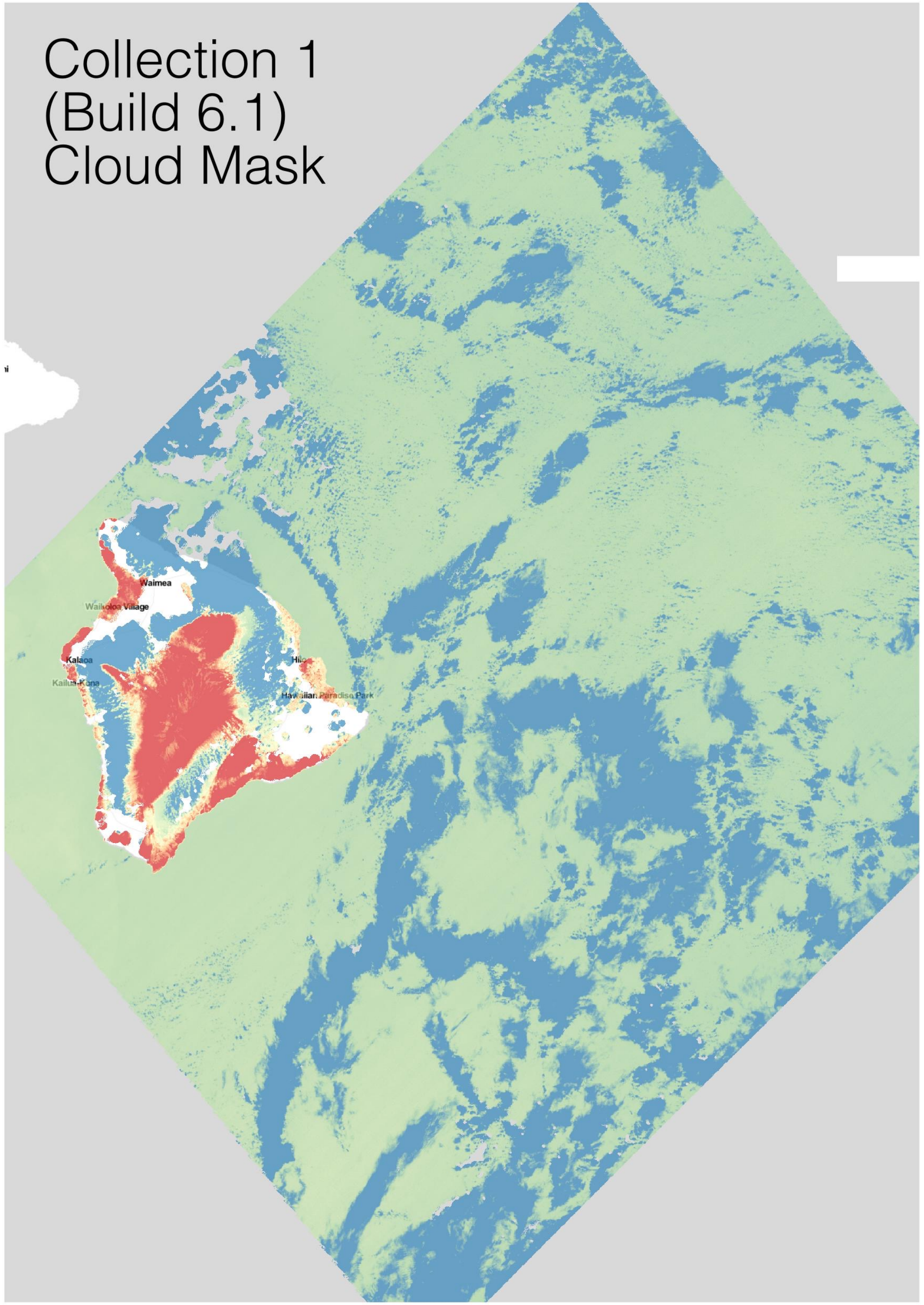


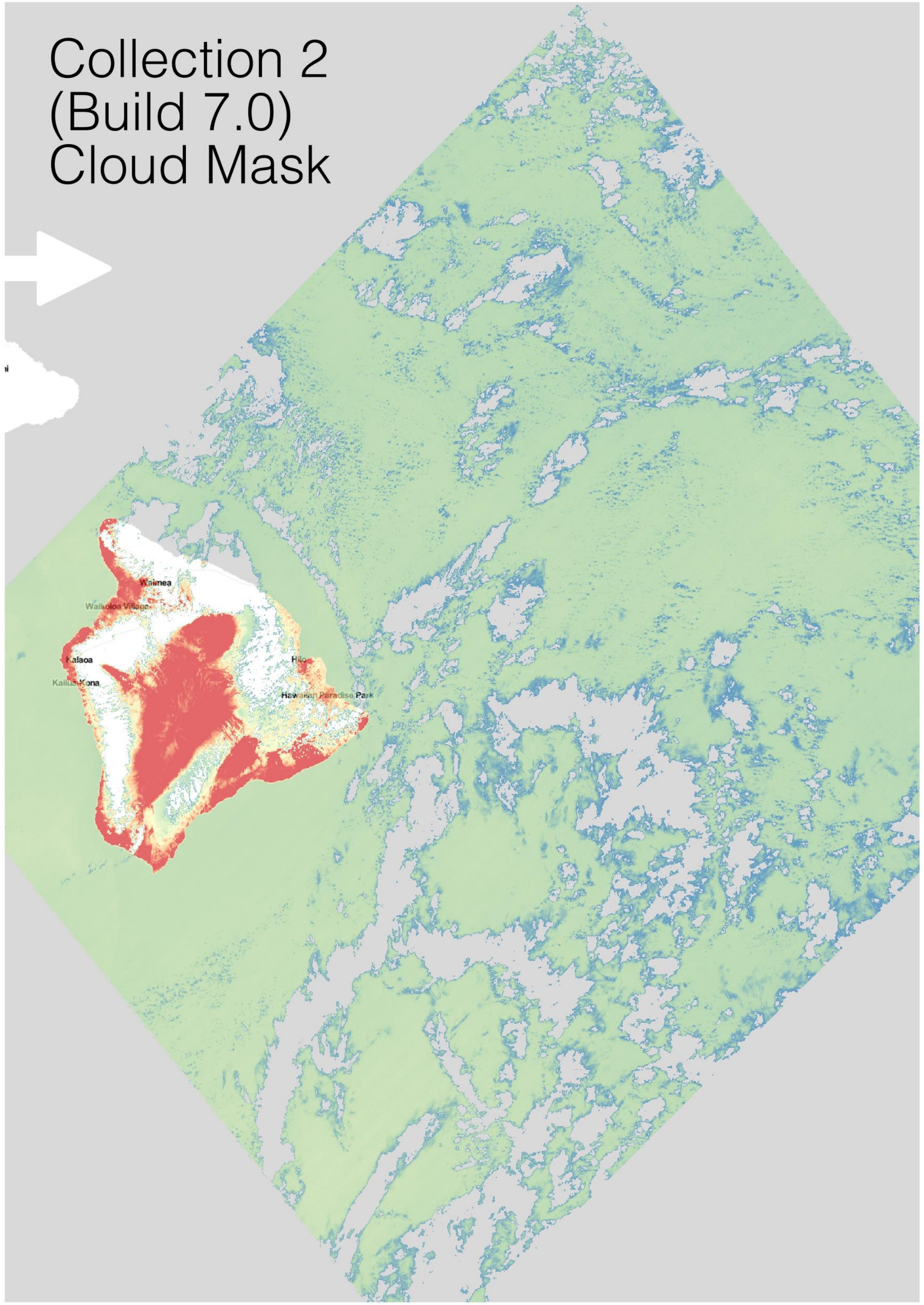


Level 1: Overlapping Scan-Line Co-Registration

A major issue in Collection 1 was the mis-registration of pixels in the overlap between scan lines. When resampling these overlapping sets of pixels onto a grid, a checkboard artifact appeared, which propagated into all products.

We are revising the spatial calibration between overlapping scans to mitigate the checkerboard artifact in the tiled and gridded products.



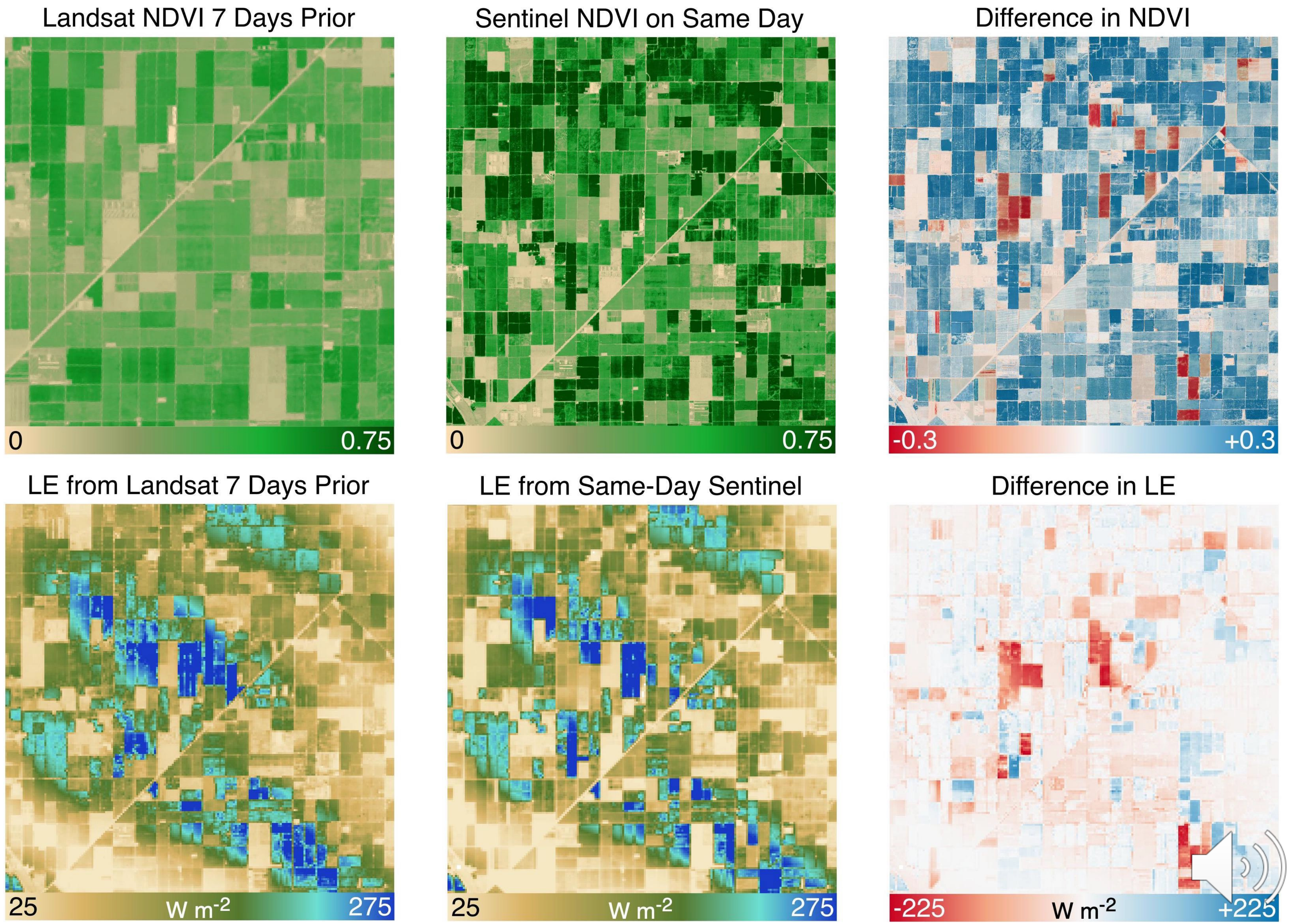


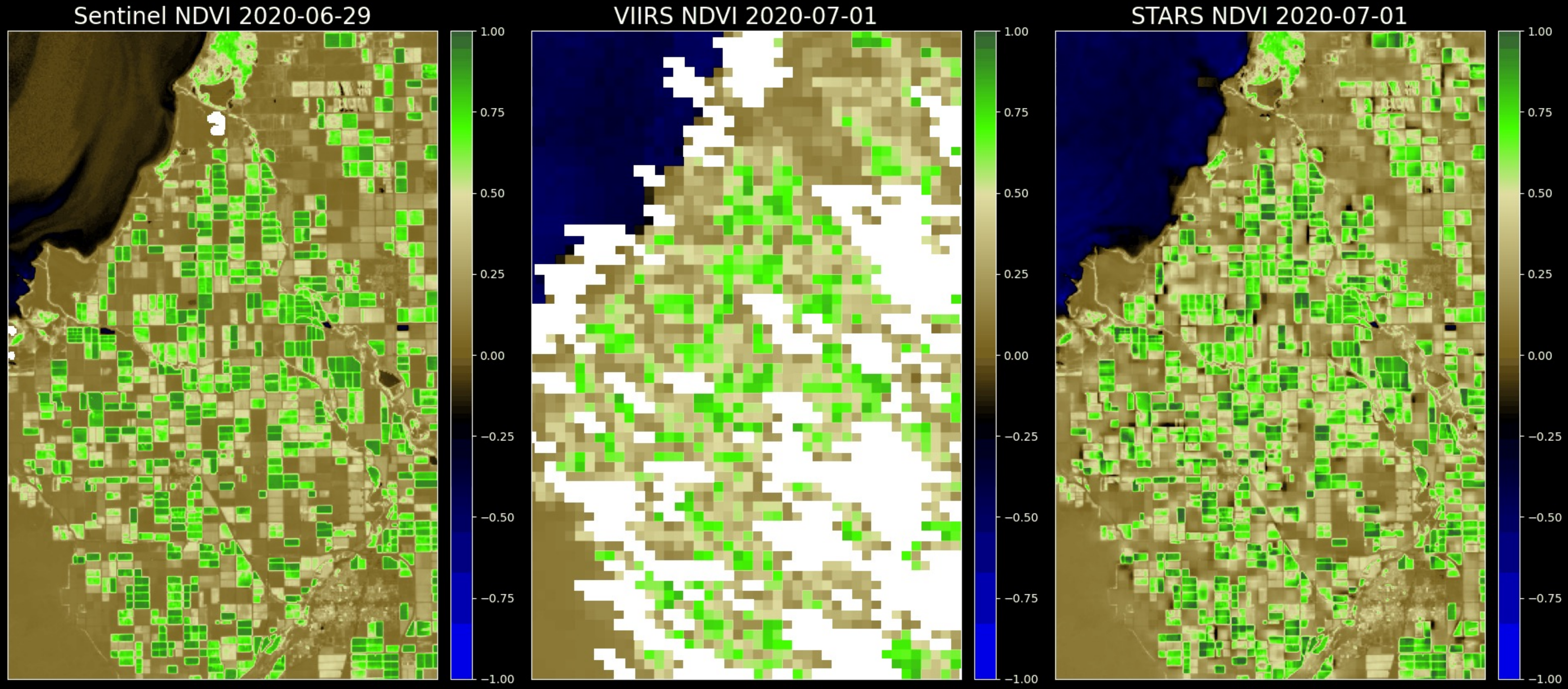
Level 2:
Cloud Mask with Less False Negatives

Another major issue in Collection 1 was false negatives in the cloud mask. The cooler temperatures of un-masked clouds propagated to the ET products as areas of high ET.

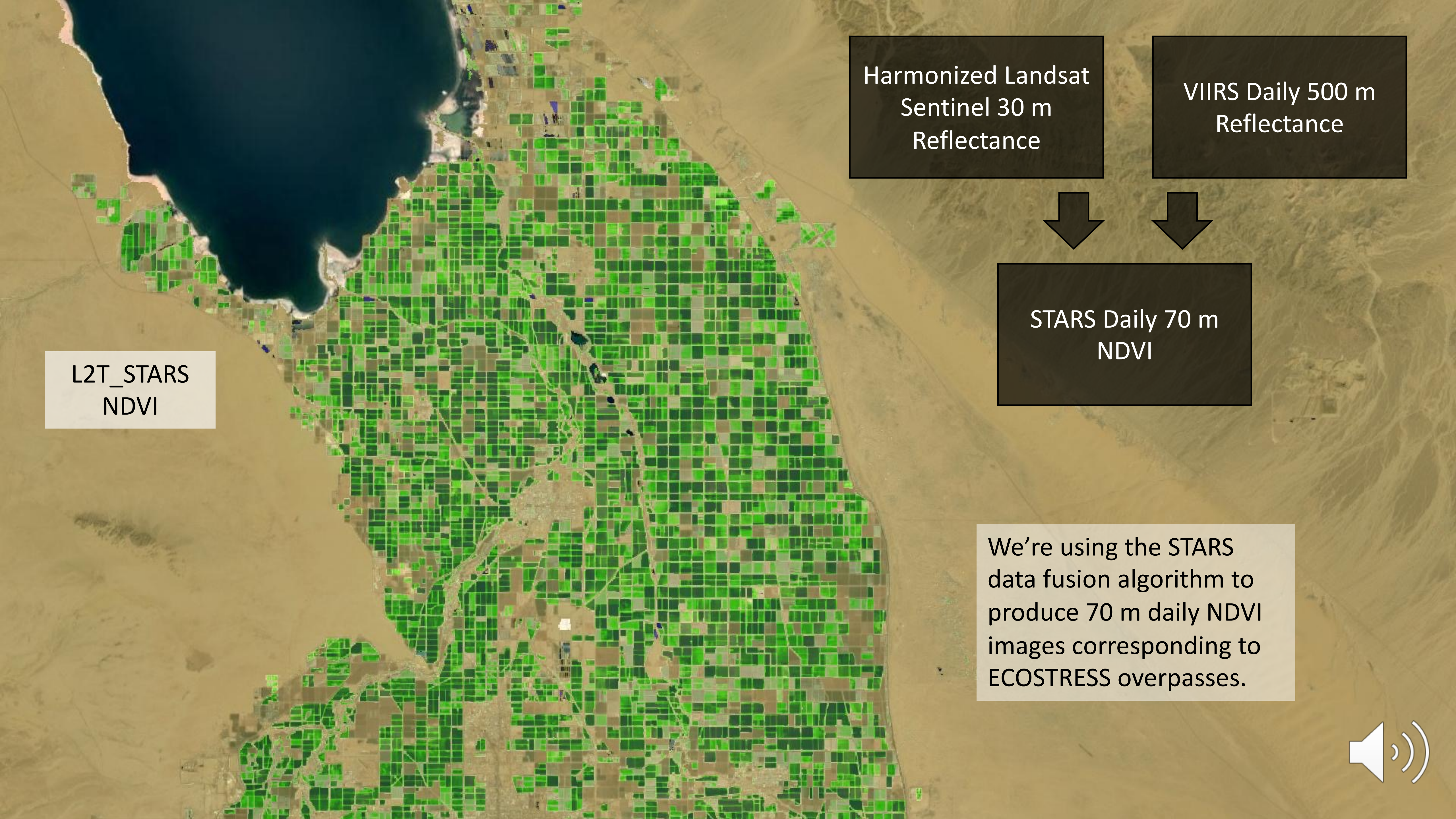
We have revised the cloud pixel identification using a radiance look-up table that allows for less cloud contamination in the temperature and evapotranspiration products.

A major challenge in using a thermal sensor to estimate evapotranspiration is co-incident high-resolution NDVI and albedo. These land surface properties are highly sensitive to abrupt changes, such as harvest and fires, so any temporal lag in these inputs can result in large errors in evapotranspiration output.





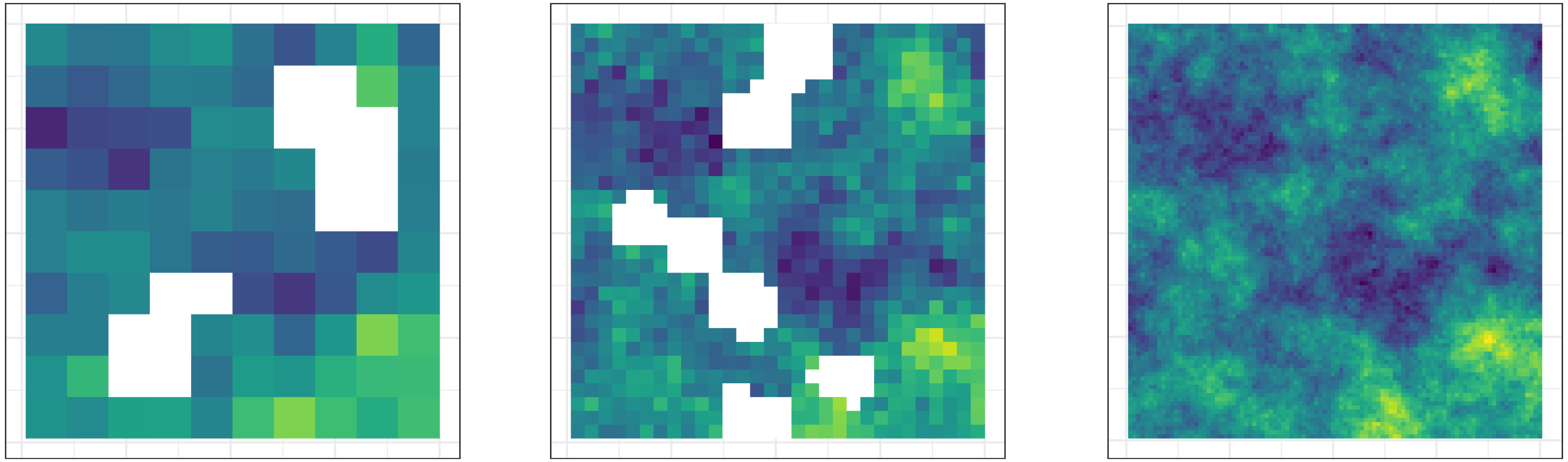
To mitigate this problem, we have developed a new data fusion technique called STARS that allows us to combine the 30 m spatial resolution of Harmonized Landsat Sentinel with the daily temporal resolution of VIIRS to generate 70 m daily products.


Harmonized Landsat Sentinel 30 m Reflectance
VIIRS Daily 500 m Reflectance
STARS Daily 70 m NDVI
L2T_STARS NDVI
We're using the STARS data fusion algorithm to produce 70 m daily NDVI images corresponding to ECOSTRESS overpasses.

STARS Change of Support Model

The STARS Change of Support model assumes that the fine and coarse images from remote sensing data are noisy spatial aggregates of the same underlying fine scale spatial structure.

Sensor 1, $\boldsymbol{y}_t^1$ Sensor 2, $\boldsymbol{y}_t^2$ Target, $\boldsymbol{\eta}_t$



Assume for a generic grid cell, *G*, the observed products on day t are a noisy, spatial aggregate of the underlying true process:

$$y_t^k(G) = \frac{1}{|\mathcal{D} \cap G|} \left\{ \sum_{i \in \mathcal{D} \cap G} \eta_{it} \right\} + v^k(G), \quad v^k(G) \sim \mathcal{N}(0, \sigma_t^2(G)^k)$$

- $\{\eta_{it} : i \in D\}$ is the latent spatial process on a discretized domain made up of n_f fine-scale, non-overlapping pixels
- e.g. Nguyen, et al. 2012, 2014; Ma and Kang, 2020; Johnson, et al., 2021

Streaming Fusion via Kalman Filtering

We have deployed a streaming form of the change of support model that runs in daily increments, loading covariance matrices from the previous day's run and storing covariance matrices for the following day's run.

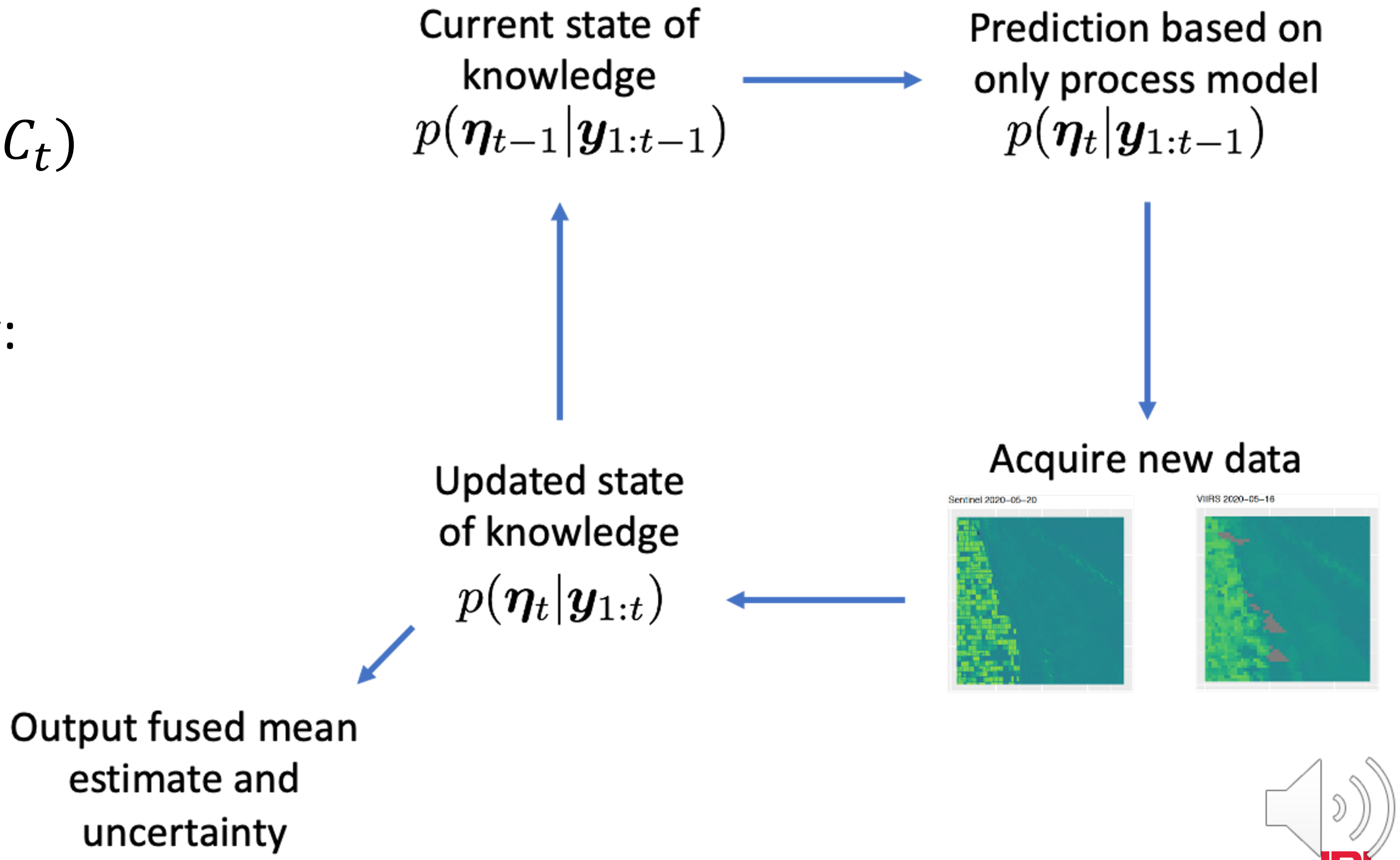
On day t:

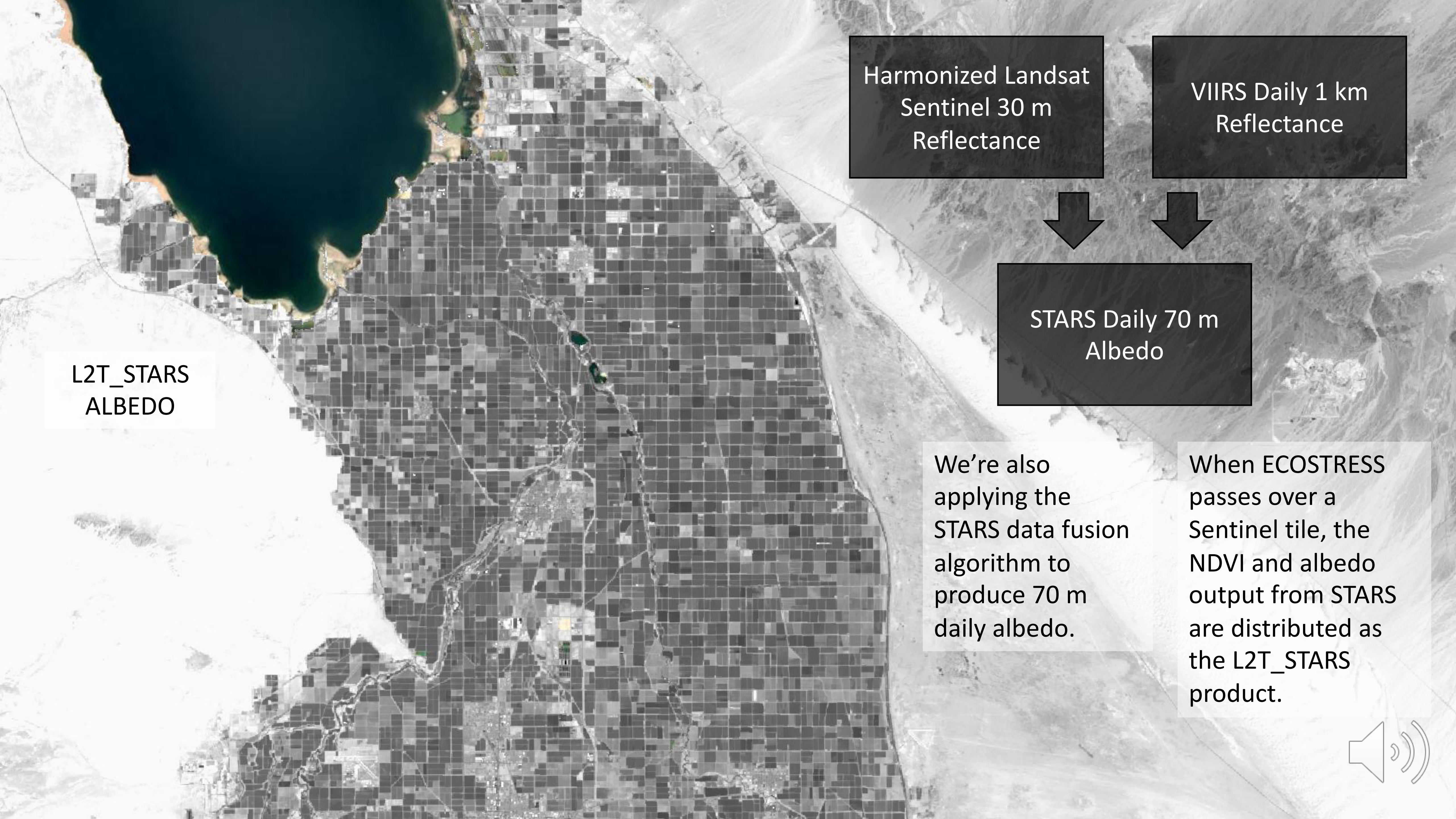
Fusion target: $\eta_t | y_{1:t} \sim N(m_t, C_t)$

Prior: $\eta_t | y_{1:t-1} \sim N(a_t, R_t)$

To obtain m_t, C_t, we need only:

- Any new data: y_t
- Prior: a_t, R_t
- Model: F_t, G_t, V_t, W_t



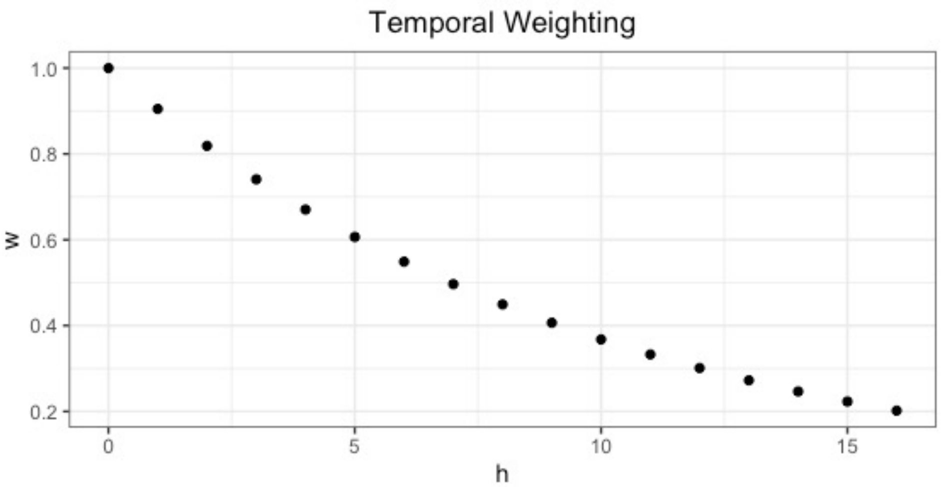

Harmonized Landsat Sentinel 30 m Reflectance
VIIRS Daily 1 km Reflectance
STARS Daily 70 m Albedo
L2T_STARS ALBEDO
We’re also applying the STARS data fusion algorithm to produce 70 m daily albedo.
When ECOSTRESS passes over a Sentinel tile, the NDVI and albedo output from STARS are distributed as the L2T_STARS product.

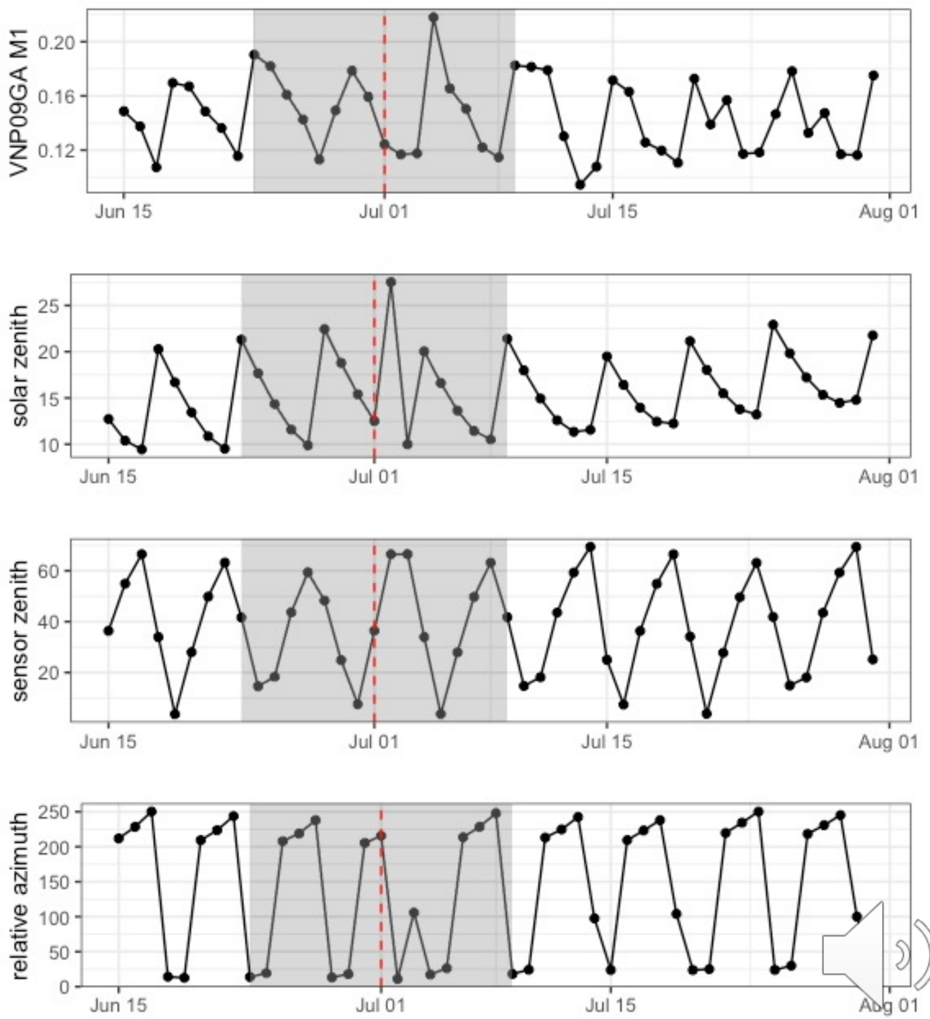
Near Real Time Daily Coarse Albedo

To provide the daily coarse input for STARS albedo, we have developed a near-real-time version of the VNP43 algorithm, running on a 16-day window of VNP09GA.

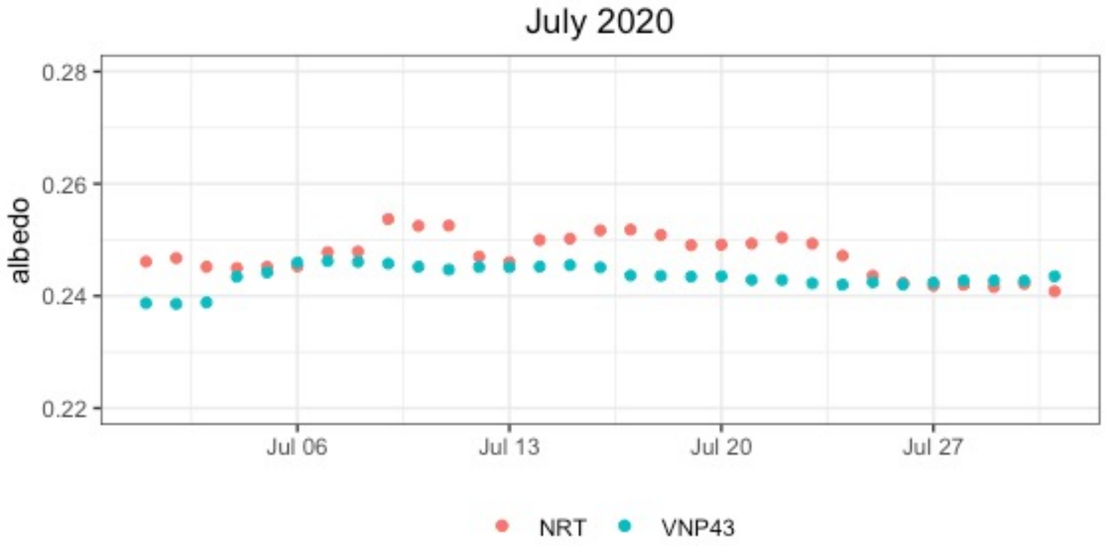
$$R(\theta,\nu,\phi,\lambda) = f_{iso}(\lambda) + f_{vol}(\lambda)K_{vol}(\theta,\nu,\phi) + f_{geo}(\lambda)K_{geo}(\theta,\nu,\phi)$$

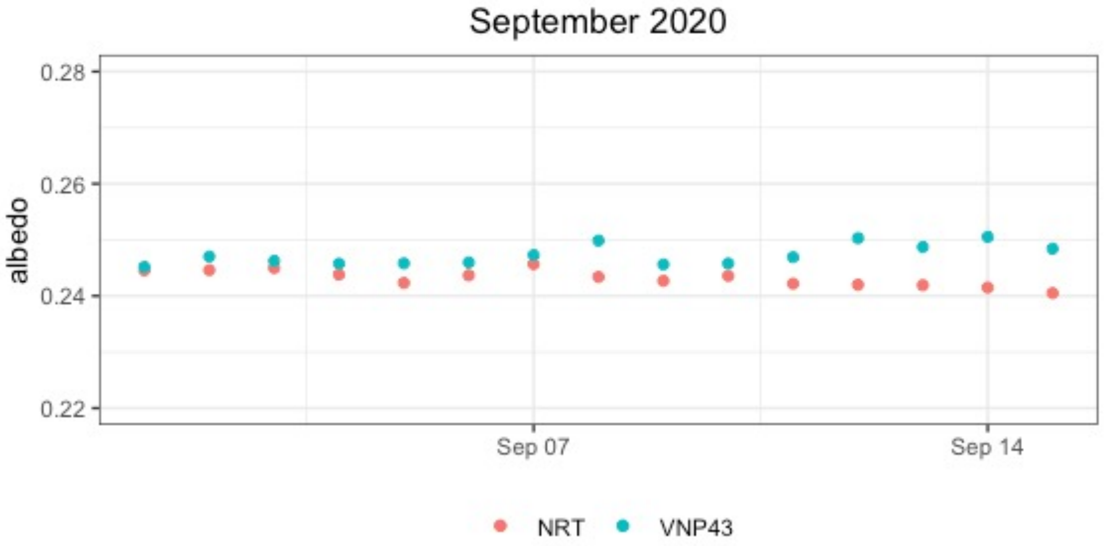
- Utilize historical 16-day window instead of centered window
- Temporally weight observations based on proximity ($h = t_0 - t$) to current day, $w_t = \exp(-h/s)$
- NBAR, WSA, BSA at solar noon with coefficients as in VNP43
- Blue-sky albedo using AOD from GEOS-5

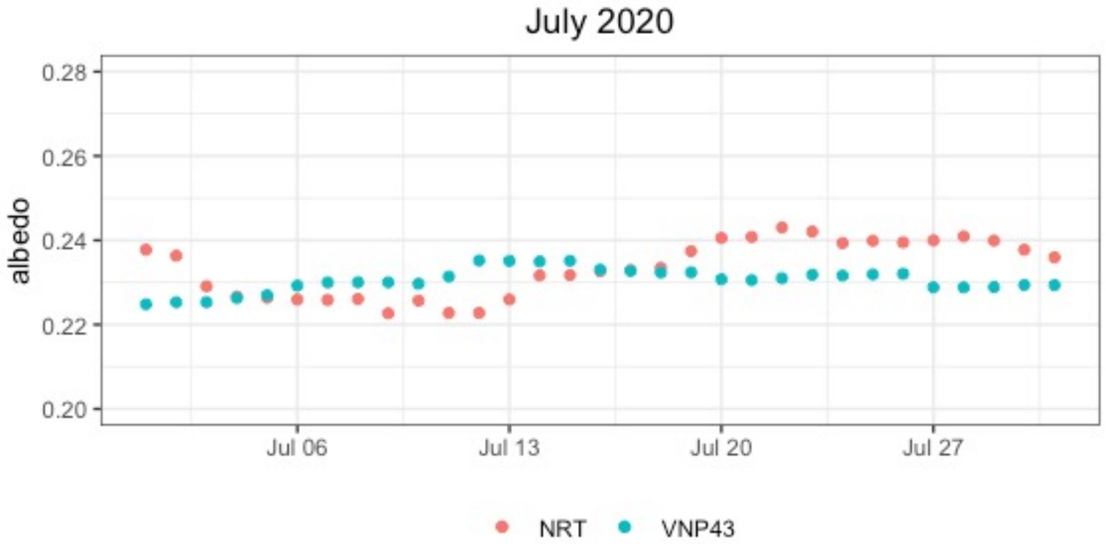


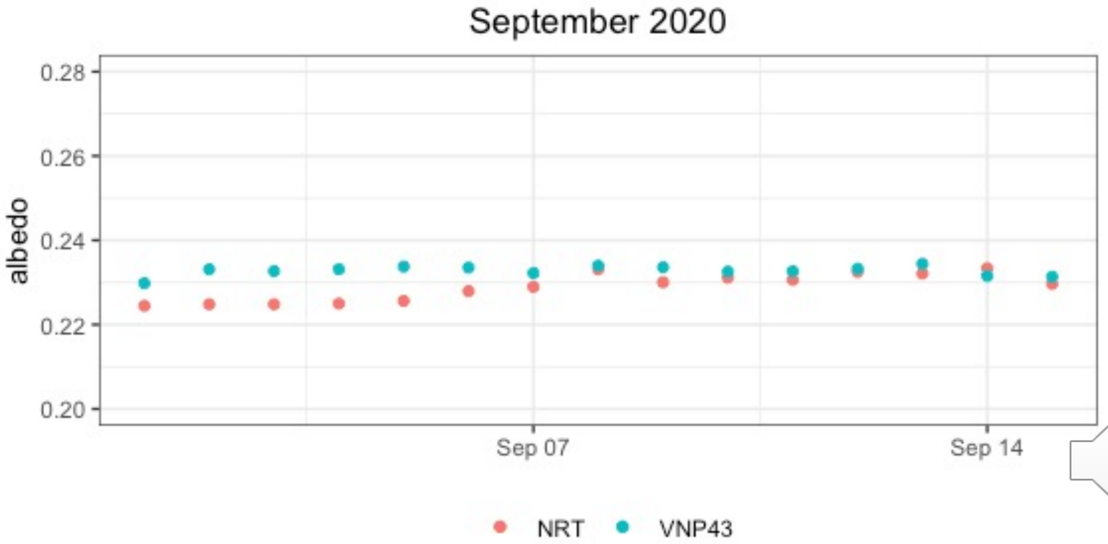


We have compared the standard VNP43 albedo product to our near-real-time implementation.

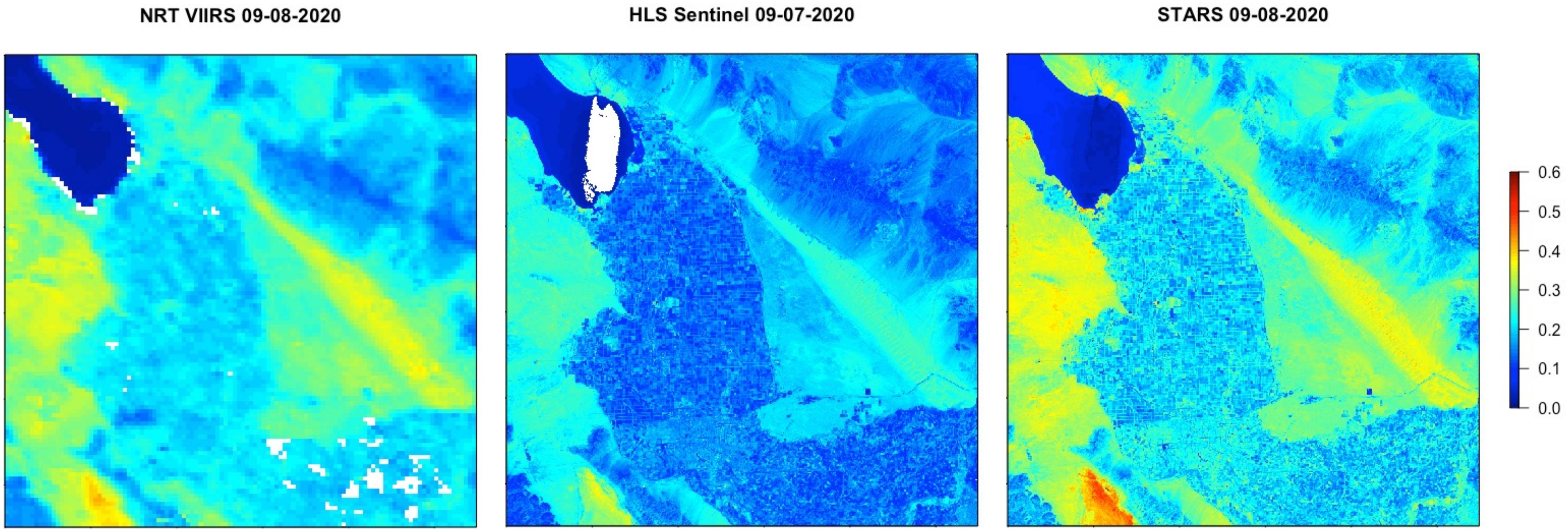


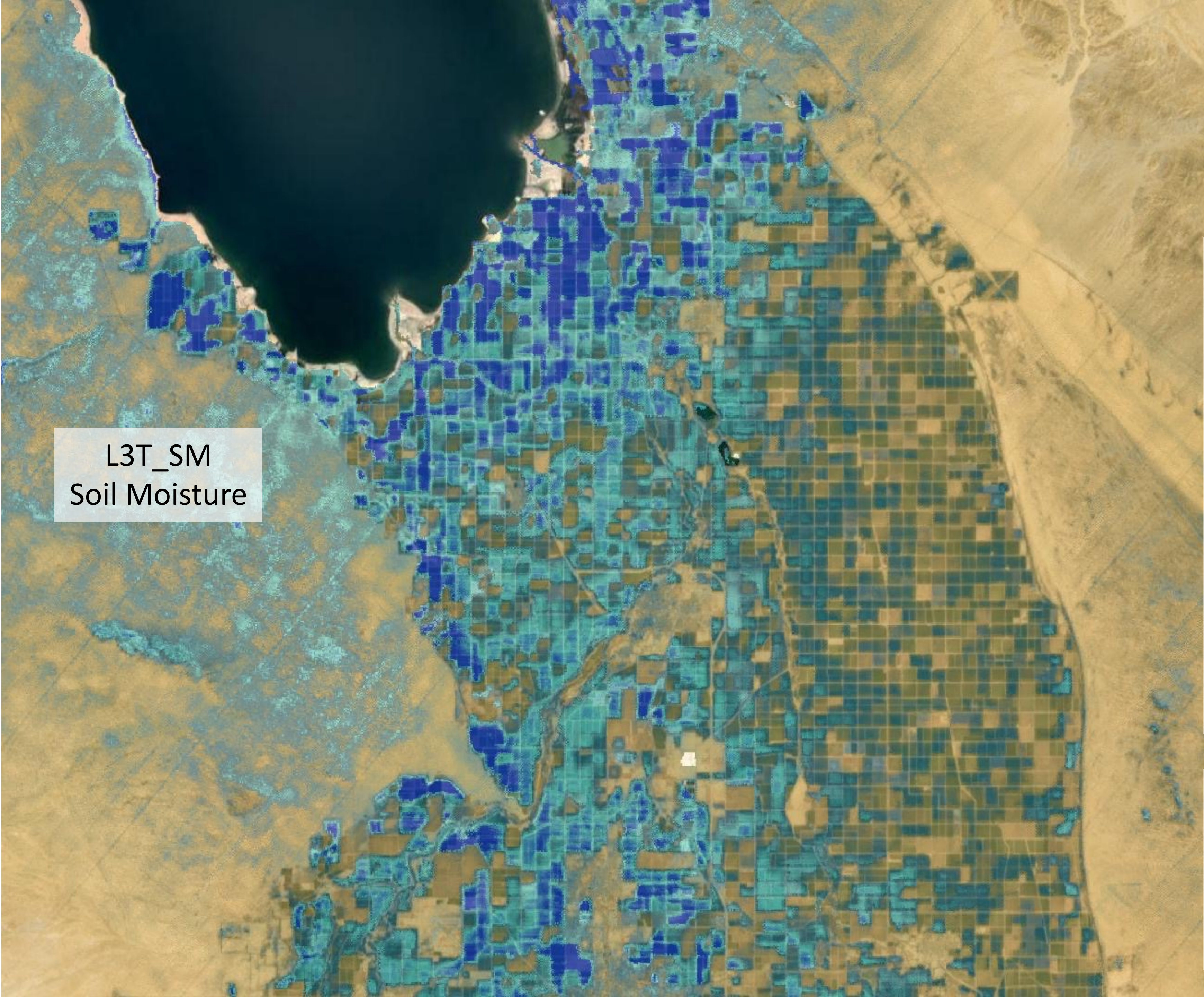






We’re fusing the 1 km low-latency BRDF-corrected VIIRS albedo with HLS 2.0 up-sampled to 70 m to generate the 70 m ECOSTRESS STARS albedo product.



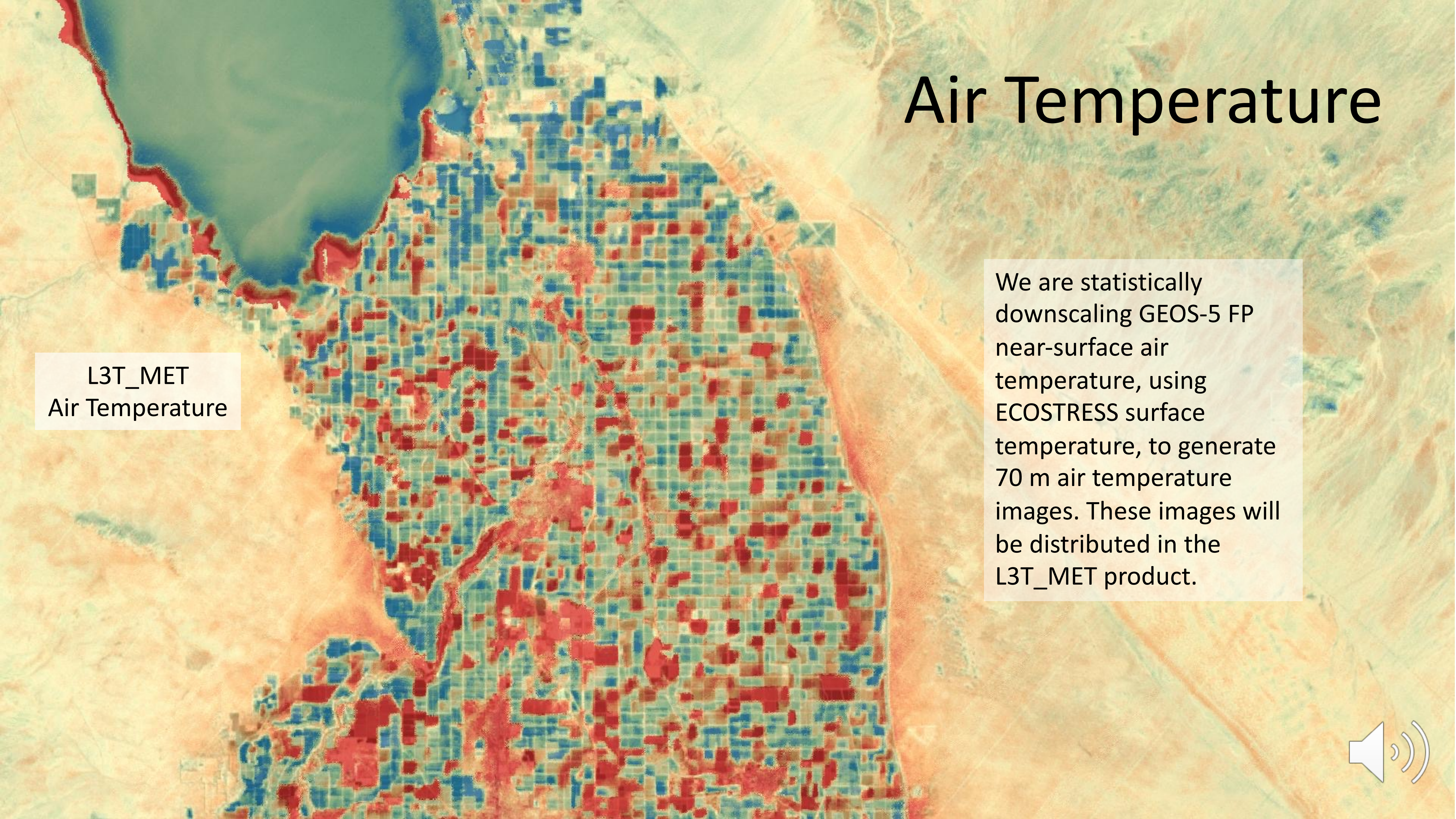


Soil Moisture

We have revised our evapotranspiration algorithm to take soil moisture into account. The 70 m soil moisture product is downscaled from GEOS-5 FP based on soil evaporation efficiency calculated from ECOSTRESS surface temperature and STARS NDVI. This downscaling method was developed by Andreas Colliander as a part of SMAP. Our soil moisture images are being distributed as the L3T_SM product.

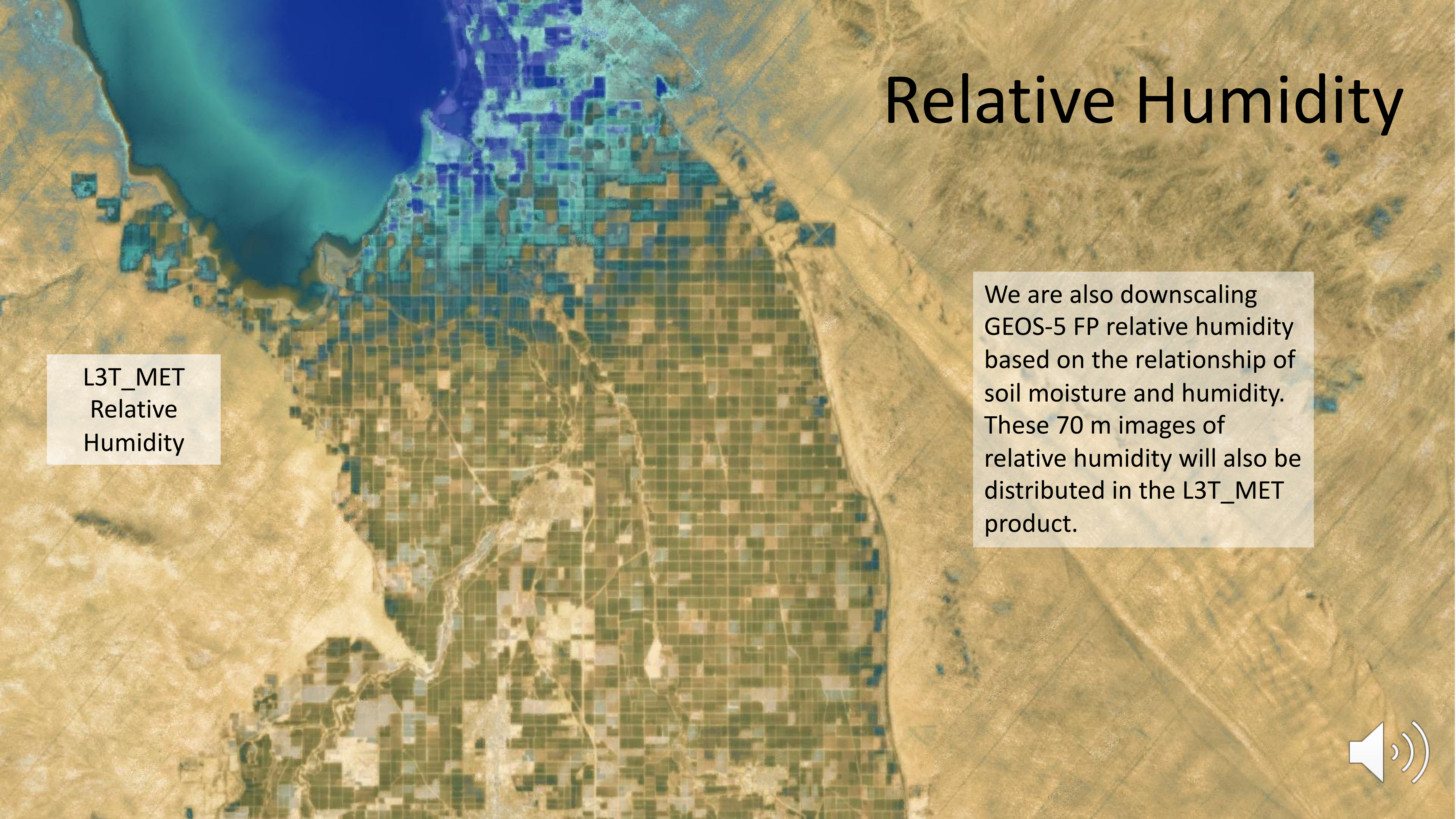
A. Colliander *et al.*, "Spatial Downscaling of SMAP Soil Moisture Using MODIS Land Surface Temperature and NDVI During SMAPVEX15," in *IEEE Geoscience and Remote Sensing Letters*, vol. 14, no. 11, pp. 2107-2111, Nov. 2017, doi: 10.1109/LGRS.2017.2753203.

Air Temperature



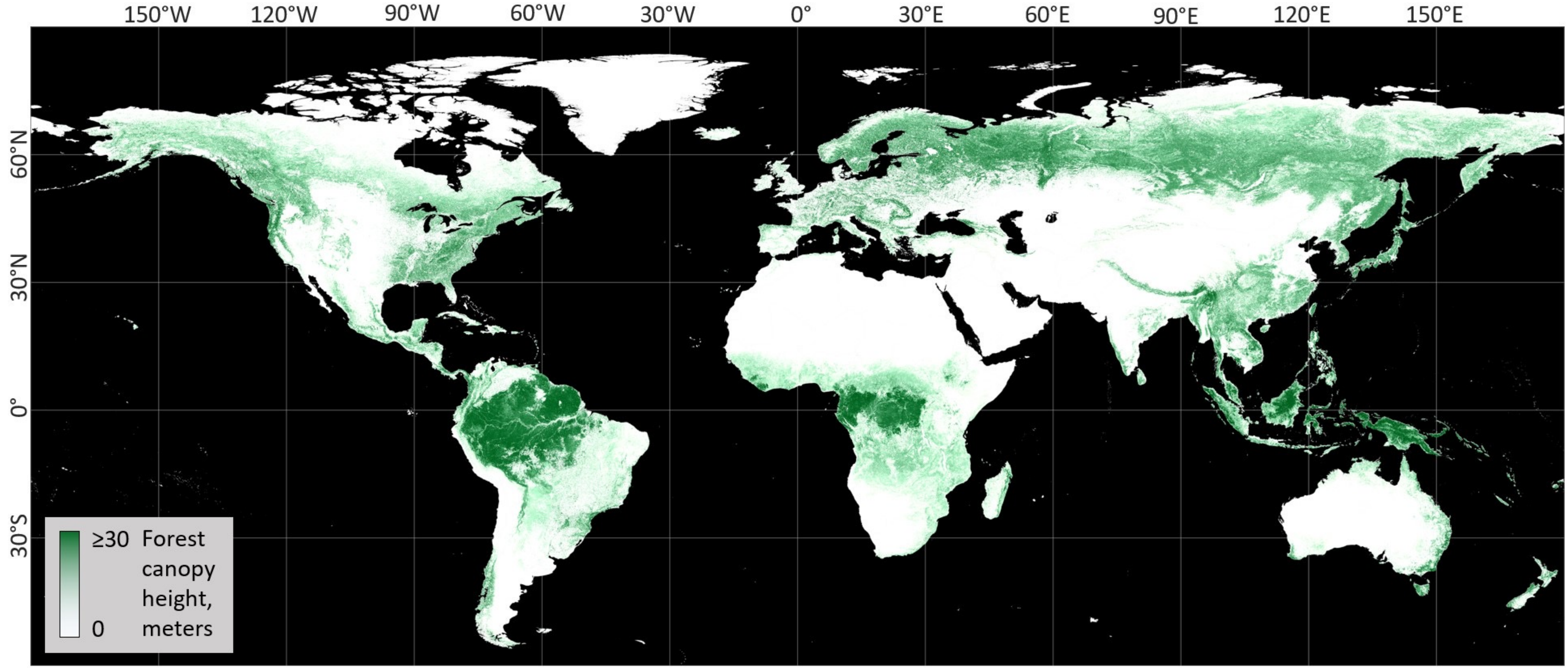
We are statistically downscaling GEOS-5 FP near-surface air temperature, using ECOSTRESS surface temperature, to generate 70 m air temperature images. These images will be distributed in the L3T_MET product.

Relative Humidity

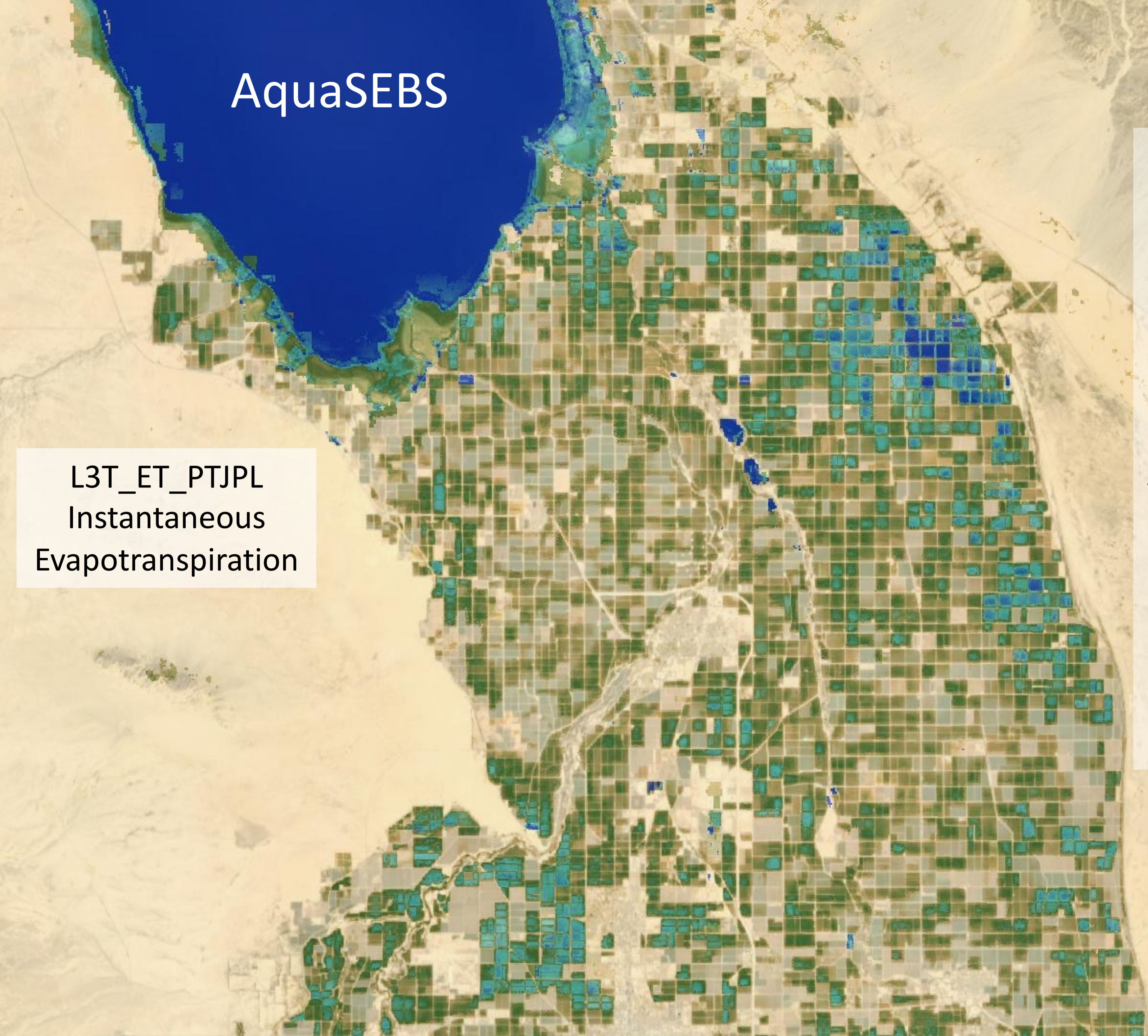


We are also downscaling GEOS-5 FP relative humidity based on the relationship of soil moisture and humidity. These 70 m images of relative humidity will also be distributed in the L3T_MET product.

The global 30 m map of canopy height produced by the GEDI mission facilitates improved estimates of evapotranspiration and gross primary production.



Global Land Analysis and Discovery https://glad.umd.edu/dataset/gedi



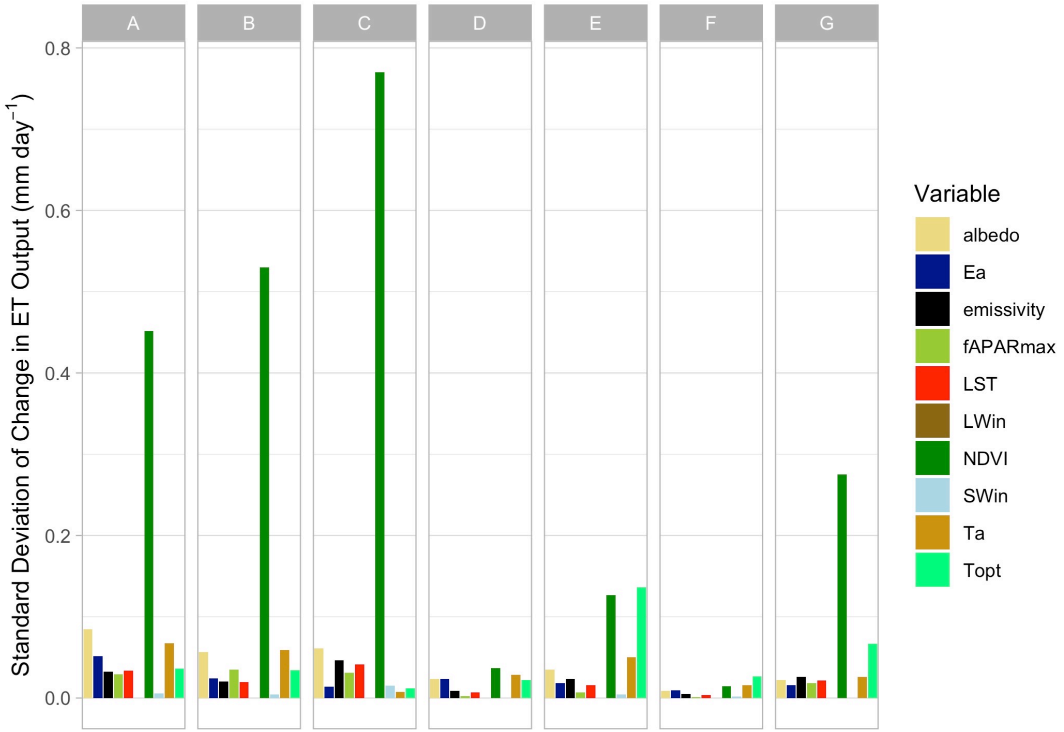
PT-JPL-SM

ECOSTRESS Collection 2 will use Adam Purdy's PT-JPL-SM model of evapotranspiration, also developed in coordination with SMAP, which ingests soil moisture and canopy height to produce a more robust ET product than the PT-JPL model used in Collection 1. We are now also processing water surface evaporation using the AquaSEBS model of water heat flux, as demonstrated in OpenET. These enhanced estimates of instantaneous and daily evapotranspiration will be distributed in the L3T_ET_PTJPL product, and normalized indices of Evaporative Stress Index will be distributed in the L3T_ESI_PTJPL product.

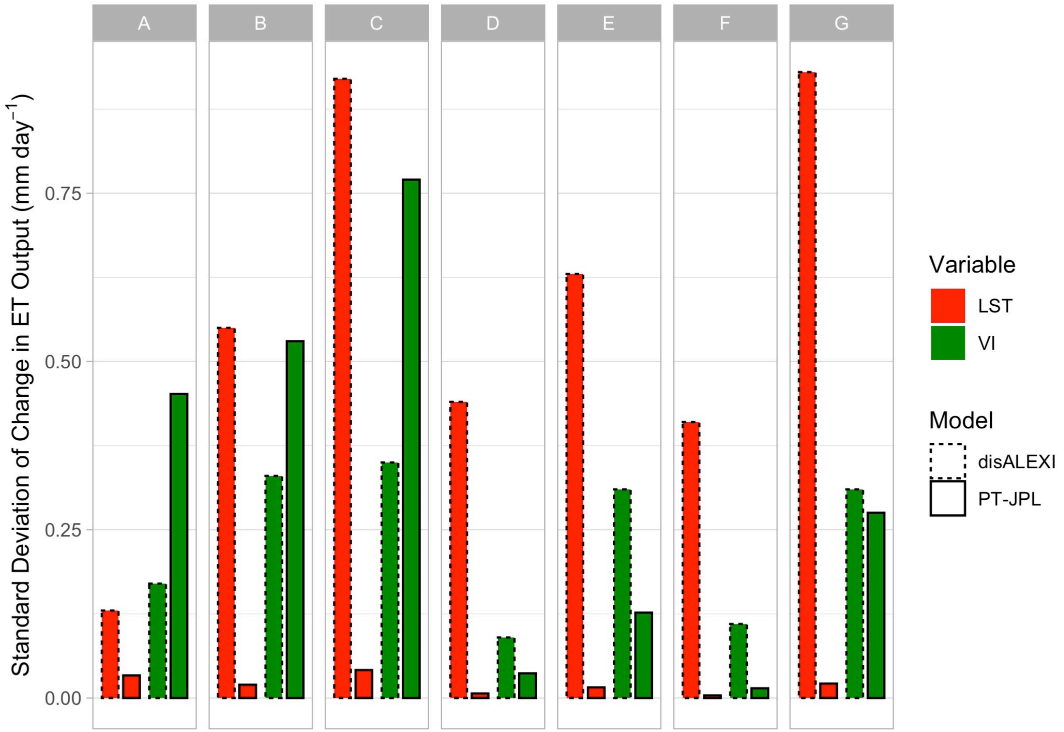
Purdy, A.J., Fisher, J.B., Goulden, M.L., Colliander, A., Halverson, G., Tu, K., Famiglietti,J.S., (2018), [SMAP soil moisture improves global evapotranspiration.](https://doi.org/10.1016/j.rse.2018.09.023) Remote Sensing of Environment 219: 1-14 https://doi.org/10.1016/j.rse.2018.09.023

Abdelrady, A.; Timmermans, J.; Vekerdy, Z.; Salama, M.S. Surface Energy Balance of Fresh and Saline Waters: AquaSEBS. *Remote Sens.* **2016**, *8*, 583. https://doi.org/10.3390/rs8070583

The advantage to using PT-JPL for ECOSTRESS evapotranspiration is its ability to distinguish transpiration from other forms of evaporation, but this comes at the cost of increased sensitivity to vegetation index. This sensitivity has prompted us to explore alternative models of evapotranspiration, including DisALEXI-JPL.



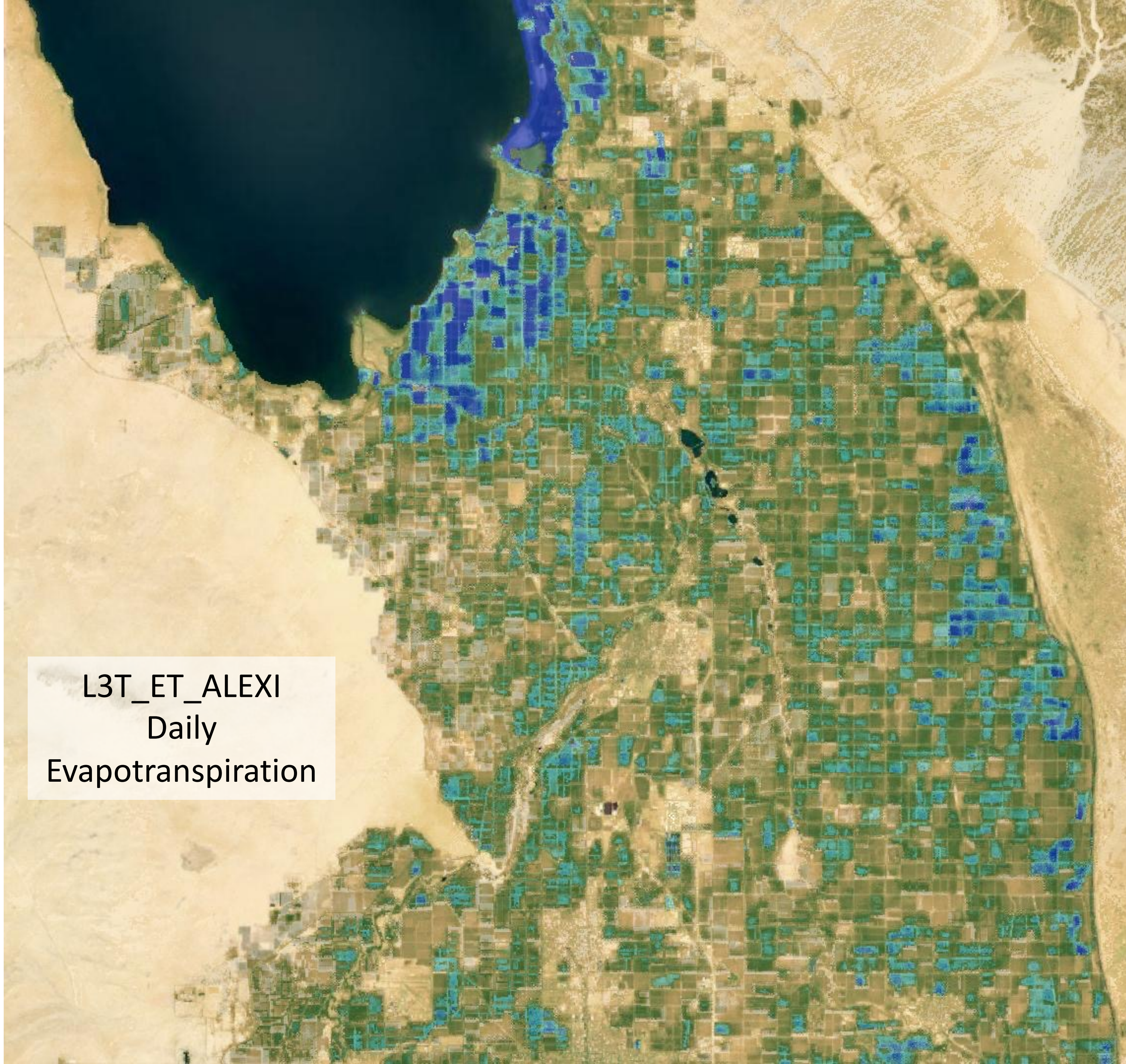
Standard deviation of changes in PT-JPL ET output using target input variable perturbations and all other variables held fixed.



Comparison of PT-JPL and disALEXI-JPL standard deviation of changes in ET output using surface temperature (LST) and vegetation index (VI) variable perturbations from the and all other variables held fixed.

Halverson et al., *Statistical Uncertainty Quantification and Sensitivity Analysis for the ECOSTRESS PT-JPL Evapotranspiration Algorithm*, in preparation

DisALEXI-JPL



ECOSTRESS Collection 2 will also produce daily evapotranspiration and Evaporative Stress Index using the DisALEXI-JPL algorithm. DisALEXI-JPL downscales the coarse resolution ALEXI ET product using high resolution ECOSTRESS surface temperature, NDVI, and albedo. The advantage to using DisALEXI-JPL is that it is more sensitive to ECOSTRESS surface temperature. The disadvantages are that it only processes daily evapotranspiration, so it cannot be used for our diurnal analysis, and it is geographically limited to the United States due to its dependence on the ALEXI product.

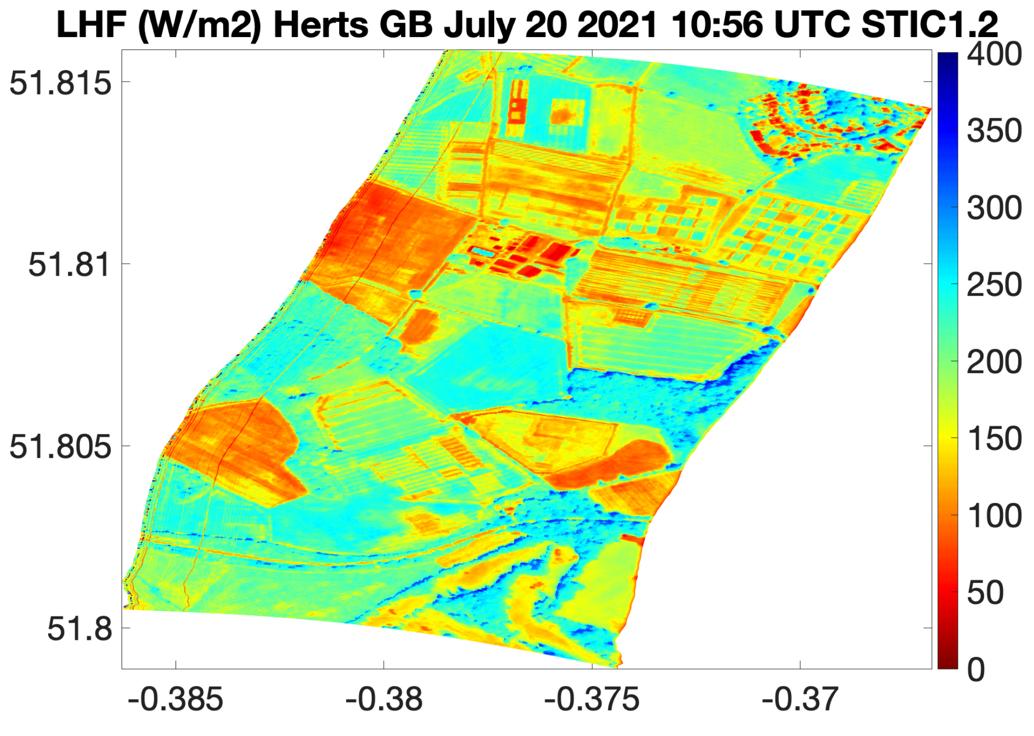
K. Cawse-Nicholson et al., "Evaluation of a CONUS-Wide ECOSTRESS DisALEXI Evapotranspiration Product," in IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing, vol. 14, pp. 10117-10133, 2021, doi: 10.1109/JSTARS.2021.3111867.

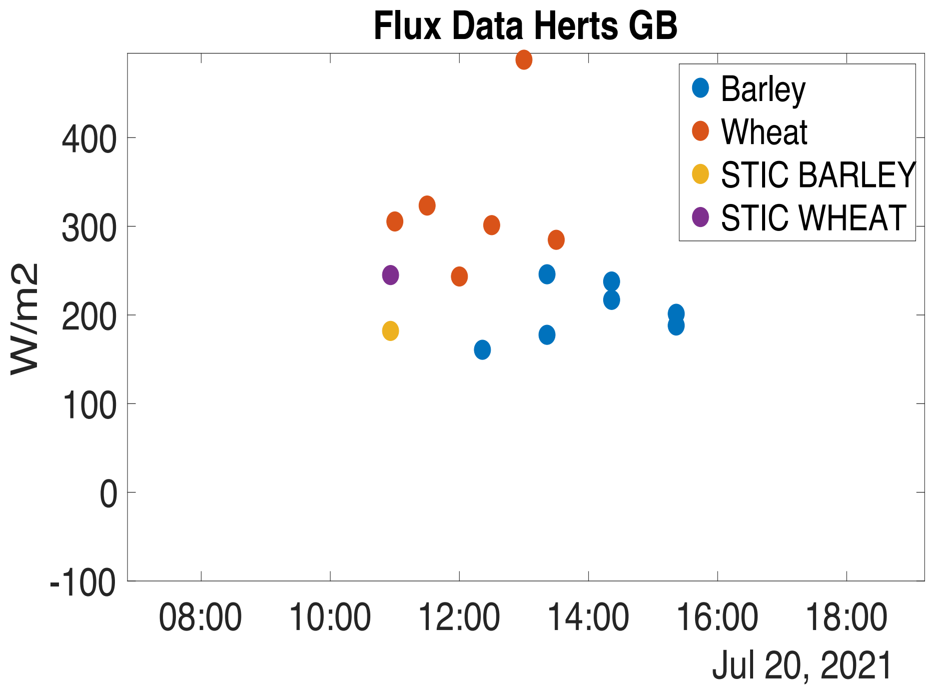
JPL Evapotranspiration Ensemble (JET)

Future work on Collection 2 development includes revising the PT-JPL ET product into the JPL Evapotranspiration Ensemble (JET) product, with multiple ET estimates including PT-JPL-SM, MOD16, adapted from the MODIS ET product, and BESS adapted from our GPP algorithm. This will allow the user to better interpret the uncertainty in the range of estimates between models. We are also adapting a more surface temperature sensitive algorithm to include in this ensemble called STIC.

Surface Temperature Initiated Closure (STIC)

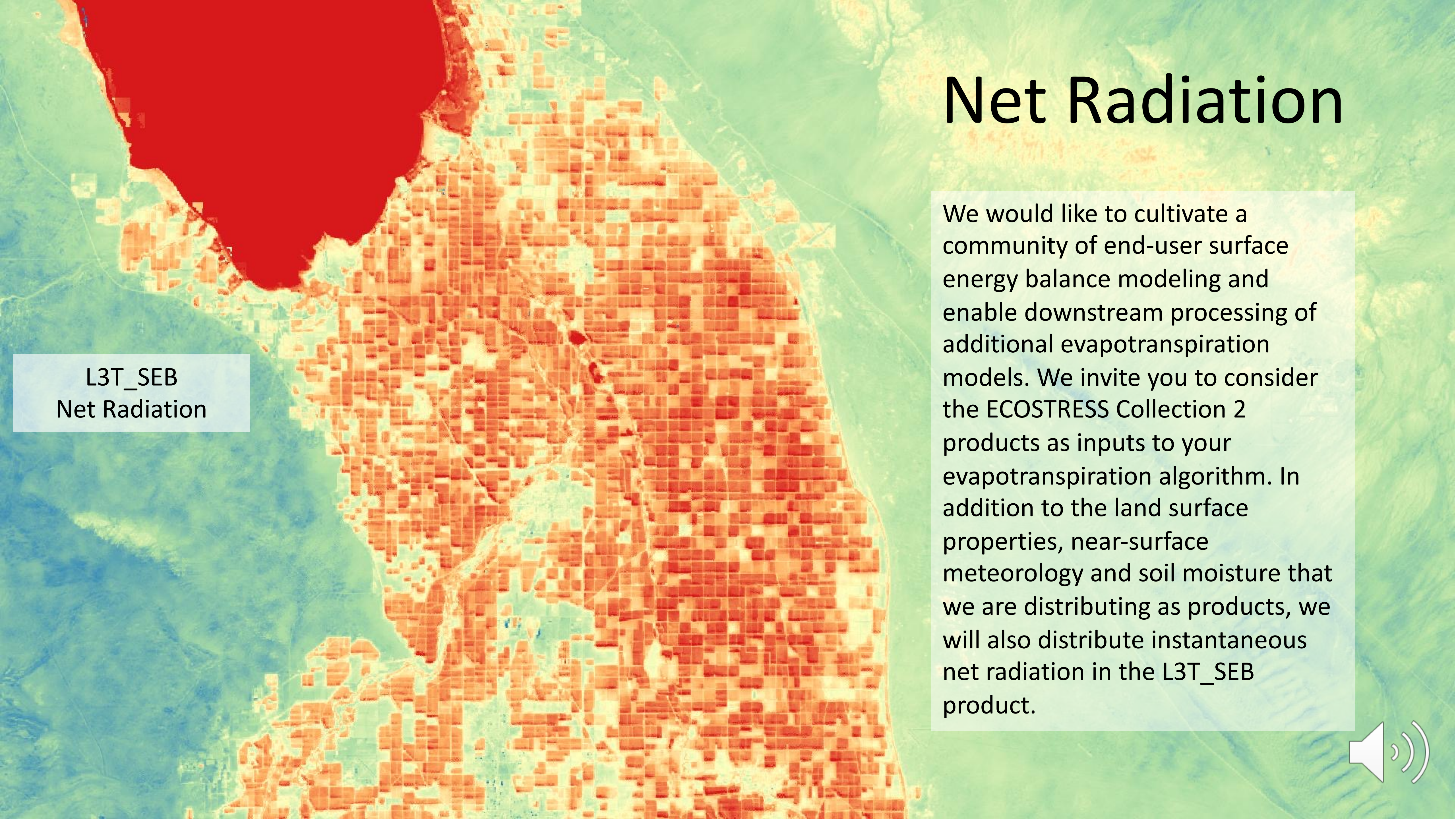
We’re working on an ECOSTRESS implementation of the Surface Temperature Initiated Closure (STIC) model of evapotranspiration to include in the JET product. The STIC model takes surface temperature into account directly in Penman-Monteith, improving sensitivity of evapotranspiration to surface temperature. We hope that STIC can complement PT-JPL-SM as a thermally sensitive evapotranspiration estimate that can help us reveal the diurnal cycle of thermal plant stress. Madeleine has been working with Kaniska Mallick, experimenting with processing the STIC model using HyTES surface temperature as a proxy for ECOSTRESS, SBG, TRISHNA, and LSTM, and comparing this initial output to eddy covariance data.





K. Mallick *et al.*, "Surface Temperature Initiated Closure (STIC) for su[...]e energy balance fluxes" in *Remote Sensing of Environment*

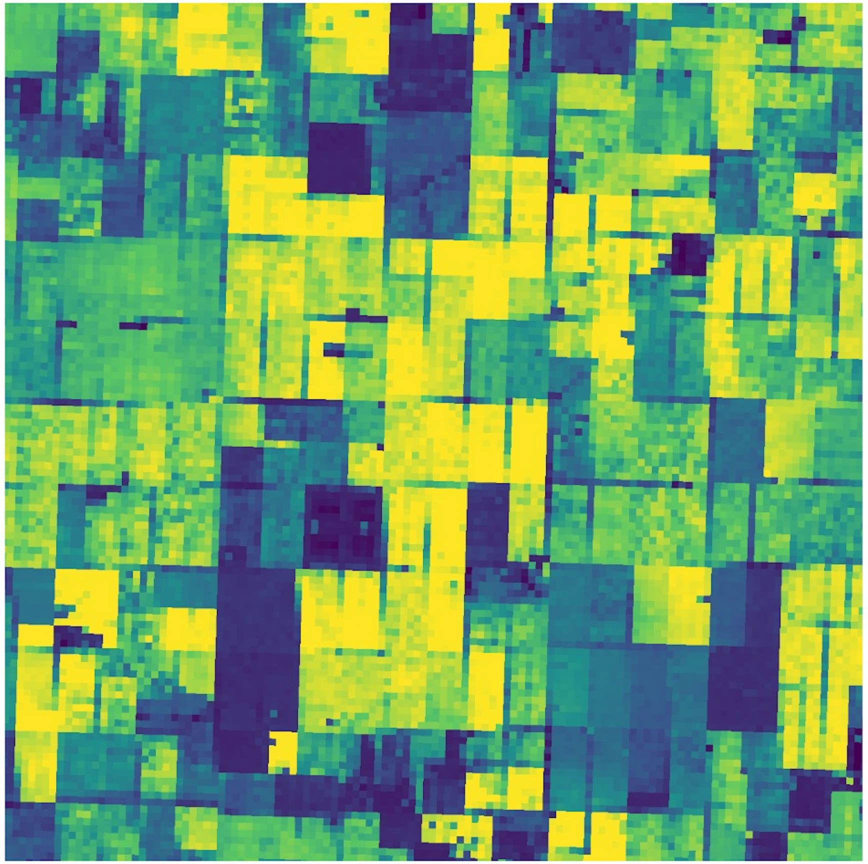
Net Radiation



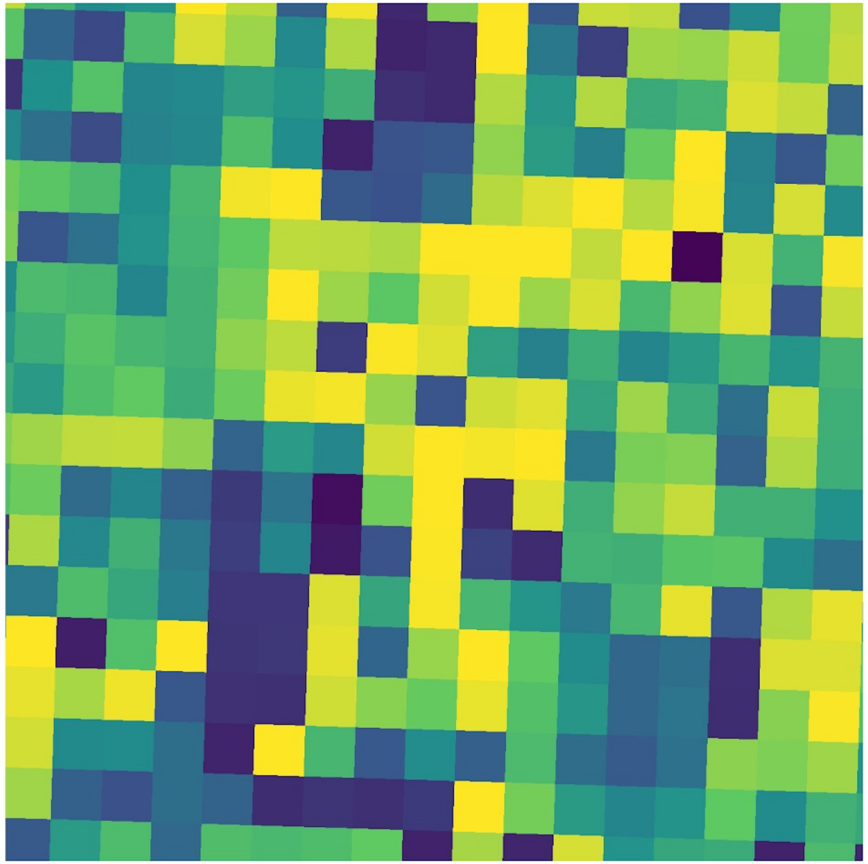
We would like to cultivate a community of end-user surface energy balance modeling and enable downstream processing of additional evapotranspiration models. We invite you to consider the ECOSTRESS Collection 2 products as inputs to your evapotranspiration algorithm. In addition to the land surface properties, near-surface meteorology and soil moisture that we are distributing as products, we will also distribute instantaneous net radiation in the L3T_SEB product.

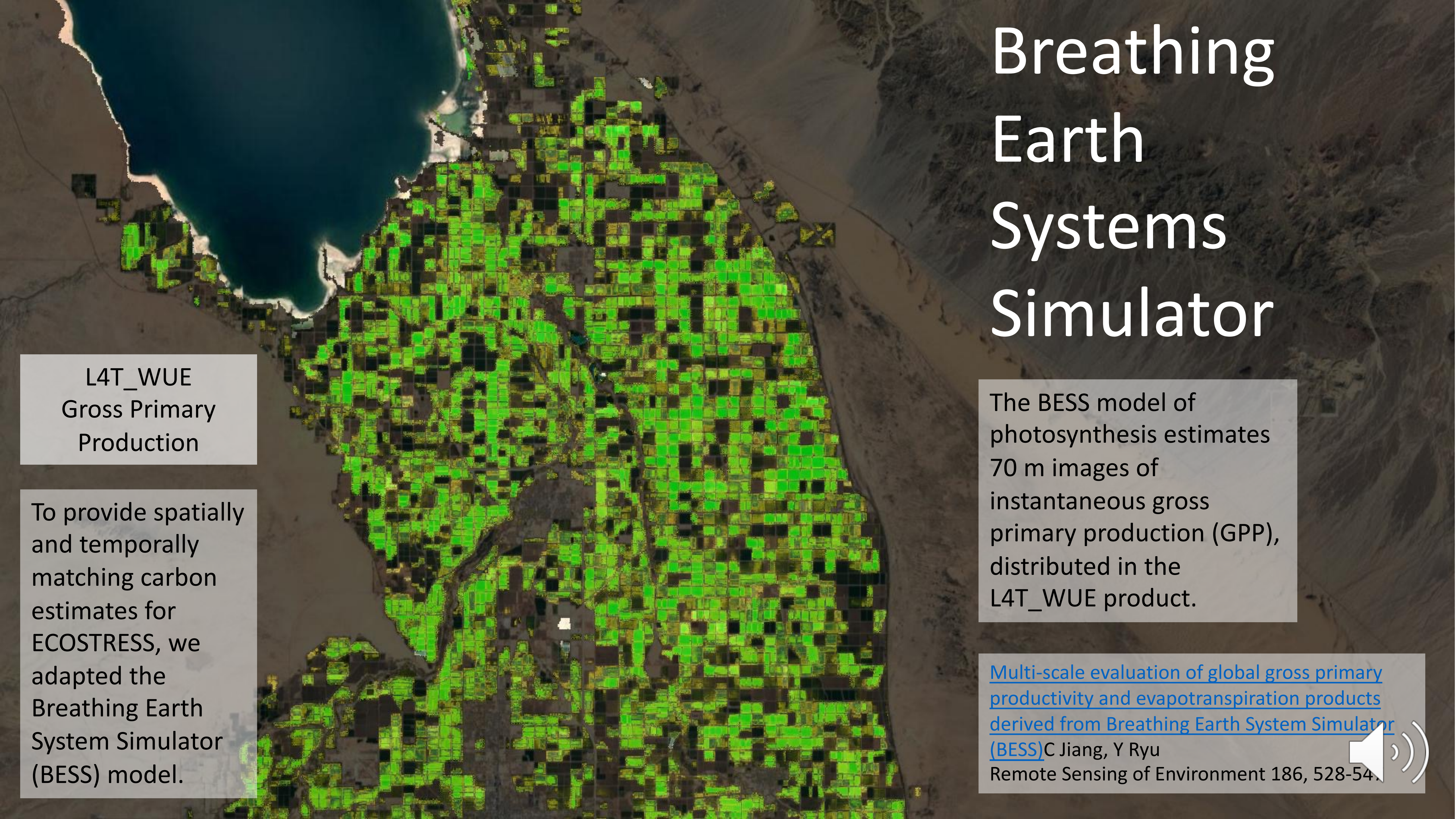
Water Use Efficiency (WUE) is the ratio of carbon that plants gain to the water that they lose. The ECOSTRESS Collection 1 Water Use Efficiency product used the MOD17 500 m 8-day Gross Primary Production product as its measure of carbon, effectively limiting water use efficiency analysis to the 500 m scale.

ECOSTRESS 70 m Resolution



MOD17 500 m Resolution





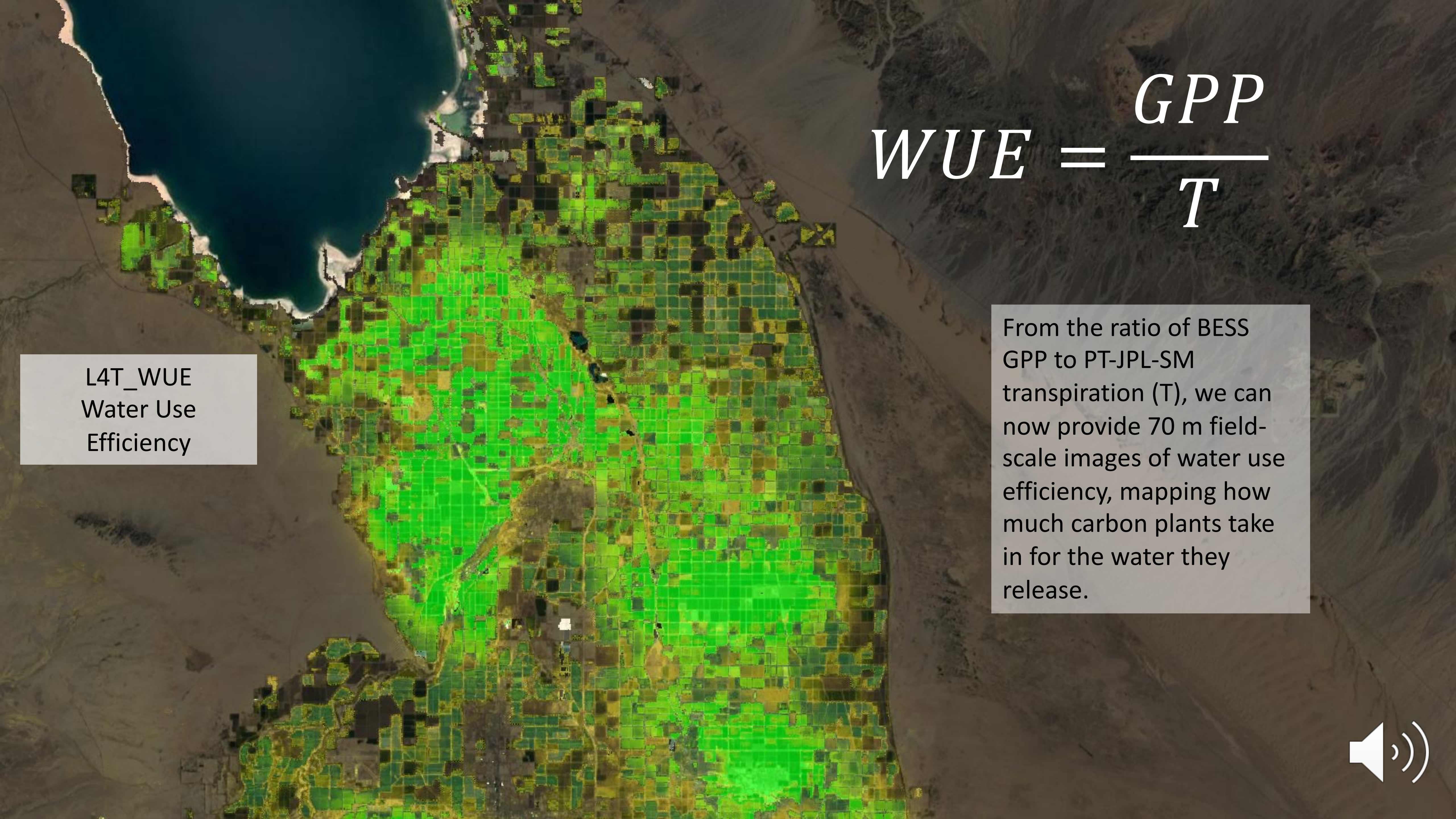
Breathing Earth Systems Simulator

L4T_WUE
Gross Primary
Production

To provide spatially and temporally matching carbon estimates for ECOSTRESS, we adapted the Breathing Earth System Simulator (BESS) model.

The BESS model of photosynthesis estimates 70 m images of instantaneous gross primary production (GPP), distributed in the L4T_WUE product.

[Multi-scale evaluation of global gross primary productivity and evapotranspiration products derived from Breathing Earth System Simulator (BESS)]C Jiang, Y Ryu
Remote Sensing of Environment 186, 528-54



$$WUE = \frac{GPP}{T}$$

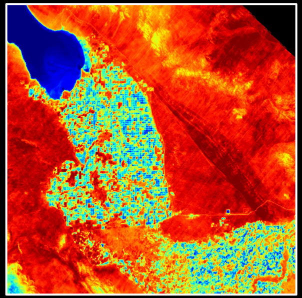
L4T_WUE
Water Use
Efficiency

From the ratio of BESS GPP to PT-JPL-SM transpiration (T), we can now provide 70 m field-scale images of water use efficiency, mapping how much carbon plants take in for the water they release.

L2T_RAD

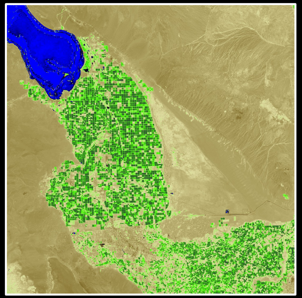
radiance_2
radiance_4
radiance_5

L2T_LSTE



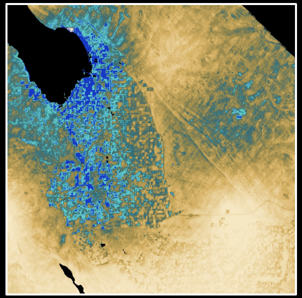
LST
LSTuncertainty
EmisWB

L2T_STARS



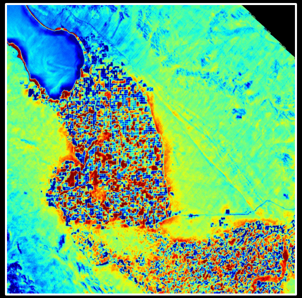
NDVI
NDVIuncertainty
albedo
albedoUncertainty

L3T_SM



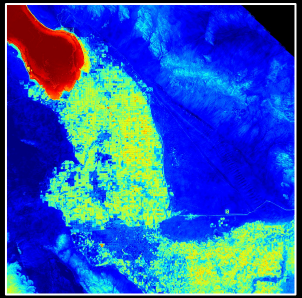
SM

L3T_MET



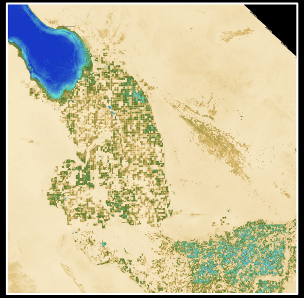
Ta
RH

L3T_SEB



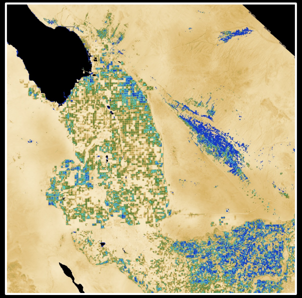
Rn

L3T_ET_PTJPL



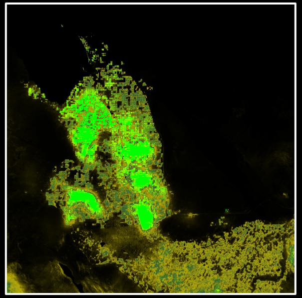
ETinst
ETinstUncertainty
ETcanopy
ETsoil
ETinterception
ETdaily

L4T_ESI_PTJPL



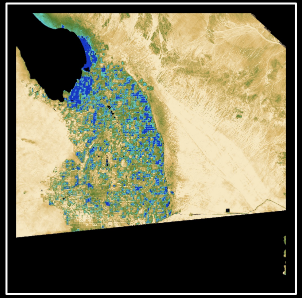
ESI
PET

L4T_WUE



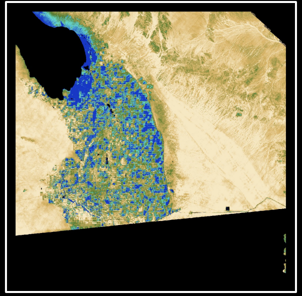
WUE
GPP

L3T_ET_ALEXI



ETdaily
ETdailyUncertainty

L4T_ESI_ALEXI



ESIdaily
ESIdailyUncertainty

We will be releasing a provisional form of the new products to an early user community this spring. Please inquire about joining our community to find points of contact between the ECOSTRESS Collection 2 products and your research and help us further refine these provisional analysis-ready products into research-grade products.

The development of these improved algorithms and implementation of these tiled data products demonstrates a feasible and cloud-enabled work-flow for the future SBG suite of surface energy balance products, coordinated with TRISHNA and LSTM.

These tiled products facilitate new opportunities for near-real time monitoring of high-resolution temperature and plant stress and allow greater ease of use for data analysis and science.

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  - DisALEXI-JPL evapotranspiration model development

Early User Community

- Christine Lee
  - Inquiries about joining early user community
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Improvements to ECOSTRESS Algorithms and Products in Collection 2

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