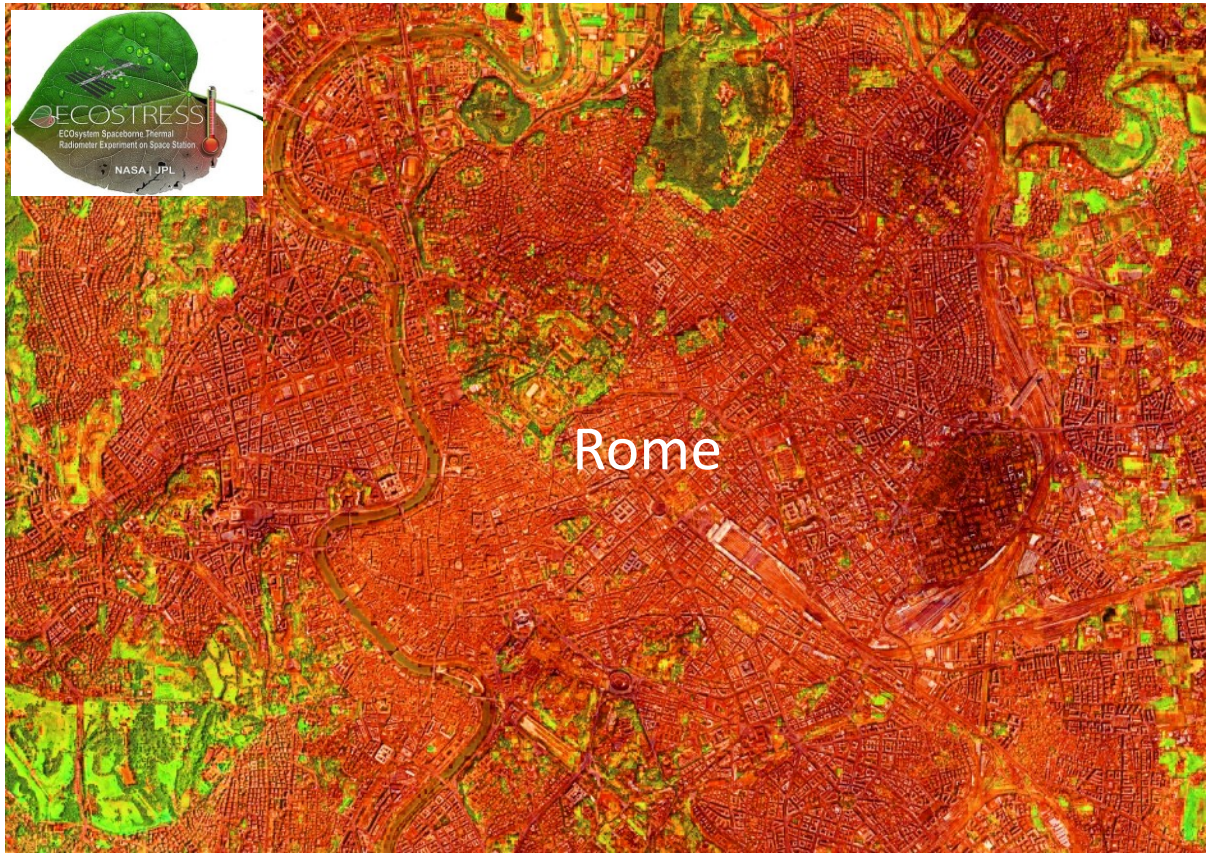
Jet Propulsion Laboratory
California Institute of Technology

High resolution thermal imaging of urban heat islands and heat waves

Glynn Hulley
Jet Propulsion Laboratory,
California Institute of Technology



Urbanization

Cities are the world's dominant **demographic and economic centers**

More than **50%** of the world population lives in cities.

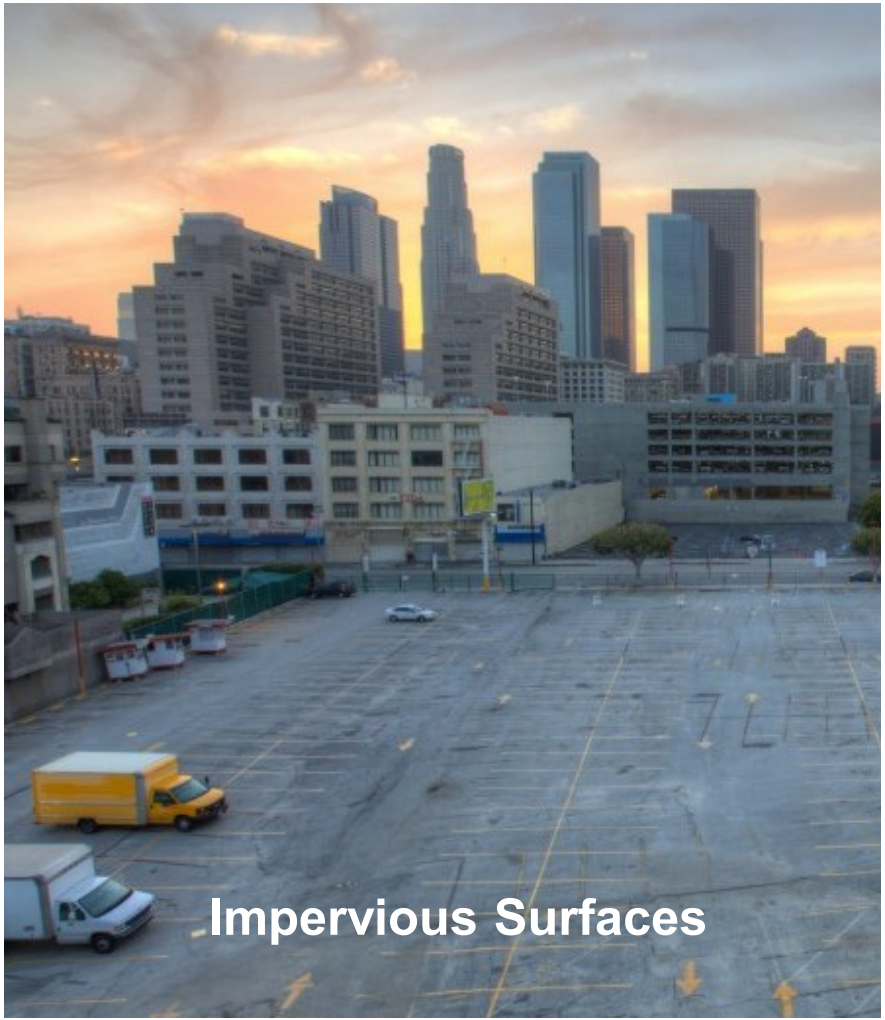
Cities generate most of the **economic output**

Cities account for **30%** of the global energy consumption.

Higher **Heat Capacity**

Lower Overall **Albedo**

Higher **Surface Temperature**



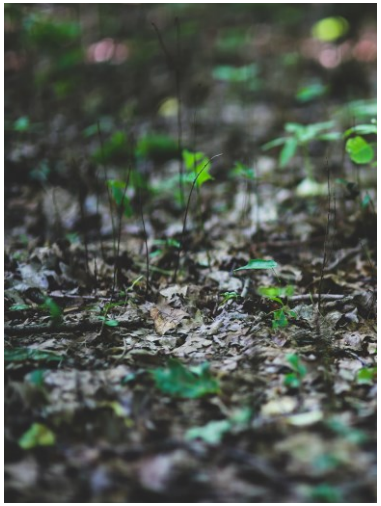
Man-made Surface and Atmospheric Modification

Decrease in **evapotranspiration**

Reduction in **turbulent heat transport** due to the geometry of the street canyons

Increased **anthropogenic heat emissions**

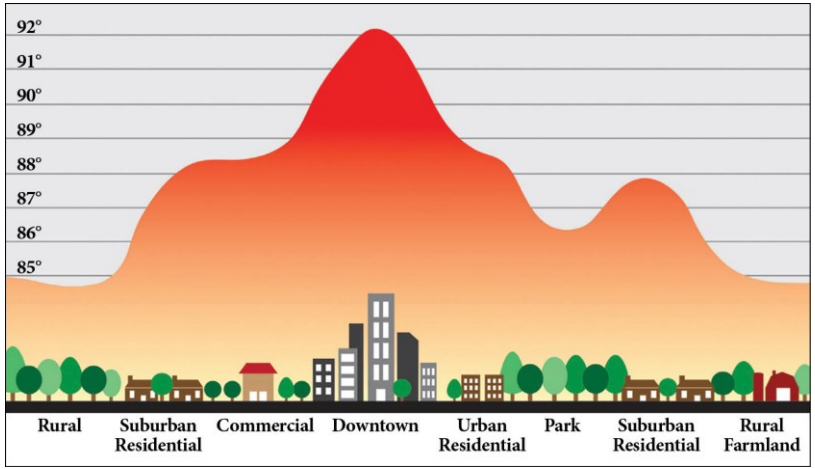
Air **pollution**



Urban Climate

Cities are **warmer** than their surrounding non-urbanized areas.

This is known as the **Urban Heat Island** effect.



Negative effects:

1. Degrade the **environment**
2. Impact the **human health**
3. Impact the **thermal comfort**
4. Increase the **energy demand**
5. Intensify and prolong **heatwaves**

Surface Temperature

It is central to the **surface energy balance**

It modulates the **air temperature** of the lowest layers of the urban atmosphere

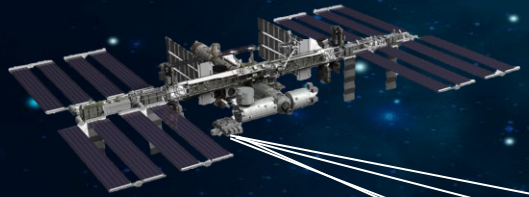
It affects the **energy exchanges** that impact the human thermal comfort

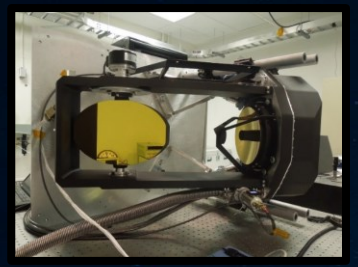
Enables the study of **surface UHIs** (SUHIs)

ECOSTRESS

ECOsystem Spaceborne Thermal Radiometer Experiment on Space Station

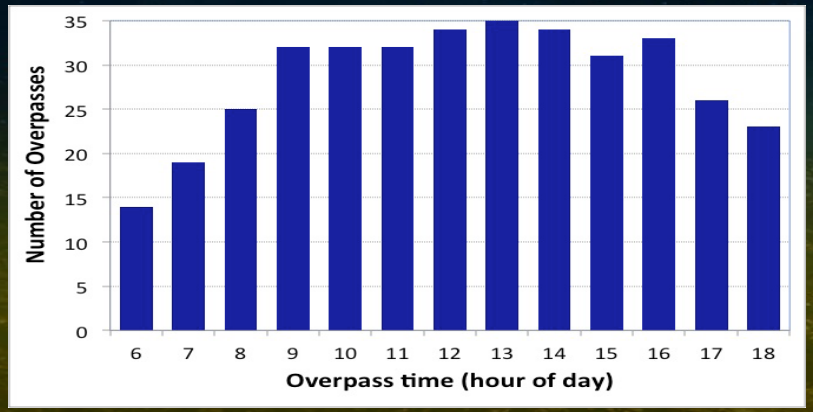
ISS JEM-EF
launch, June 2018



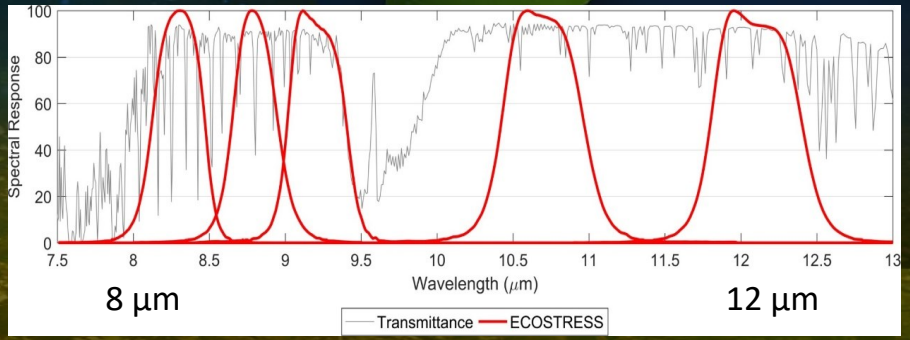


70 m resolution pixels

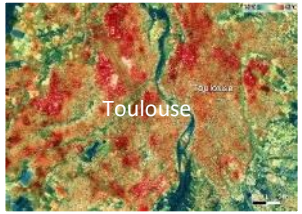
Observations over the diurnal cycle every 3-5 days

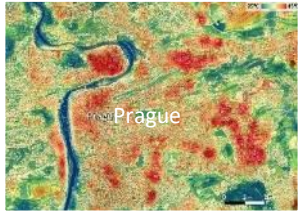


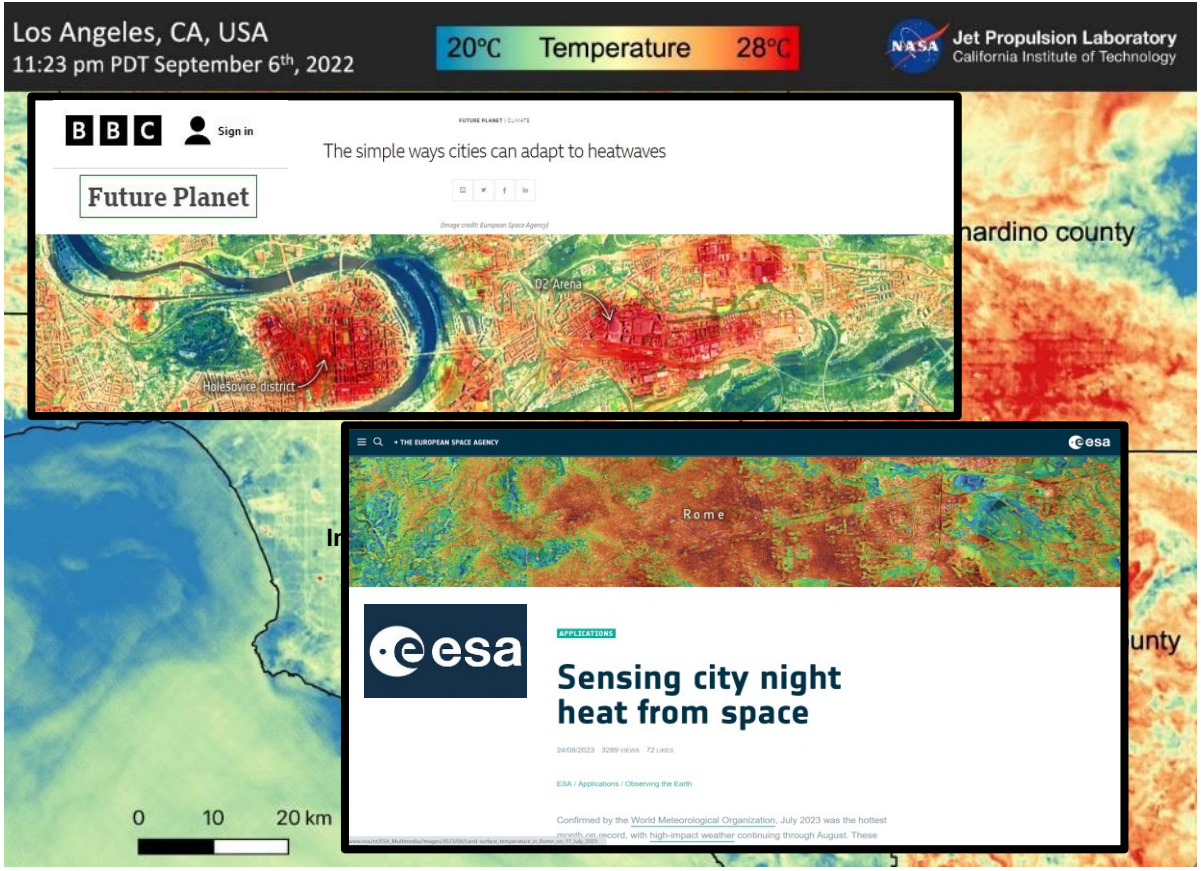
Five thermal infrared bands

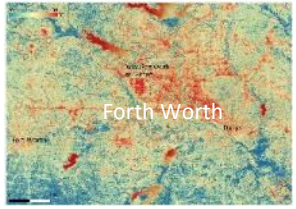


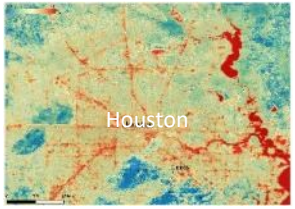
Mapping urban extreme heat across the globe

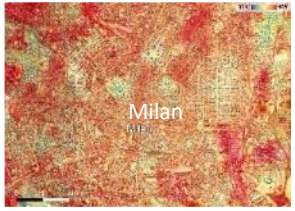




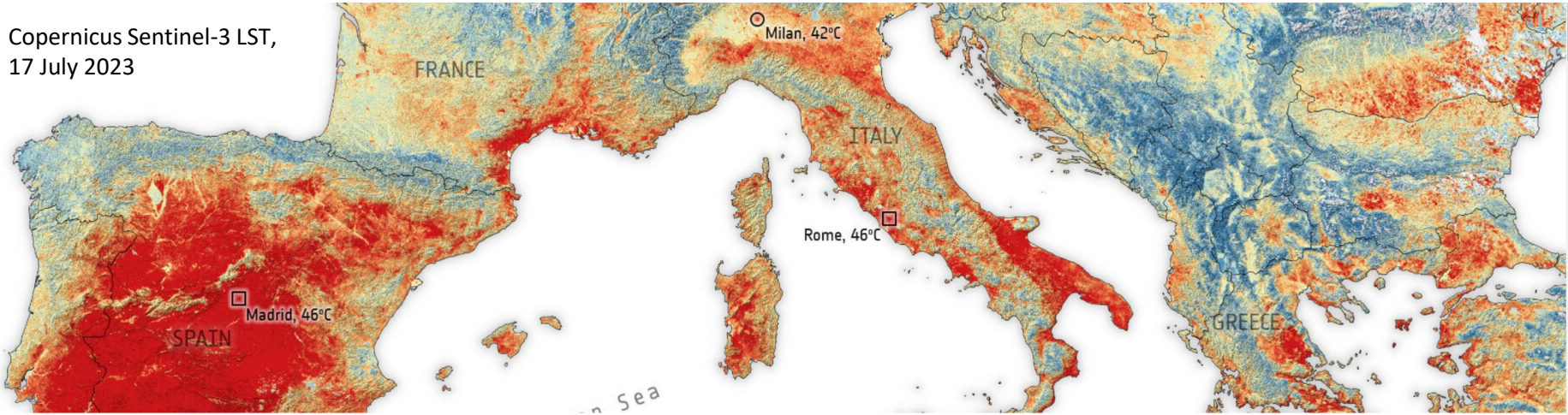








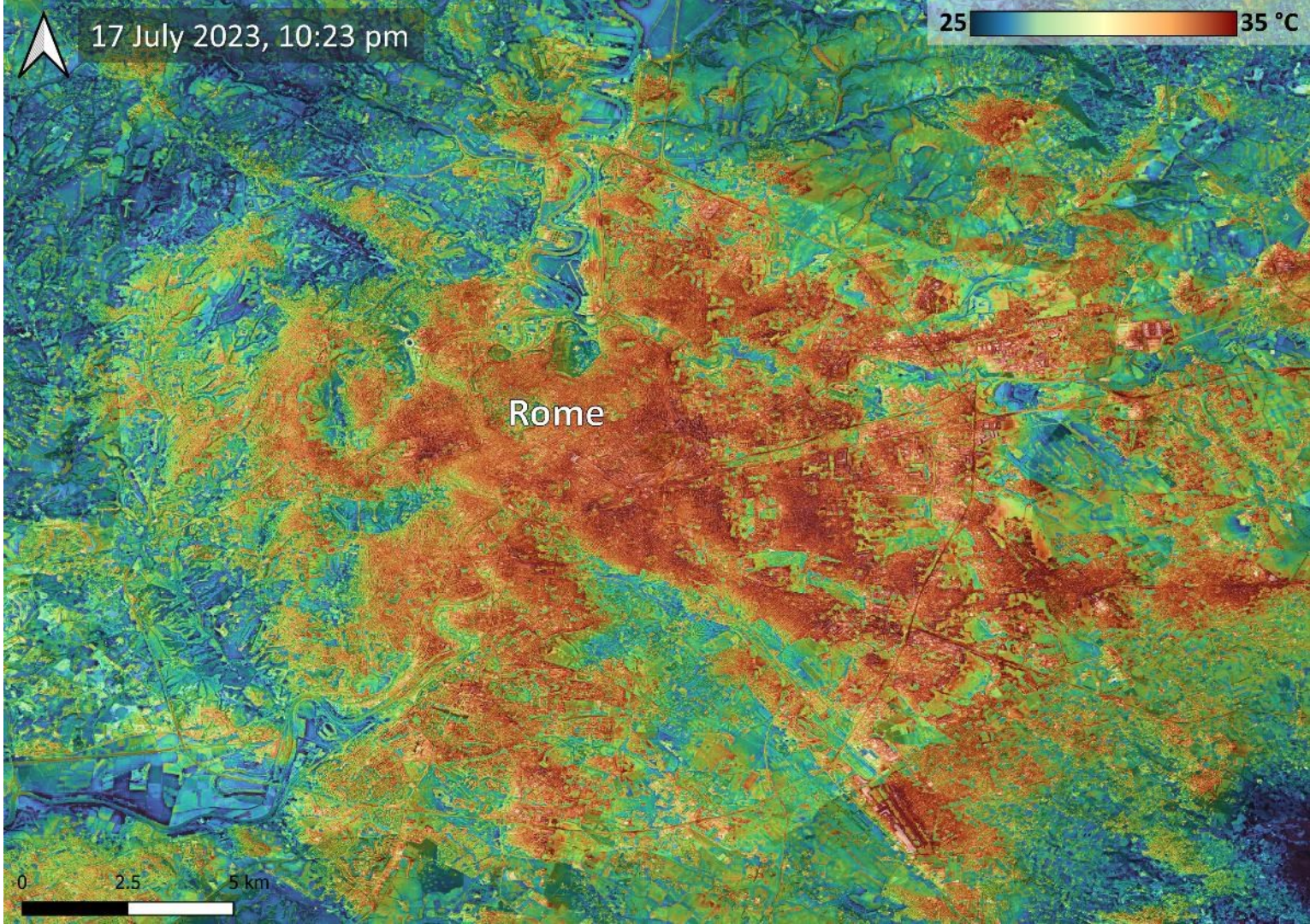
Extreme heat across Europe – July 2023



- The July 2023 ‘cerebus’ heatwave brought the hottest temperatures ever across Europe
- Numerous city temperature records broken
- 70,000 people died from heat related illness in 2023
- Highest mortality rates in Italy, Greece, Spain and Portugal

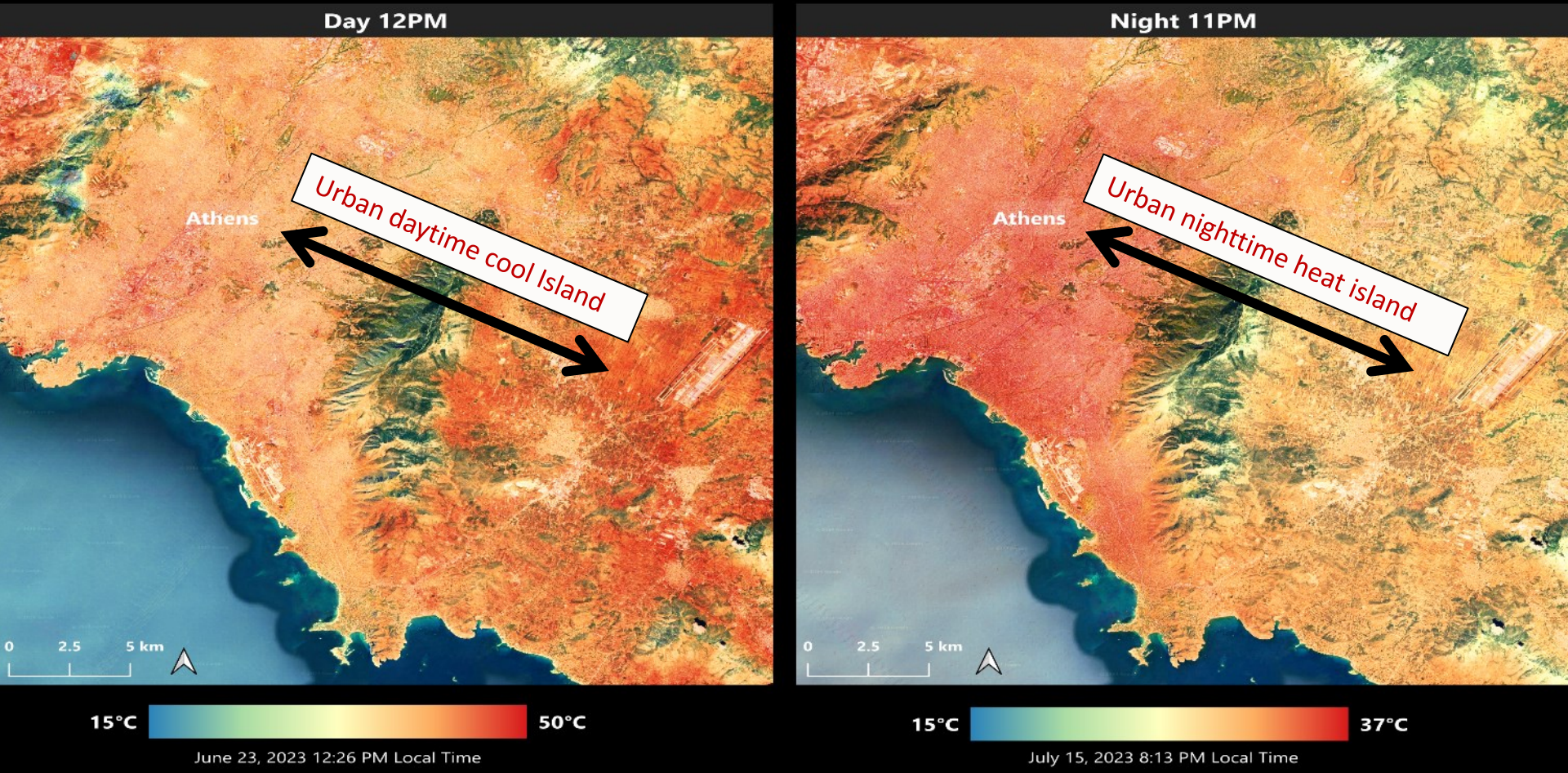
ECOSSTRESS LST,
17 July 2023

Rome's highest air temperature ever was recorded at 41.8 C on 18 July 2023, breaking previous year's record of 40.7 C in June 2022



ECOSTRESS Land Surface Temperature

Eureopean ‘Cerberus’ Heatwave: July 2023



URBAN HEAT APPLICATIONS AND EARTH ACTION EXAMPLES

Blazing hot surfaces are a danger for catastrophic burn injuries in the urban desert Southwest

Sizzling sidewalks and unshaded playgrounds are a danger for catastrophic burn injuries as air temperatures reach new summer highs in desert cities like Phoenix and Las Vegas

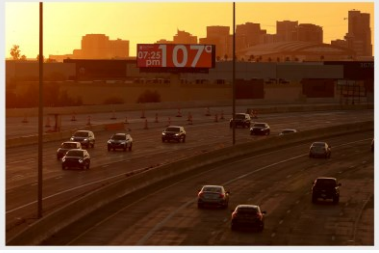
By ANITA SNOW Associated Press
July 2, 2024, 9:02 PM

JULY 3, 2024 | 4 MIN READ

New Heat Map Shows Scorching Streets that Can Burn Skin in Seconds

Under the scorching summer sun, pavement can reach temperatures hot enough to cause second-degree burns

BY ANDREA THOMPSON



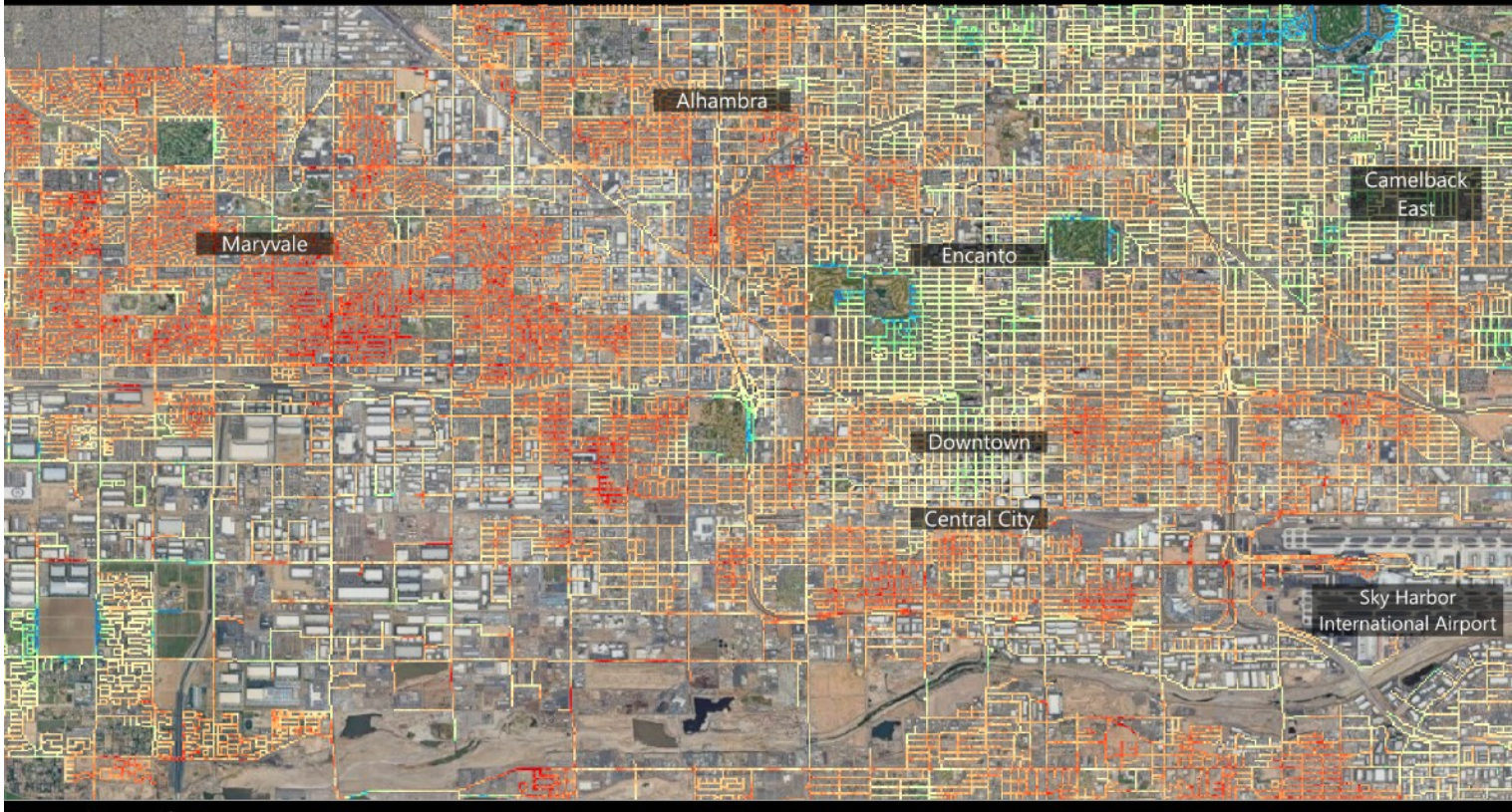
People walk in the street in "The Zone," a vast homeless encampment where hundreds reside, during a record heat wave in Phoenix on July 19. PATRICK T. FALLON/AFP VIA GETTY IMAGES

USGS NASA

ECOSTRESS

ECOSTRESS Land Surface Temperature
Second-degree Burn Risk Exposure Map – Phoenix, Arizona

Jet Propulsion Laboratory
California Institute of Technology



Optimizing water distribution locations in Los Angeles

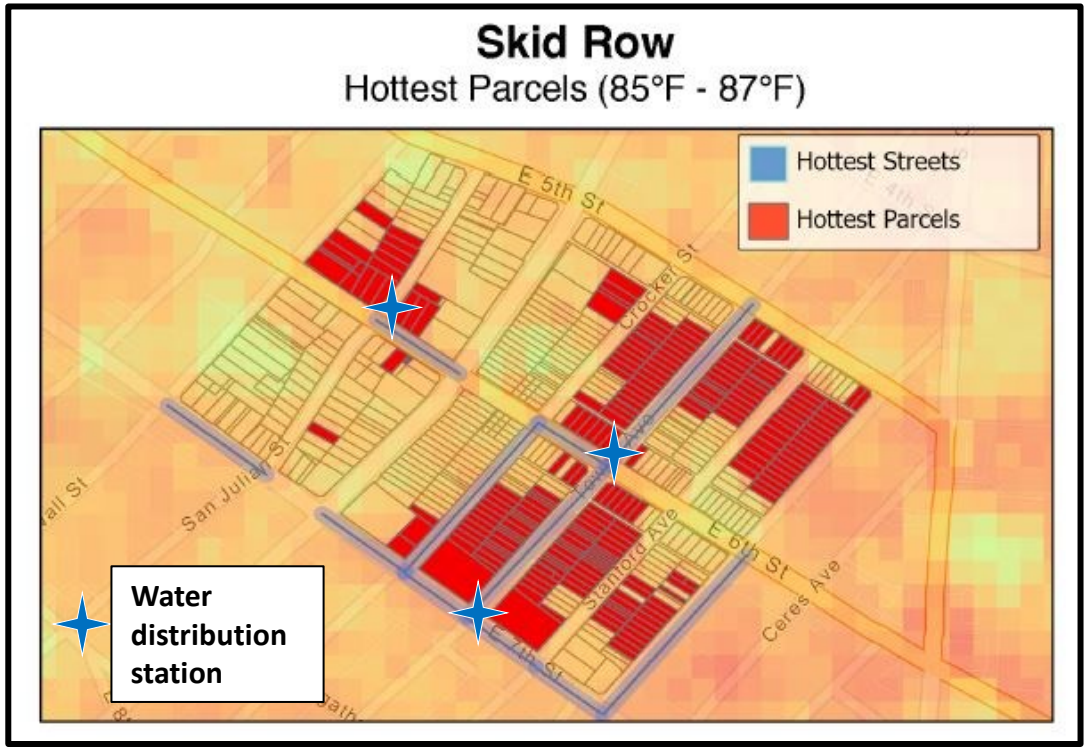
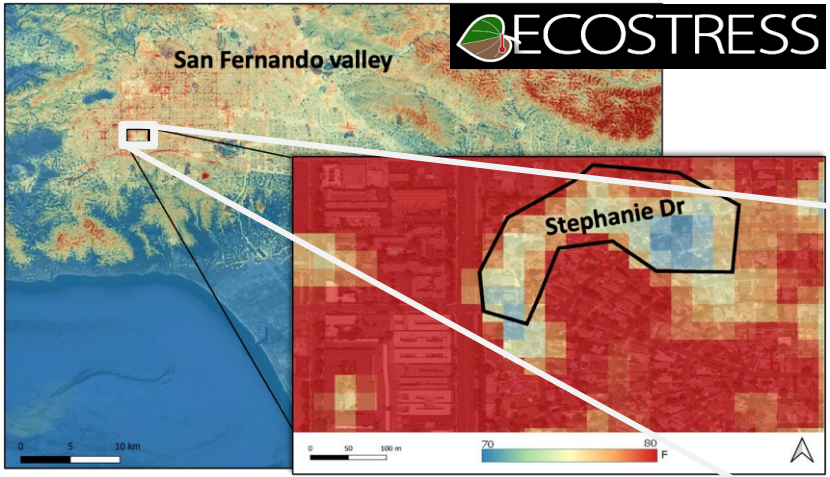


Image Credits: Climate Resolve, ECOSTRESS Land Surface Temperature and Parcel Analysis in Skid Row, 2021

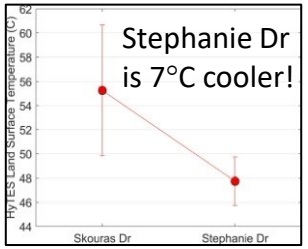
JPL's ECOSTRESS & HyTES Demonstrate Cooling Effects of Reflective Coatings in LA

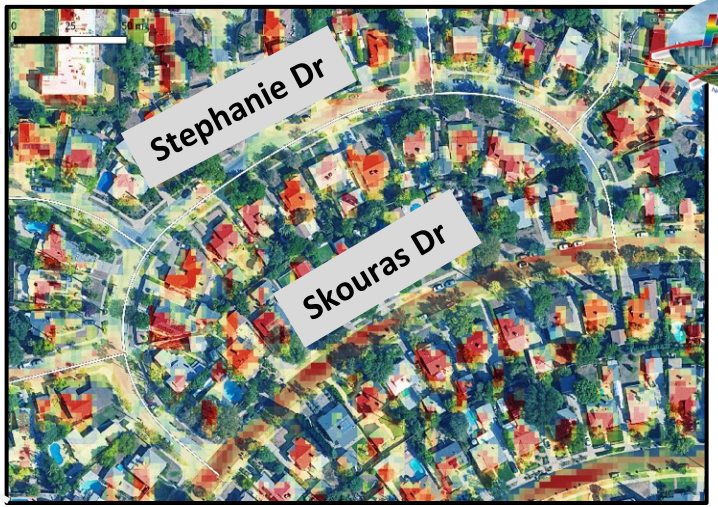
In 2021-2023 the city of LA painted 200 city blocks with cool pavement coating across 8 underserved neighborhoods



"I call this my ~~4, 6,~~ 8 million dollar slide" – Greg Spotts, streetsLA
$ 4 million – cool roads (2021-2022)
$ 2 million – shade trees (2021-2022)
$ 2 million – federal earmark 2022-2023


Stephanie Dr, 05/29/2019





HYPERSPECTRAL THERMAL EMISSION SPECTROMETER
HyTES
NASA • JET PROPULSION LABORATORY

USGS NASA

HOW TO OBTAIN ECOSTRESS DATA?

About the LP DAAC

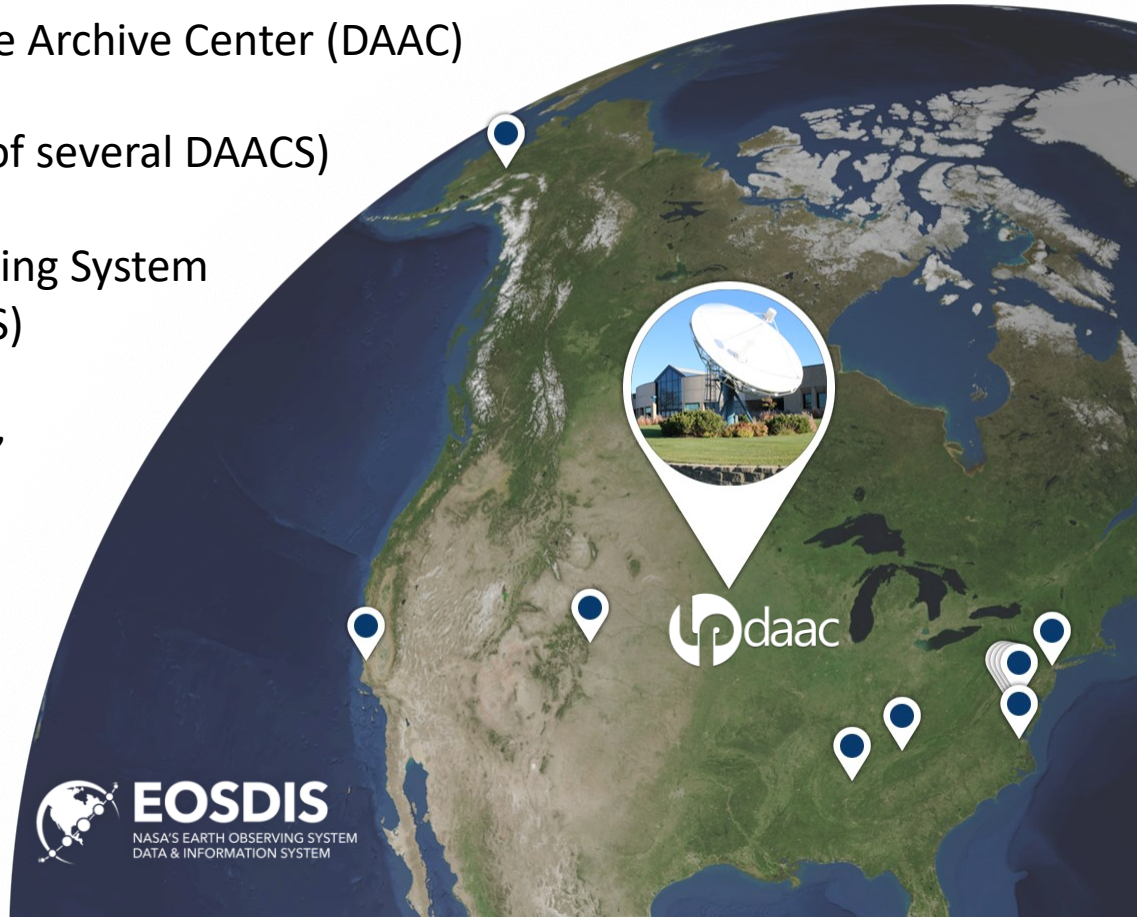
Land Processes (LP) Distributed Active Archive Center (DAAC)

NASA's Land Discipline Archive (one of several DAACS)

Sponsored by the NASA Earth Observing System Data and Information System (EOSDIS)

Located and Managed at USGS EROS, Sioux Falls, SD

All data and resources available at no cost



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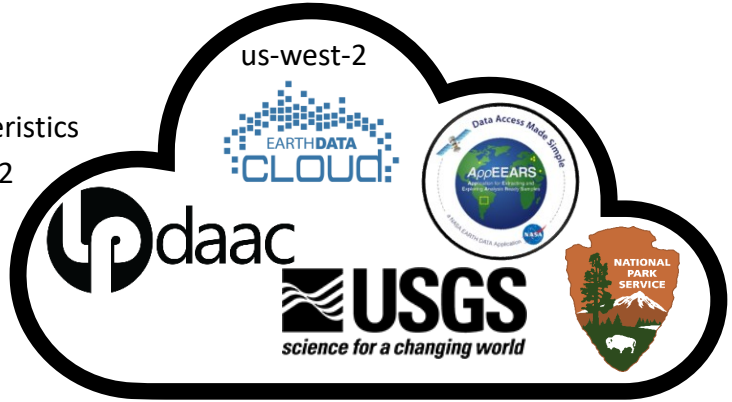
Common resources for accessing NASA data

- NASA's Earthdata Search (https://search.earthdata.nasa.gov/search)
  - GUI for spatio-temporal querying of ECOSTRESS (and all other NASA Earthdata) observations
- NASA's Common Metadata Repository (CMR) (https://cmr.earthdata.nasa.gov/search)
  - API for querying ECOSTRESS (and all other NASA Earthdata) observations
  - I would recommend users looking for direct access use the earthaccess python package: https://earthaccess.readthedocs.io/en/latest/
- The Application for Extracting and Exploring Analysis Ready Samples (AppEEARS) (https://appeears.earthdatacloud.nasa.gov/)
  - Easy to use web application (and API!) interface for accessing, processing, and visualizing NASA Earthdata, including ECOSTRESS
  - Allows spatio-temporal and band/layer subsetting
  - Reformatting options
  - Time Series visualizations
  - Quality decoding
  - Analysis ready outputs
- USGS EarthExplorer (https://earthexplorer.usgs.gov/)
  - ECOSTRESS will no longer be available in the USGS EarthExplorer Application as of August 30, 2024
  - It would be good to let users know that this option is going away and it is not recommended
    - https://lpdaac.usgs.gov/news/lp-products-to-be-removed-from-earthexplorer-and-m2m-on-aug-30-2024/
- ECOSTRESS Tutorials
- https://github.com/nasa/ECOSTRESS-Data-Resources

USGS NASA

Application for Extracting and Exploring Analysis Ready Samples (AppEEARS)

- New Product Releases (September 2022 – Present)
  - MODIS Version 6.1 Products
  - Harmonized Landsat Sentinel-2 Products
  - **ECOSTRESS V2 L1-L2 Radiance, LSTE, Cloud Swath and Tiled Products**
  - SEDAC Gridded Population of the World, V4 Basic Demographic Characteristics
  - MEaSUREs Geostationary Earth Orbit LST Hourly North/South America V2
  - Daymet V4R1 2022 data update in collaboration with ORNL DAAC
  - USGS Landsat C2 U.S. ARD Surface Reflectance Products
  - NPS Daily & Monthly Historical Water Balance Model V1.5 Products
  - EMIT L1B and L2A Products
  - VIIRS Version 2 Products



- New Features:
  - Input feature preview: See spatial details of point/area requests immediately after submission
  - Layer Selector—Ability to “Select All” or “Remove All” layers button
  - Changelog: https://appeears.earthdatacloud.nasa.gov/changelog
- Decommissioned MODIS Version 6.0 from AppEEARS
- Coming Soon!:
  - **Integrate ECOSTRESS V2 L3-L4 Products**

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AppEEARS Videos

Overview:

Webinar:

Use Cases Recording:

AppEEARS Area Requests:

AppEEARS Point Requests:

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HOW TO SHARPEN ECOSTRESS LAND SURFACE TEMPERATURE DATA FROM 70m TO 20m using Sentinel-2?

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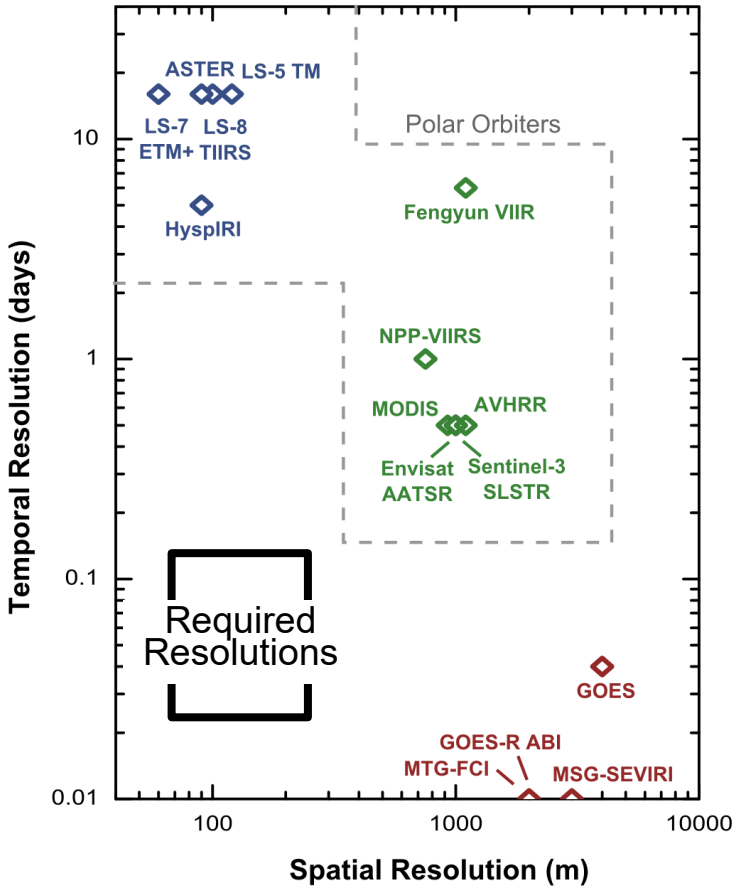
Resolution Trade-off

Satellites **cannot** acquire data that combine high spatial and temporal resolution

We need a spatial resolution of <**50 m** in urban areas

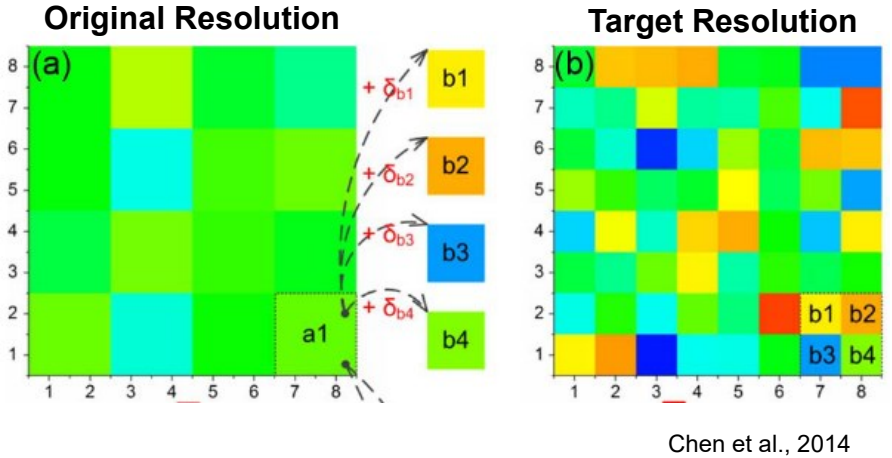
And a temporal resolution of approximately **1-2 h**



LST Downscaling

Statistical downscaling **disaggregates** coarse-scale LST to its components

It uses auxiliary data of **superior** spatial resolution are statistically correlated to the LST



Chen et al., 2014

Vegetation index

Albedo

Surface Reflectance

Topography

Emissivity

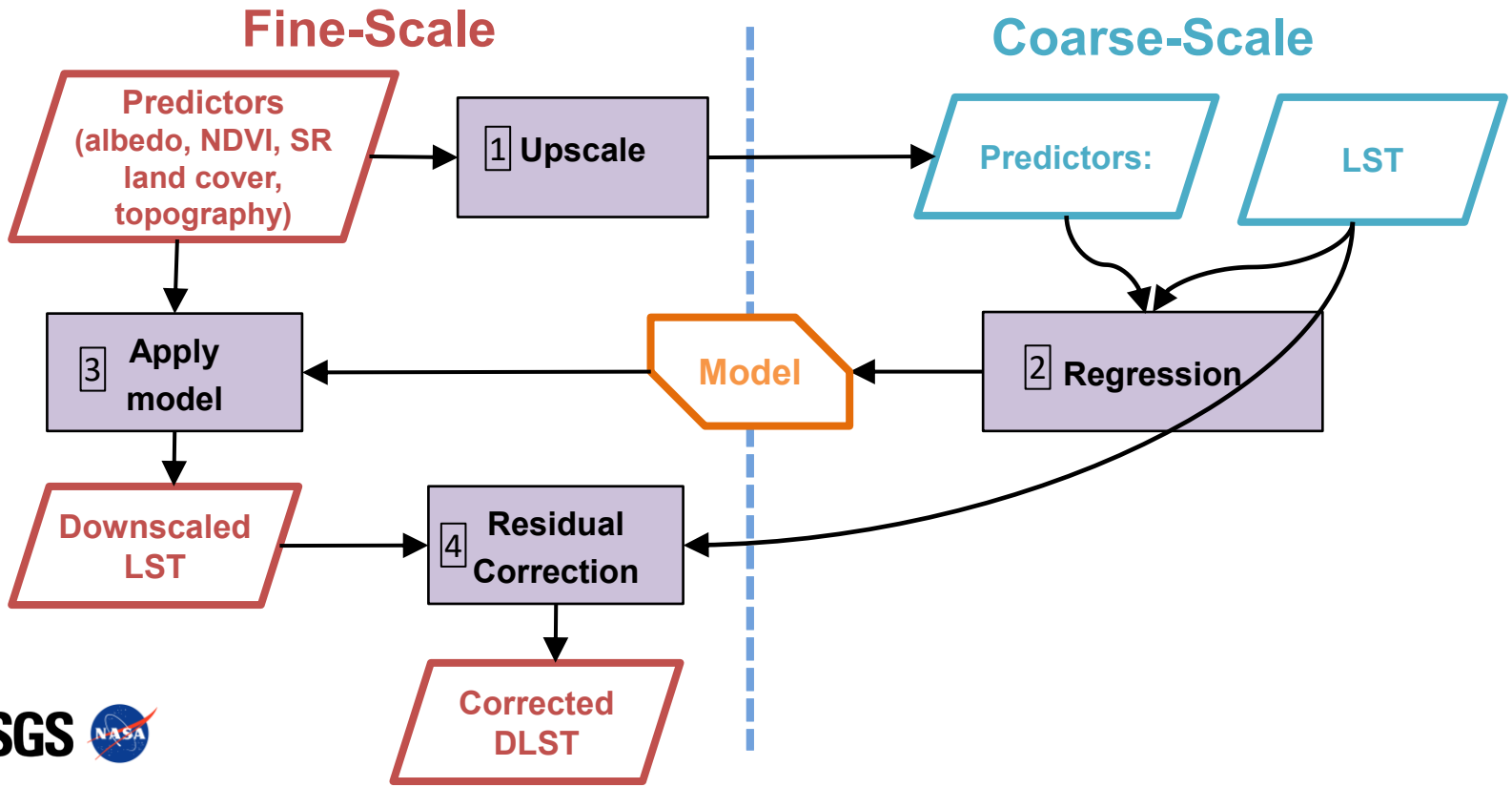
LST predictors

or

LST disaggregation Kernels

USGS NASA

Typical Workflow

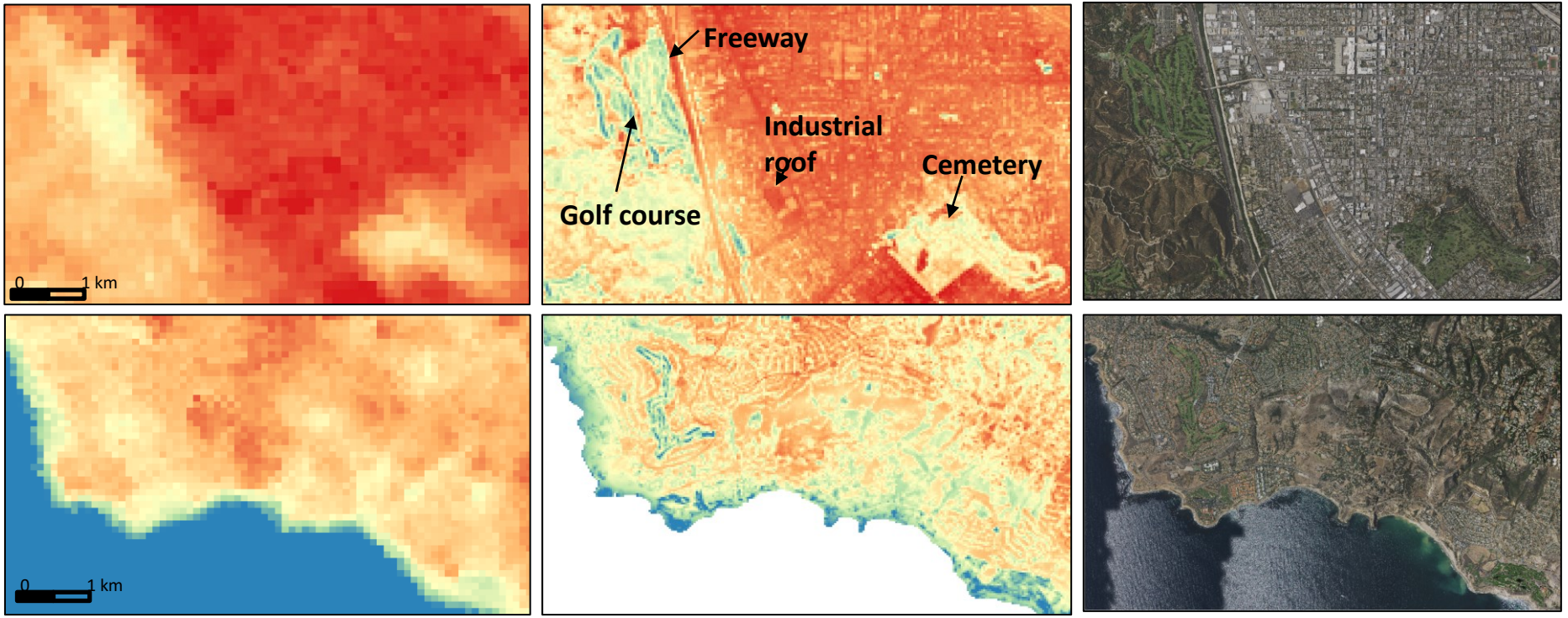


LST Downscaling or ‘thermal sharpening’

ECOSTRESS Land Surface Temperature **(70m)**

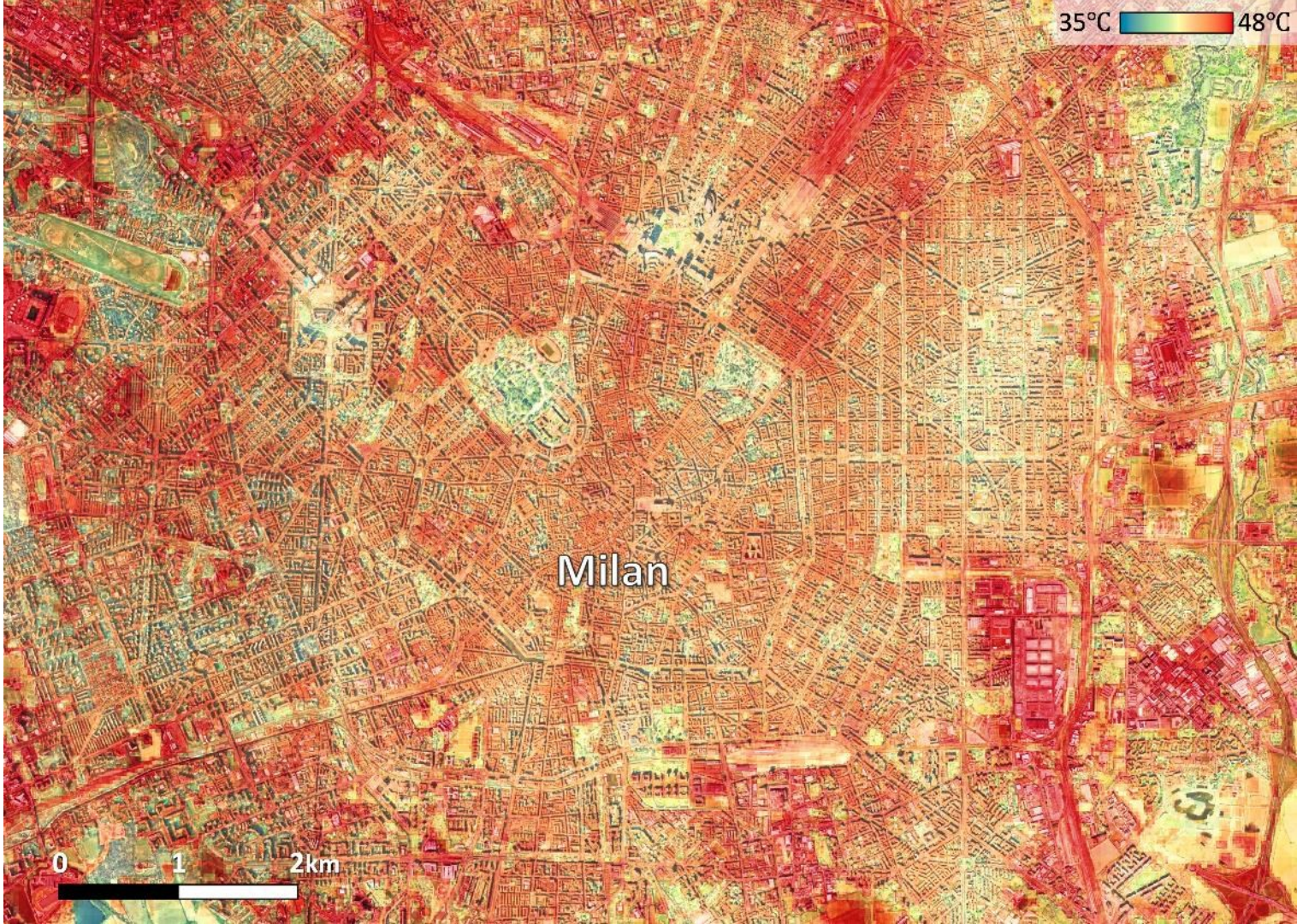
ECOSTRESS Land Surface Temperature **(30m)**

Visible imagery (0.6 m)



ECOSSTRESS LST,
18 June 2022

Milan, Italy
Sharpened using
Sentinel-2 20m
reflectance data



Github Urban-umbrella

ECOSTRESS LST sharpening python jupyter notebook and tutorial readme using Sentinel-2 surface reflectance data

Questions:
Quentin Dehaene:
quentin.dehaene@jpl.nasa.gov

Glynn Hulley
glynn.hulley@jpl.nasa.gov

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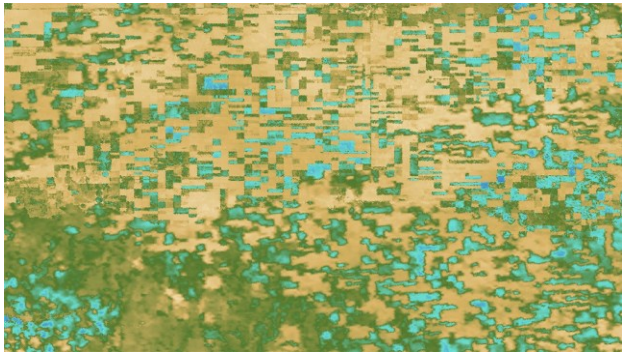
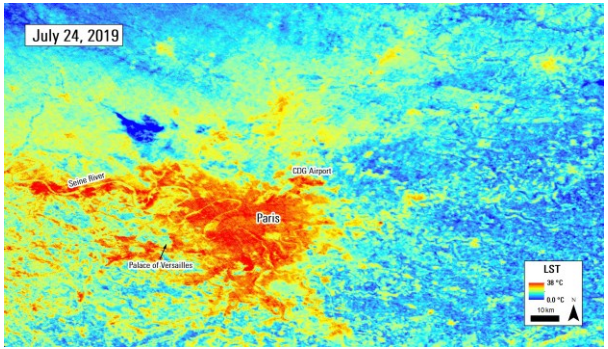
ECOSTRESS Updates

- **Nov 14, 2022:** Released ECOSTRESS V2 Level 1-2 (Swath, Tiled) Products
- **Apr 25, 2023:** Released ECOSTRESS V2 L2 Gridded LSTE and Cloud Mask V2 Products
- **May 18, 2023:** Released ECOSTRESS V2 L2 Gridded and Tiled Radiance Products (2)
- **May 18, 2023:** ECOSTRESS successfully returned to 5-band mode
- **May 2024:** ECOSTRESS V2 L3-L4 Product Release
- ECOSTRESS V1 products available on-prem, V2 products available in the
- ECOSTRESS V1 and V2 (L2) available in AppEEARS (V3-V4 coming Summer 2024!)
- In Progress: Reprocessing Historical Observations to Version 2





Earthdata Search and CMR

- https://www.earthdata.nasa.gov/learn/articles/ed-search_esds
- Webinar on Earthdata Search: https://www.youtube.com/watch?v=QtfMlkd7kII
- https://cmr.earthdata.nasa.gov/search
- Check out the following quick guide for additional instructions on how to Query ECOSTRESS in Earthdata Search: https://lpdaac.usgs.gov/documents/1573/Quick_Guide_for_Accessing_ECOSTRESS_Swath_Data_in_NASA_Earthdata_Search.pdf

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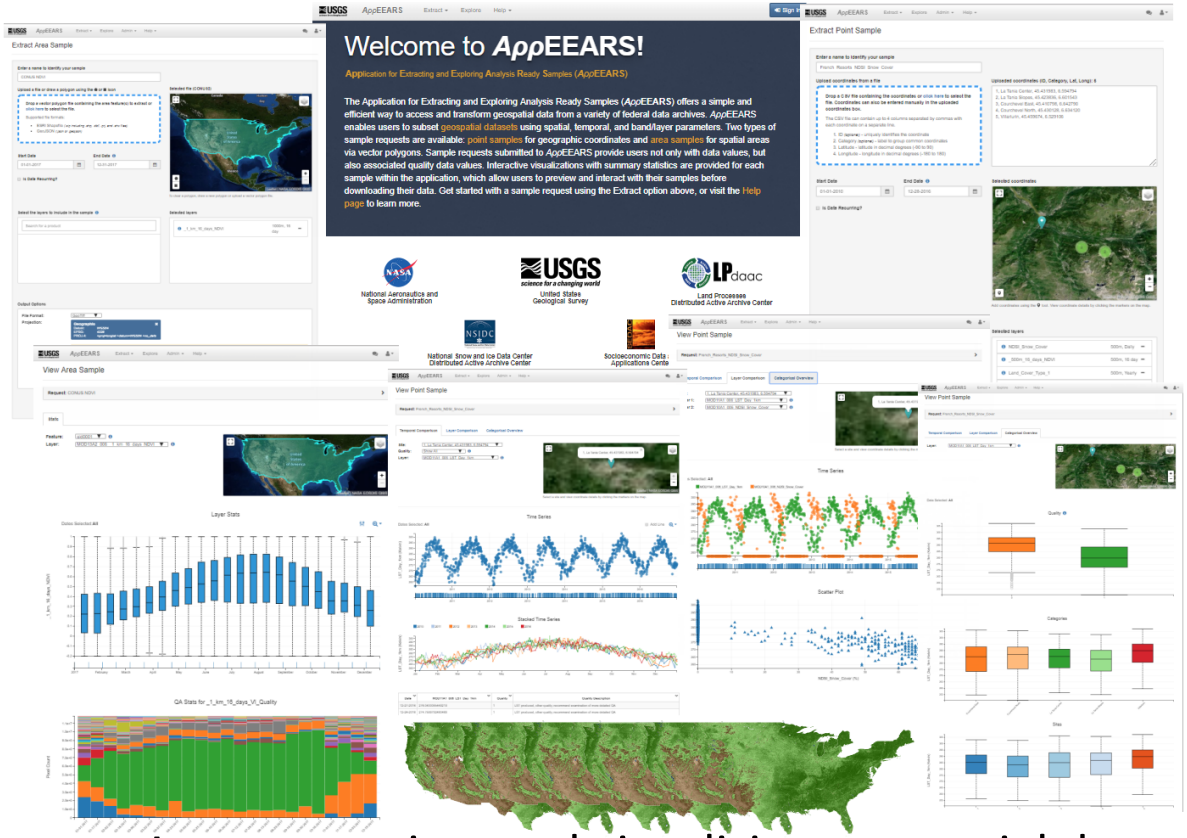
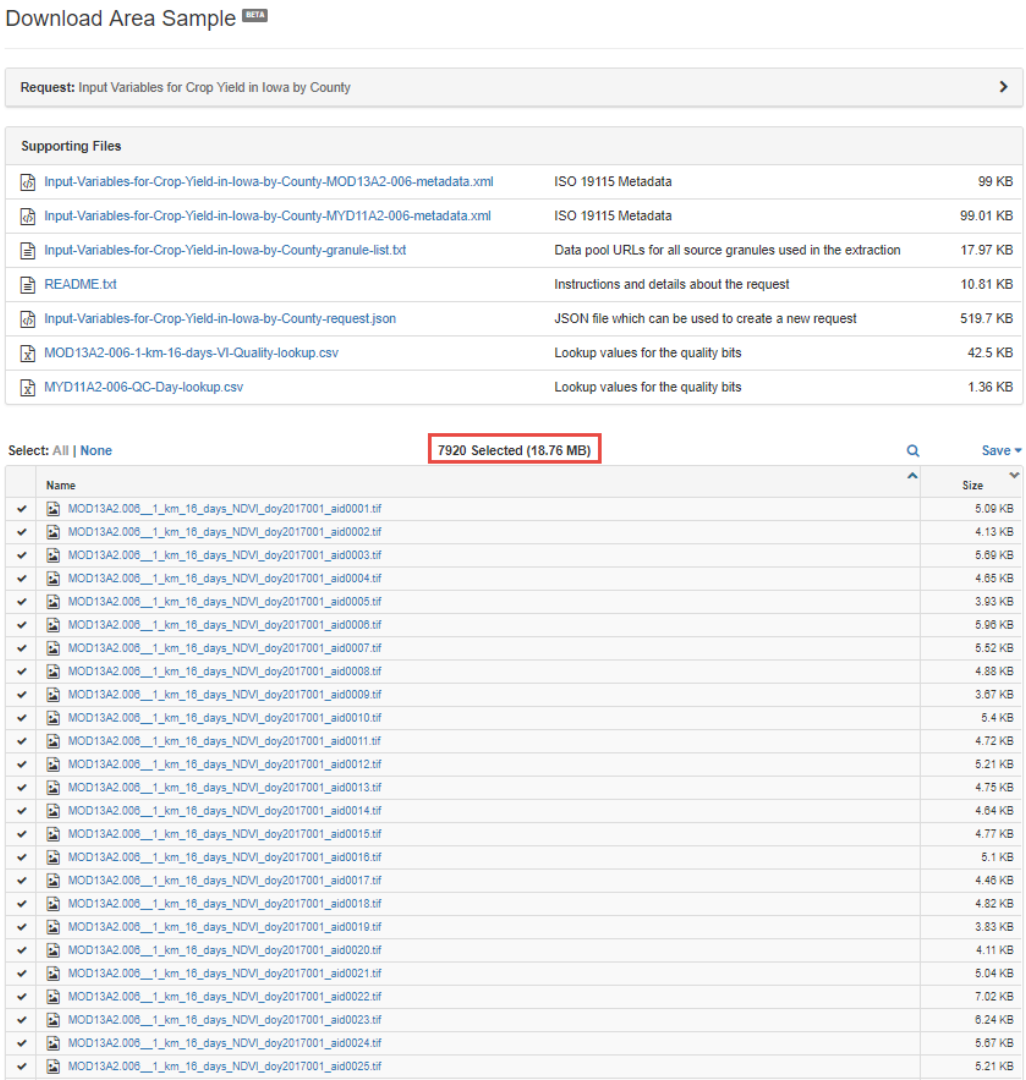
Application for Extracting and Exploring Analysis Ready Samples



Web application interface for accessing, processing, and visualizing geospatial data products that addresses data challenges by…

https://appeears.earthdatacloud.nasa.gov/

- ✓ **Spatial, temporal & band subsetting**
- ✓ **Reprojection & reformatting**
- ✓ **Interactive visualization**
- ✓ **Quality measures apparent & usable**
- ✓ **Interoperability & traceability**
- ✓ **Reduced at-archive data volumes**



Download Area Sample BETA

Request: Input Variables for Crop Yield in Iowa by County

Supporting Files

Input-Variables-for-Crop-Yield-in-Iowa-by-County-MOD13A2-006-metadata.xml	ISO 19115 Metadata	99 KB
Input-Variables-for-Crop-Yield-in-Iowa-by-County-MYD11A2-006-metadata.xml	ISO 19115 Metadata	99.01 KB
Input-Variables-for-Crop-Yield-in-Iowa-by-County-granule-list.txt	Data pool URLs for all source granules used in the extraction	17.97 KB
README.txt	Instructions and details about the request	10.81 KB
Input-Variables-for-Crop-Yield-in-Iowa-by-County-request.json	JSON file which can be used to create a new request	519.7 KB
MOD13A2-006-1-km-16-days-VI-Quality-lookup.csv	Lookup values for the quality bits	42.5 KB
MYD11A2-006-QC-Day-lookup.csv	Lookup values for the quality bits	1.36 KB

Select: All | None — 7920 Selected (18.76 MB) — Save

Name	Size
MOD13A2.006__1_km_16_days_NDVI_doy2017001_aid0001.tif	5.09 KB
MOD13A2.006__1_km_16_days_NDVI_doy2017001_aid0002.tif	4.13 KB
MOD13A2.006__1_km_16_days_NDVI_doy2017001_aid0003.tif	5.69 KB
MOD13A2.006__1_km_16_days_NDVI_doy2017001_aid0004.tif	4.65 KB
MOD13A2.006__1_km_16_days_NDVI_doy2017001_aid0005.tif	3.93 KB
MOD13A2.006__1_km_16_days_NDVI_doy2017001_aid0006.tif	5.96 KB
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MOD13A2.006__1_km_16_days_NDVI_doy2017001_aid0009.tif	3.67 KB
MOD13A2.006__1_km_16_days_NDVI_doy2017001_aid0010.tif	5.4 KB
MOD13A2.006__1_km_16_days_NDVI_doy2017001_aid0011.tif	4.72 KB
MOD13A2.006__1_km_16_days_NDVI_doy2017001_aid0012.tif	5.21 KB
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MOD13A2.006__1_km_16_days_NDVI_doy2017001_aid0014.tif	4.64 KB
MOD13A2.006__1_km_16_days_NDVI_doy2017001_aid0015.tif	4.77 KB
MOD13A2.006__1_km_16_days_NDVI_doy2017001_aid0016.tif	5.1 KB
MOD13A2.006__1_km_16_days_NDVI_doy2017001_aid0017.tif	4.46 KB
MOD13A2.006__1_km_16_days_NDVI_doy2017001_aid0018.tif	4.82 KB
MOD13A2.006__1_km_16_days_NDVI_doy2017001_aid0019.tif	3.83 KB
MOD13A2.006__1_km_16_days_NDVI_doy2017001_aid0020.tif	4.11 KB
MOD13A2.006__1_km_16_days_NDVI_doy2017001_aid0021.tif	5.04 KB
MOD13A2.006__1_km_16_days_NDVI_doy2017001_aid0022.tif	7.02 KB
MOD13A2.006__1_km_16_days_NDVI_doy2017001_aid0023.tif	6.24 KB
MOD13A2.006__1_km_16_days_NDVI_doy2017001_aid0024.tif	5.67 KB
MOD13A2.006__1_km_16_days_NDVI_doy2017001_aid0025.tif	5.21 KB

USGS NASA

Available Products

EOSDIS
NASA'S EARTH OBSERVING SYSTEM DATA & INFORMATION SYSTEM

- Terra, Aqua, Combined MODIS Land Products
- S-NPP and NOAA-20 NASA VIIRS Land Products
- ASTER GDEM, NASADEM, SRTM DEMs
- MEaSUREs GEOLST
- ECOSTRESS
- Harmonized Landsat Sentinel-2 (HLS)
- EMIT Hyperspectral Radiance & Reflectance

LP daac
EARTHDATA CLOUD

ORNL DAAC
DISTRIBUTED ACTIVE ARCHIVE CENTER FOR BIOGEOCHEMICAL DYNAMICS

- Daymet Gridded Estimates of daily weather parameters

NSIDC
National Snow and Ice Data Center

- Terra and Aqua MODIS Snowcover Products
- Soil Moisture Active Passive (SMAP) Soil Moisture

SEDAC

- Gridded Population of the World

USGS
science for a changing world
aws

- Landsat C2 ARD Surface Reflectance

NATIONAL PARK SERVICE

National Park Service
- Historical Water Balance Model

aws

Data Access Made Simple
AppEEARS
Application for Extracting and Exploring Analysis Ready Samples
a NASA EARTH DATA Application
NASA

Use Case: AppEEARS Area Request

- Combining Species Abundance data with Remote Sensing Data-derived Environmental Descriptors using AppEEARS

Coops, N. C., Wulder, M. A., & Iwanicka, D. (2009) (RSE)
https://doi.org/10.1016/j.rse.2008.11.012

USGS NASA

Exploring the relative importance of satellite-derived descriptors of production, topography, and land cover for predicting breeding bird species richness in Ontario, CA

WHAT: Study investigated the predictive power of remote sensing-derived environmental descriptors of land cover and productivity to predict species richness of breeding birds

WHERE: Ontario, CA: 10x10 km grid (Ontario Breeding Bird Atlas (OBBA) units)

WHY: Map current patterns of species richness and environmental factors to understand relationship and impacts of changes

WHEN: 2001-2005

HOW: Derived environmental descriptors from remote sensing data and species richness counts from OBBA to analyze predictive power on species richness using a decision tree approach

FINDINGS: Variance in distributions of species richness well predicted by environmental descriptors (esp. land cover (richness) & veg. productivity (# species))

- Results indicate that remotely sensed environmental descriptors provide an effective tool for predicting bird species richness at regional scales

- Coops, N. C., Wulder, M. A., & Iwanicka, D. (2009) (RSE) https://doi.org/10.1016/j.rse.2008.11.012

USGS NASA

Combining Species Abundance data with Remote Sensing Data-derived Environmental Descriptors

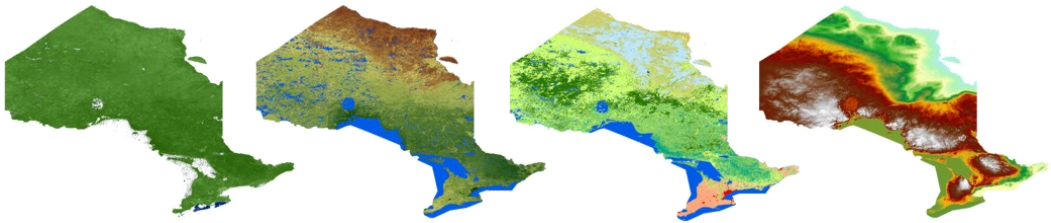
- **Research Question:**
  - How can AppEEARS be used to generate remote sensing-derived environmental descriptors for predicting species richness?

- **Goal:**
  - Access remotely sensed data that can be used to derive environmental descriptors for use in species richness studies without:
    - (1) downloading the source data for the remote sensing datasets
    - (2) needing to open remote sensing software

USGS NASA

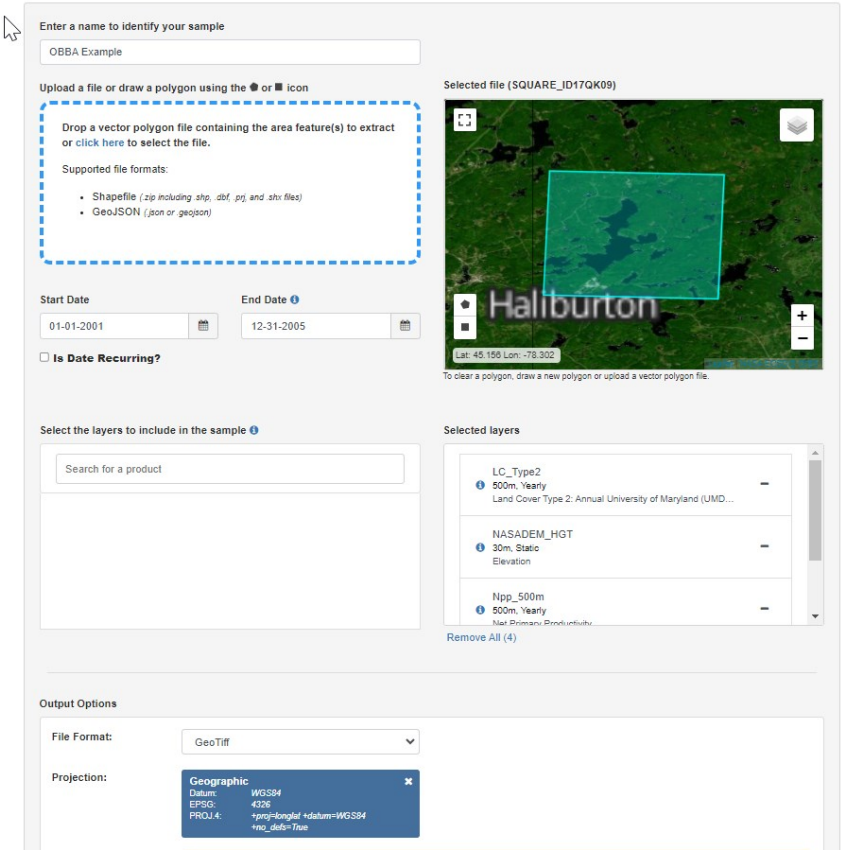
Data Product	Temporal Extent	Temporal Resolution	Spatial Resolution	Layer Name	Description	Units	Environmental Descriptors:
Vegetation Indices (MOD13A3.061)	2000-Present	Monthly	1000 m	_1_km_monthly_NDVI	Monthly NDVI average	NDVI	Minimum Level of Perennial Cover, Degree of Veg Seasonality
Net Primary Production (MOD17A3HGF.061)	2000-2014	Annual	500 m	Npp_500m	Gridded 1 km Annual Net Primary Productivity	Kg C/m^2	Total Annual Productivity
Land Cover Type (MCD12Q1.061)	2001-2016	Annual	500 m	LC_Type2	Land Cover Type 2: Annual UMD Classification	Class	Dominant Land Cover Class, Land Cover Dominance, Richness of Land Cover Classes
Digital Elevation Model (NASADEM_NC.001)	2000's	Static	30 m	DEM	Elevation	m	Topographic Coefficient of Variation

Products Accessed



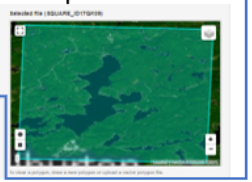
AppEEARS Request Parameters

- Spatial Subset: Shapefile containing 10x10 km OBBA Tile
- Temporal Subset: 2001-2005
- Layer Subset:
  - Vegetation Indices (MOD13A3.061)
    - _1_km_monthly_NDVI
  - Net Primary Production (MOD17A3HGF.061)
    - Npp_500m
  - Land Cover Type (MCD12Q1.061)
    - LC_Type2
  - Digital Elevation Model (NASADEM_NC.001)
    - DEM
- Format:
  - File Format: GeoTIFF
  - Projection: Geographic



AppEEARS Step-by-Step Instructions:

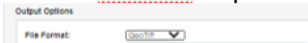
1. Define ROI via shapefile/geojson or draw a polygon in the map



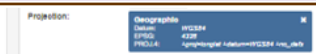
2. Set time period of interest

3. Search for products and subset layers

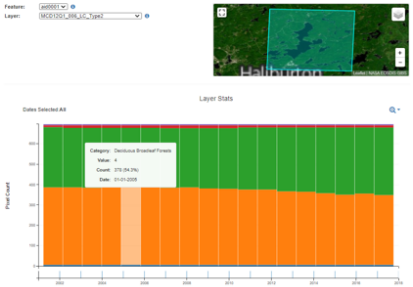
4. Pick .nc4 or GeoTIFF output file format



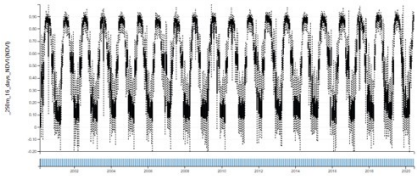
5. Select common output projection

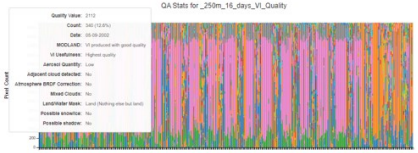


Visualize: Bar Chart Time Series for Categorical Variables (Land Cover)



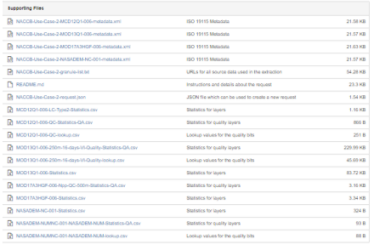
Boxplot Time Series for Continuous Variables (NDVI)



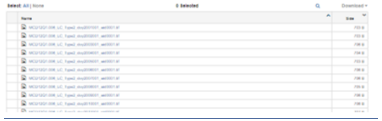


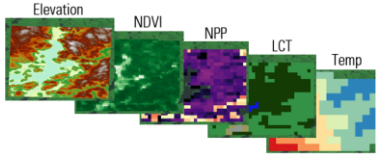
Decoded quality information

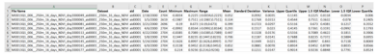
Download: readme, metadata, summary stats, json of request params, quality csv



Output files, including bulk downloads







Environmental Descriptors for OBBA Tile (2001-2005)

- Dominant Land Cover Class: (4) Deciduous Broadleaf Forests
- Land Cover Dominance: 54.37%
- LCT Richness: 5 (land cover classes present in tile)
- Topographic Coefficient of Variation: 8.544516163
- Total Annual Productivity (NPP): 0.5552 kg C/m^2
- Minimum Level of Perennial Cover (NDVI): 0.00424
- Degree of Vegetation Seasonality (CV): 19.17308619

https://git.earthdata.nasa.gov/projects/LPDUR/repos/naccb/browse

USGS NASA

Use Case: AppEEARS Point Sampler

- Tracking Deer Counts from Trail Cam-based Citizen Science and linking with vegetation, snow cover, and temperature data extracted from AppEEARS

https://science.nasa.gov/earth-science/applied-sciences/making-space-for-earth/wisconsin-wildlife-says-cheese

USGS NASA

Citizen Science Project: Snapshot Wisconsin

WHAT: Combining Whitetail Deer frequency data with environmental metrics such as land surface temperature, snow cover, and vegetation greenness to predict species richness for a given location

WHERE: U.S. State of Wisconsin

WHY: Assess # of deer in WI to aid wildlife management decisions

WHEN: 2010-Present

HOW: Citizen Science Project: Snapshot Wisconsin

- 1,700 volunteers maintaining over 2,100 trail cameras
- Collecting 42 million images
- Crowd-sourced image classification
- Combined with satellite data from MODIS

USGS NASA

Combining Species Abundance Data with Remote Sensing Data-derived Environmental Descriptors

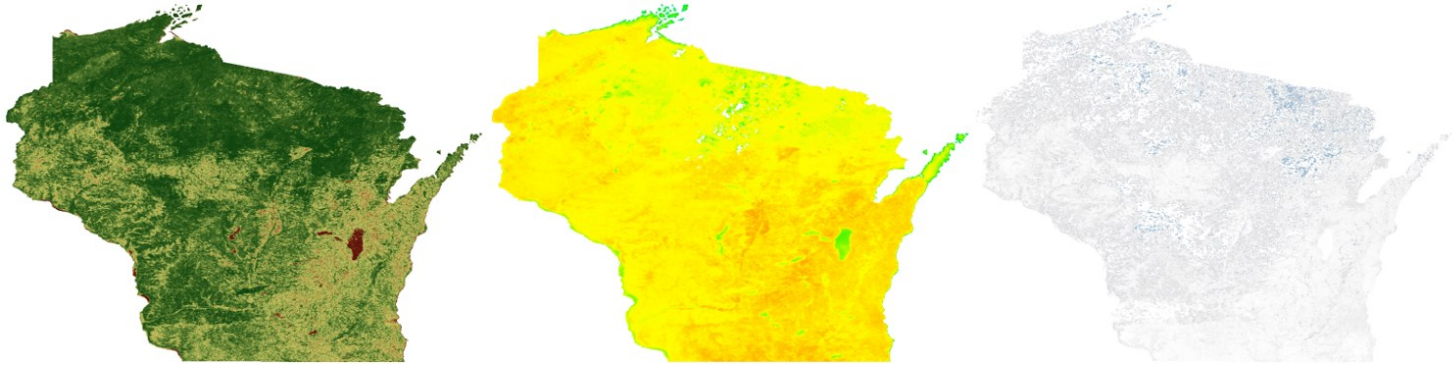
- **Research Question:**
  - How can AppEEARS be used to generate remote sensing-derived environmental descriptors for predicting species richness and behavior for point locations?

- **Goal:**
  - Access remotely sensed data that can be used to derive environmental descriptors for use in species richness studies without:
    - (1) downloading the source data for the remote sensing datasets
    - (2) needing to open remote sensing software

USGS NASA

Products Used

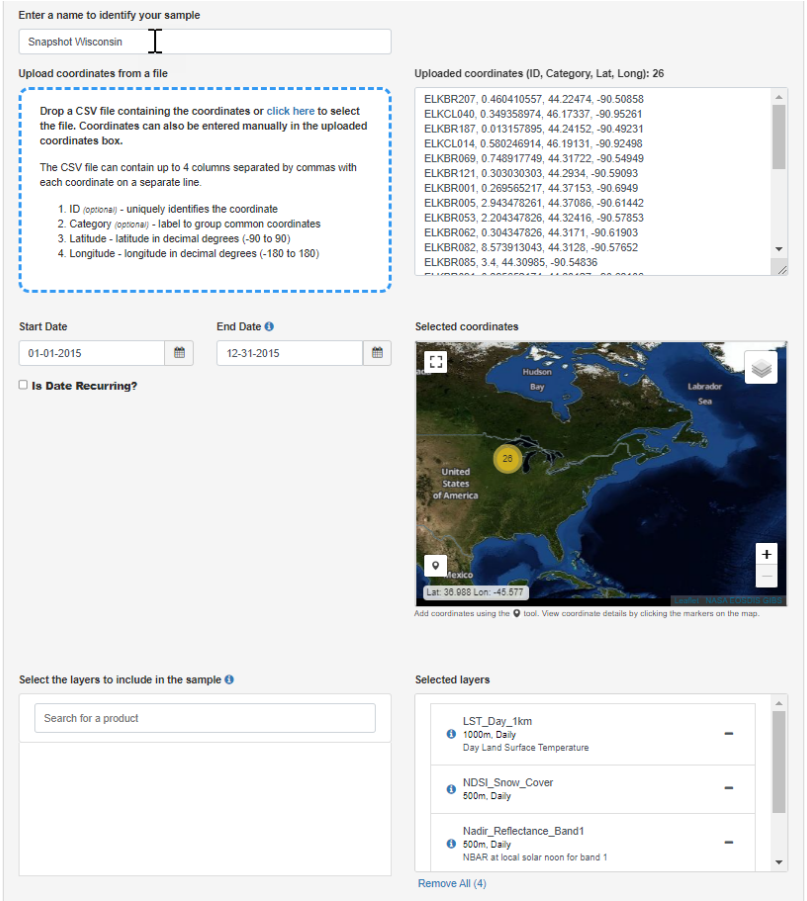
Data Product	Temporal Extent	Temporal Resolution	Spatial Resolution	Layer Name	Description	Units	Environmental Descriptors:
NBAR Surface Reflectance (MCD43A4.061)	2000-Present	Daily	500 m	Nadir_Reflectance_Band1Nadir_Reflectance_Band2	NBAR at local solar noon	Ref	Daily NDVI
Land Surface Temperature (MOD11A1.061)	2000-Present	Daily	1000 m	LST_Day_1km	Daytime Land Surface Temperature	K	Daily Max Temp
Snow Cover (MOD10A1.061)	2000-Present	Daily	500 m	NDSI_Snow_Cover	NDSI snow cover	%	Percent Snow Cover



USGS NASA

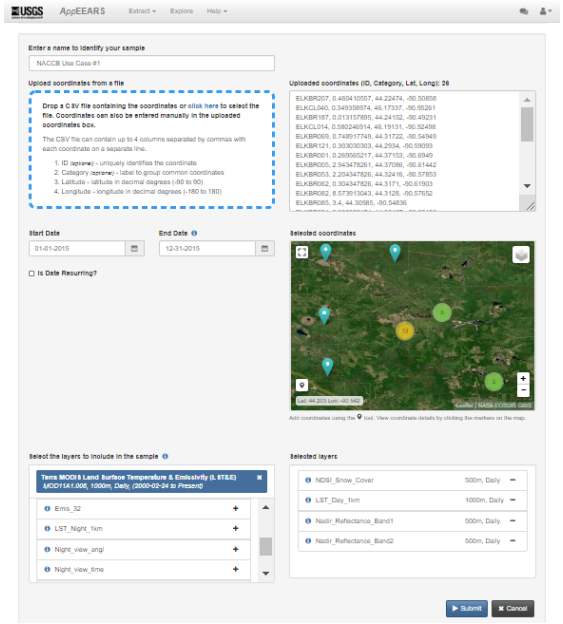
AppEEARS Request Parameters

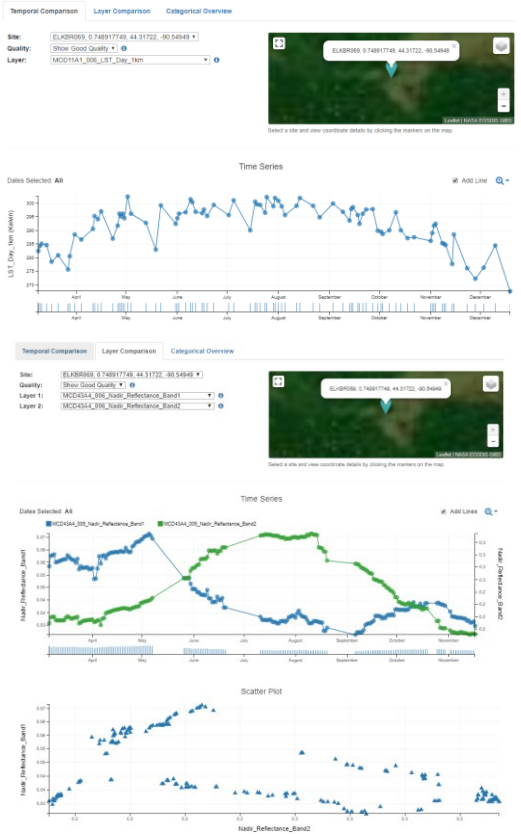
- **Spatial Subset:**
  - CSV file containing lat/lon locations of trail cameras throughout Wisconsin
- **Temporal Subset:**
  - Jan 1 to December 31, 2015 (one season)
- **Layer Subset:**
  - MODIS NBAR Surface Reflectance (MCD43A4.006)
    - Nadir_Reflectance_Band1
    - Nadir_Reflectance_Band2
  - MODIS Land Surface Temperature (MOD11A1.006)
    - LST_Day_1km
  - MODIS Snow Cover (MOD10A1.006)
    - NDSI_Snow_Cover

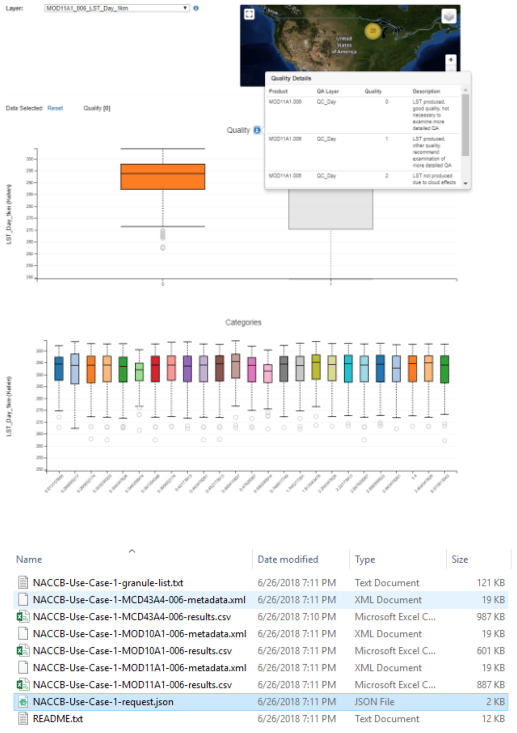


AppEEARS Step by Step

https://git.earthdata.nasa.gov/projects/LPDUR/repos/naccb/browse





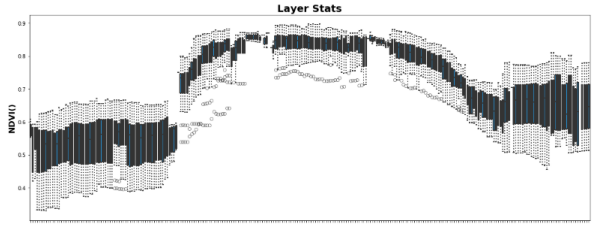


Name	Date modified	Type	Size
NACCB-Use-Case-1-granule-list.txt	6/26/2018 7:11 PM	Text Document	121 KB
NACCB-Use-Case-1-MCD43A4-006-metadata.xml	6/26/2018 7:11 PM	XML Document	19 KB
NACCB-Use-Case-1-MCD43A4-006-results.csv	6/26/2018 7:10 PM	Microsoft Excel C...	987 KB
NACCB-Use-Case-1-MOD10A1-006-metadata.xml	6/26/2018 7:11 PM	XML Document	19 KB
NACCB-Use-Case-1-MOD10A1-006-results.csv	6/26/2018 7:11 PM	Microsoft Excel C...	601 KB
NACCB-Use-Case-1-MOD11A1-006-metadata.xml	6/26/2018 7:11 PM	XML Document	19 KB
NACCB-Use-Case-1-MOD11A1-006-results.csv	6/26/2018 7:11 PM	Microsoft Excel C...	887 KB
NACCB-Use-Case-1-request.json	6/26/2018 7:11 PM	JSON File	2 KB
README.txt	6/26/2018 7:11 PM	Text Document	12 KB

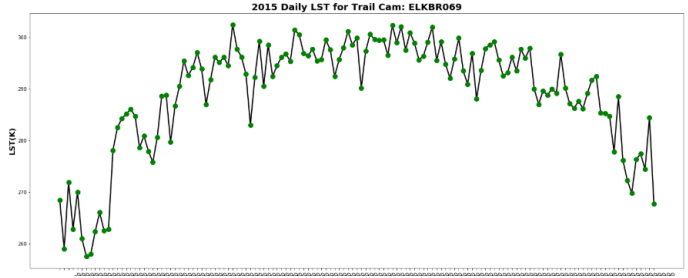
R Script for Additional Analysis

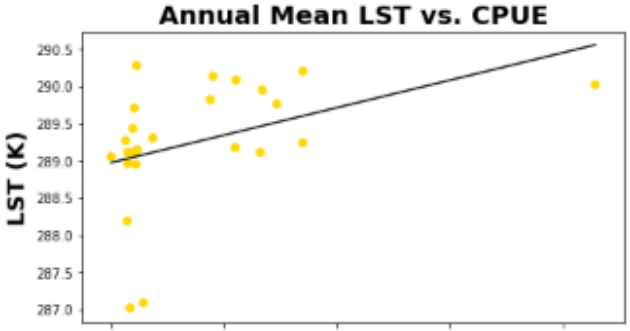
7. Calculate Normalized Difference Vegetation Index (NDVI)

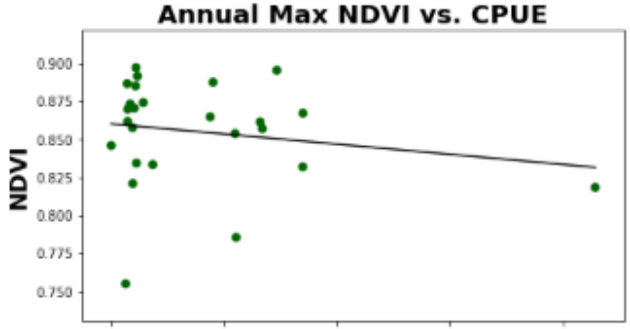
```
In [103]: # Write a function to calculate NDVI from Red & NIR Reflectance
          def calc_NDVI(x, y):
              return (x - y) / (x + y) # NDVI = (NIR - Red)/(NIR + Red)

In [109]: # Call the NDVI function on the SR data
          cNDVI = calc_NDVI(sr["MCD43A4_006_Nadir_Reflectance_Band2"], sr["MCD43A4_006_Nadir_Reflectance_Band1"])

In [171]: # Boxplot Time Series
          fig = plt.figure(1, figsize=(20, 7.5))              # Set the figure size
          ax = fig.add_subplot(111)                           # Create a subplot
          box = ax.boxplot(NDVIAll[4:] , patch_artist=True);  # Boxplot of quality-filtered croplands-only data for 1st 12 layers (2008)
          # Set boxplot attributes similar the AppEEARS UI
          for b in box['boxes']: b.set( color='#333333', linewidth=2), b.set(facecolor='#2794D8')  # Set box outline and fill color
          for m in box['medians']: m.set(color='#333333', linewidth=2)                             # Set color/linewidth of medians
          for w in box['whiskers']: w.set(color='#333333', linewidth=2), w.set_linestyle(':')      # Set color/linewidth of whiskers
          for c in box['caps']: c.set(color='#333333', linewidth=2)                                # Set color/linewidth of caps
          for f in box['fliers']: f.set(marker='o', color='#cccccc', alpha=0.5)                    # Set the style of fliers
          ax.set_xticklabels(sorted(NDVI['Date'].unique()[4:]),fontsize=14, fontweight='bold', rotation=45)
          ax.set_xlabel('Date', fontsize=16, fontweight='bold')                                    # Add label to x-axis
          ax.set_ylabel("{}({})".format(layerId, units), fontsize=16, fontweight='bold')           # Add label/units to y-axis
          ax.set_title('Layer Stats', fontsize=20, fontweight='bold');                             # Add title
```

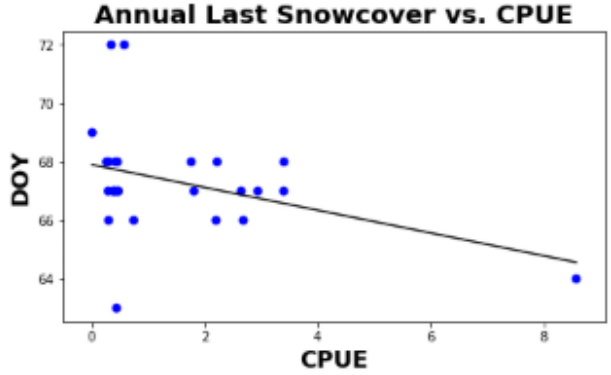



```
In [259]: lst['LST'][lst['TrailCam'] == "ELKBR069"]                                              # Plot LST for single trail cam
          layerId, units = 'LST', 'K'
          fig = plt.figure(1, figsize=(25, 10))                                                  # Set the figure size
          ax = fig.add_subplot(111)                                                              # Create a subplot
          ax.plot(list(lst['LST'][lst['TrailCam'] == "ELKBR069"]), 'k', lw=2.5, color='black')   # Plot as a black line
          ax.plot(list(lst['LST'][lst['TrailCam'] == "ELKBR069"]), 'bo', ms=10, color='green')   # Plot as a green circle
          ax.set_xticks((np.arange(0,len(lst['LST'][lst['TrailCam'] == "ELKBR069"])))            # Arrange x ticks
          ax.set_xticklabels(lst['Date'][lst['TrailCam'] == "ELKBR069"], rotation=45,fontsize=12) # Set x tick labels
          ax.set_xlabel('Date',fontsize=16,fontweight='bold')                                    # Set x-axis label
          ax.set_ylabel("{}({})".format(layerId, units),fontsize=16,fontweight='bold')           # Set y-axis label
          ax.set_title('2015 Daily LST for Trail Cam: ELKBR069',fontsize=20,fontweight='bold');  # Set title
```









https://git.earthdata.nasa.gov/projects/LPDUR/repos/scgis-workshop/browse/NACCB_UseCase.R

AppEEARS API

- Documentation: https://appeears.earthdatacloud.nasa.gov/api/
  - Available in Python, R, cURL

- Tutorials: https://lpdaac.usgs.gov/resources/e-learning/appeears-data-resources/
  - Available in Python and R

USGS NASA

ECOSTRESS

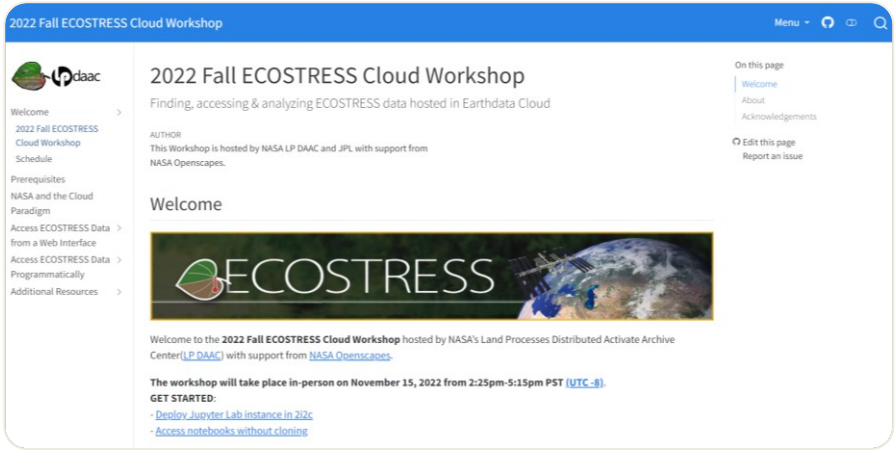
github.com/nasa/ECOSTRESS-Data-Resources

Repository Contents

Content in this repository includes Python tutorials, how-tos, scripts, defined modules that will be called from the Python resources, and setup instructions. The supporting files for use cases are stored in `Data` folder.

> Resources stored in this repository are listed below:

Repository Contents	Type	Summary
ECOSTRESS_Tutorial.ipynb	Jupyter Notebook	Demonstrates how to work with the ECOSTRESS Evapotranspiration PT-JPL Daily L3
ECOSTRESS_swath2grid.py	Command line executable	Demonstrates how to converts ECOSTRESS swath data products into projected GeoTIFFs



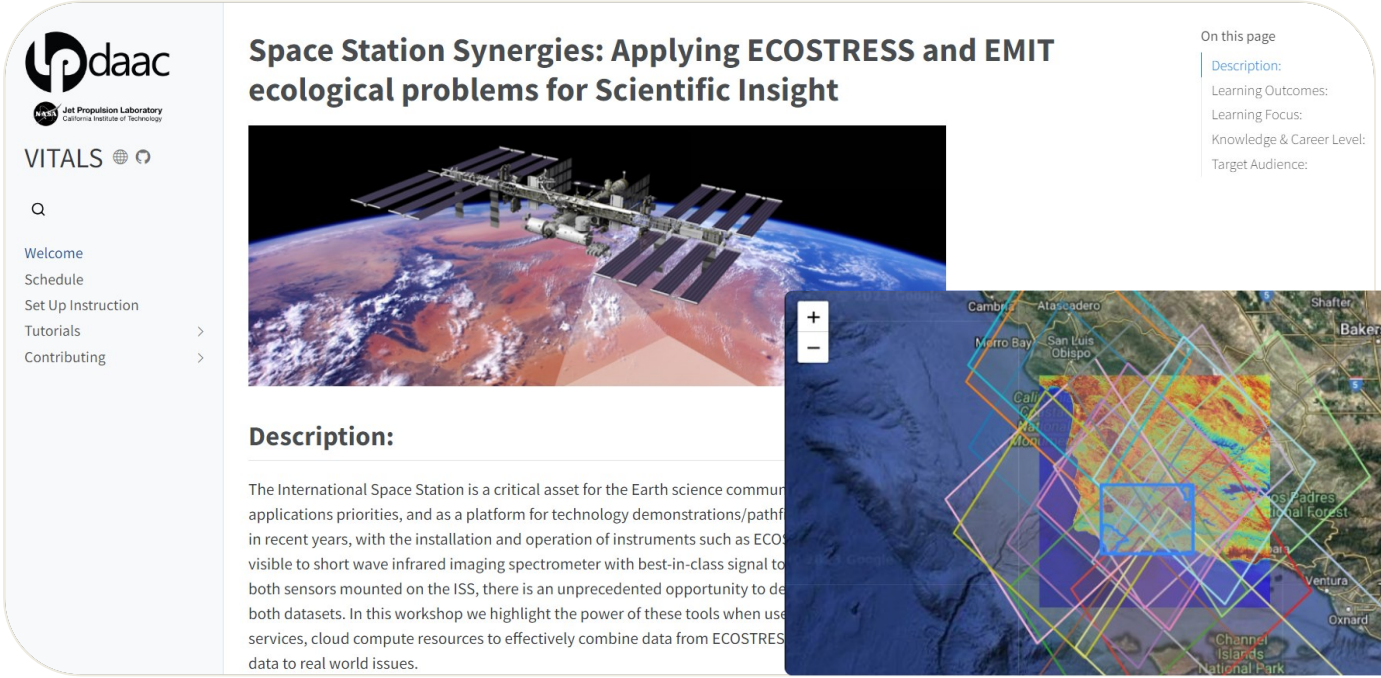
USGS NASA

VITALS Web Book

Repo: https://github.com/nasa/VITALS
Web Book: https://nasa.github.io/VITALS/

VSWIR **I**maging and **T**hermal **A**pplications, **L**earning, and **S**cience GitHub Repo

Resources from the "*Space Station Synergies: Applying ECOSTRESS and EMIT Data to Ecological Problems for Scientific Insight*" AGU Workshop



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