

Time Series & Multidimensional Definitions

Alberto Meroni

Session agenda

Introduction to
multidimensional raster

Visualization

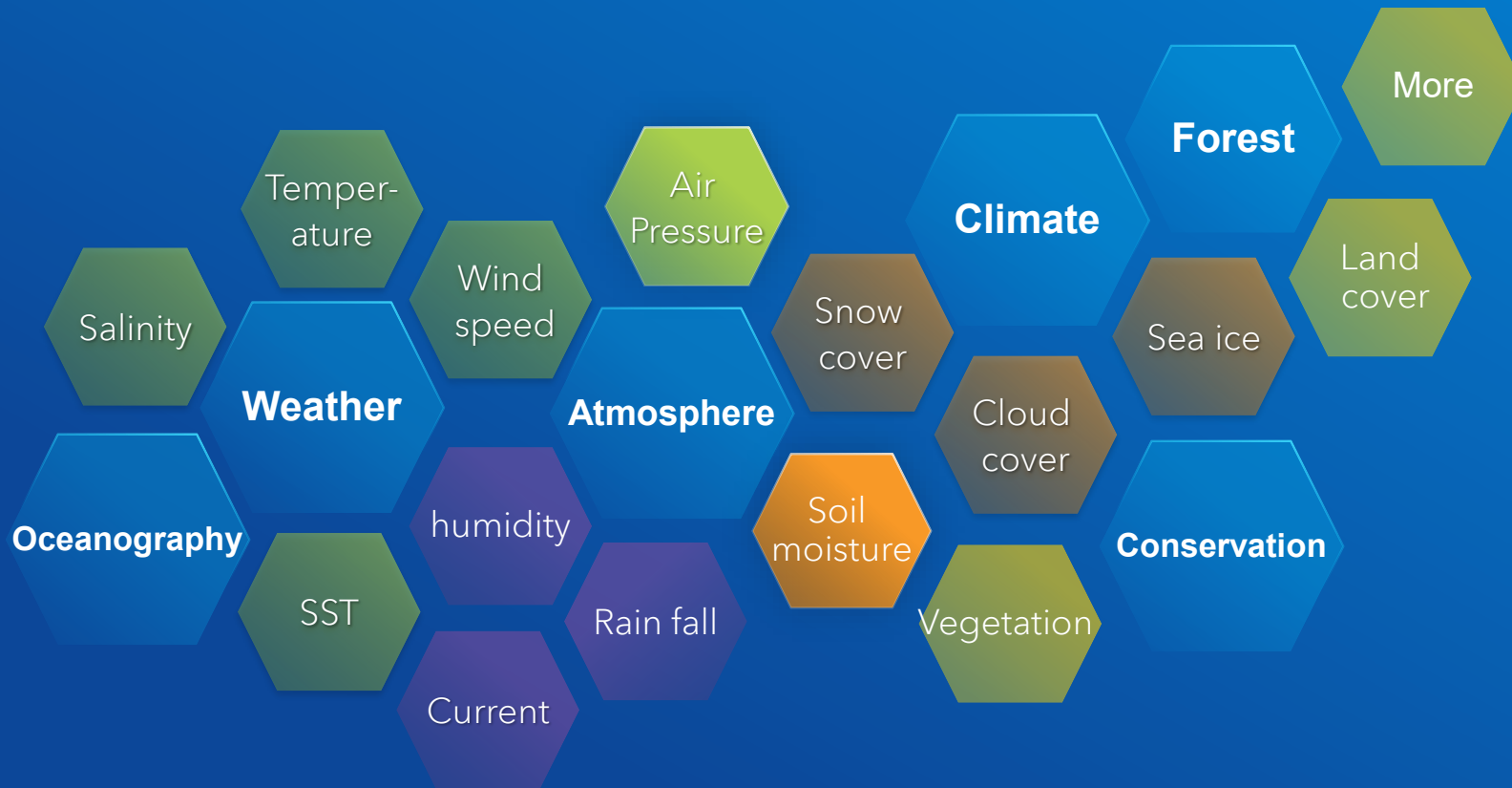
Creating Data cubes

Analysis

Q&A

What is multidimensional data?

Geospatial data of our earth over time



Detect changes

Find anomalies

Explore trends

Predict and forecast

How is multidimensional raster stored?

A multidimensional raster is also called image/data cube

- Formats

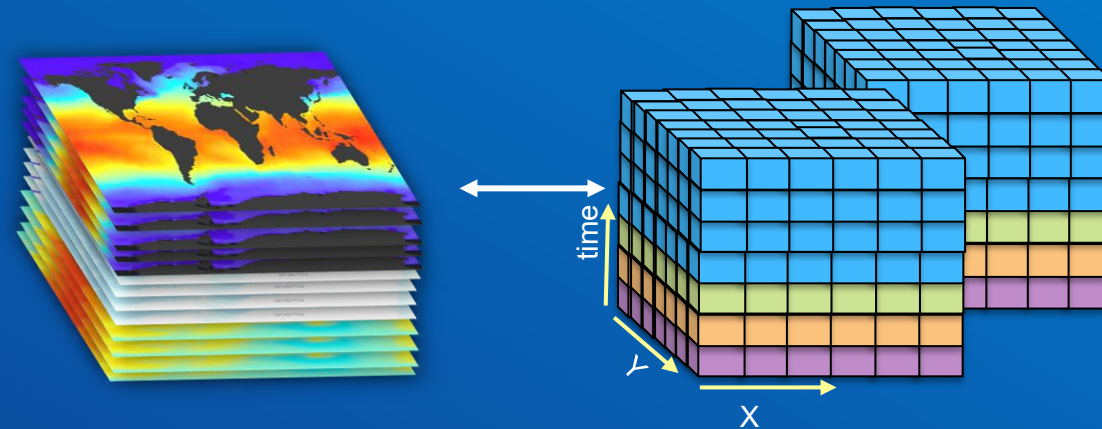
- netCDF, GRIB, HDF, Zarr, OPeNDAP
- Multidimensional CRF and multidimensional mosaic dataset

- Multiple variables

- Temperature
- Surface height
- etc.

- Multiple dimensions

- (Time, Depth/Height/Pressure, Lat, Lon)
- (Time, Lat, Lon)



Multidimensional capabilities in ArcGIS

ArcGIS Pro, ArcGIS Enterprise, and ArcGIS Online

Visualization

Data
Management

Analysis



Visualization and Exploration

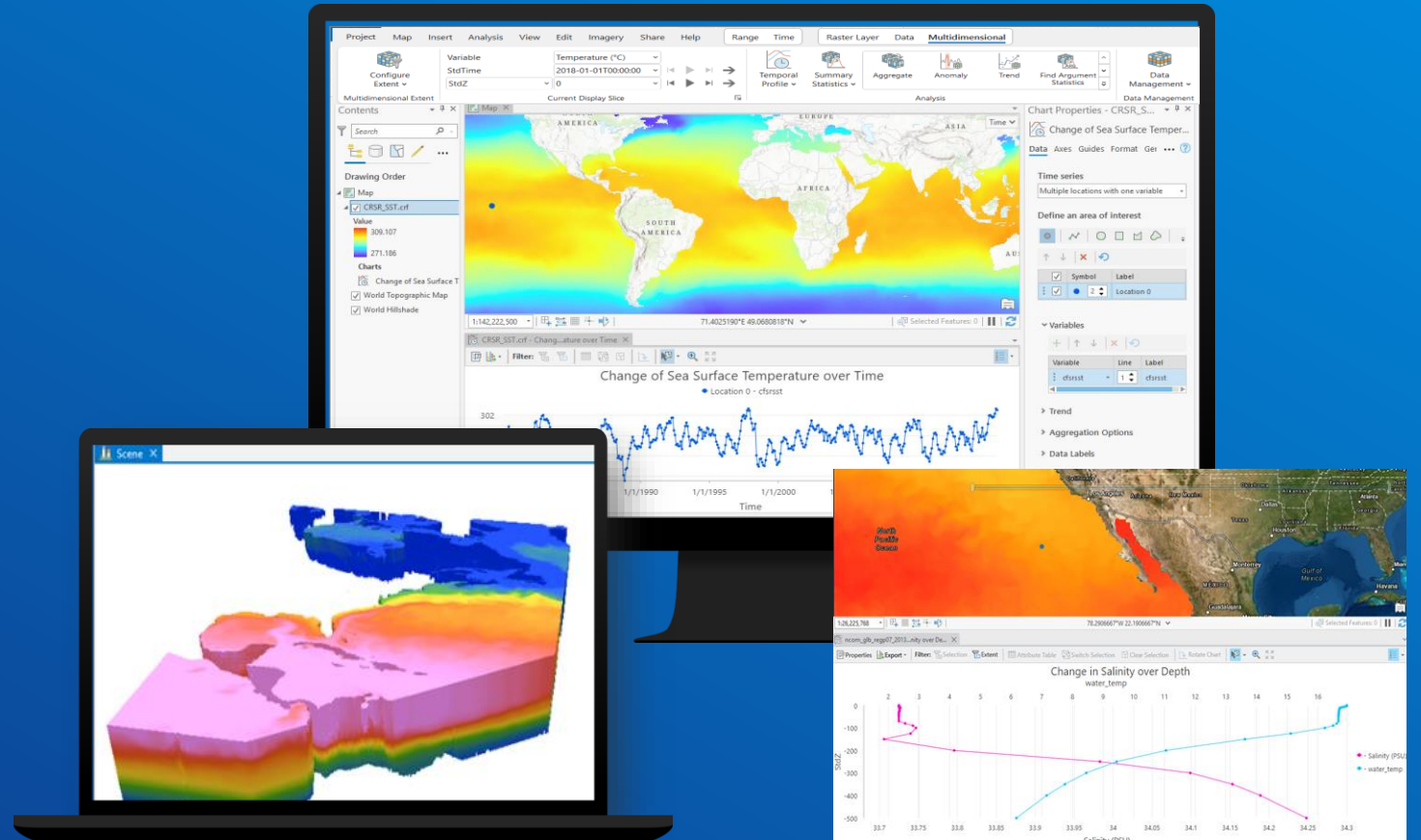


Multidimensional raster visualization in ArcGIS Pro

Slicing, extracting pixel time series, 3D volumes, and animation

- Multidimensional tab
- Temporal profile
- Dimension profile
- Animation
- Voxel layer

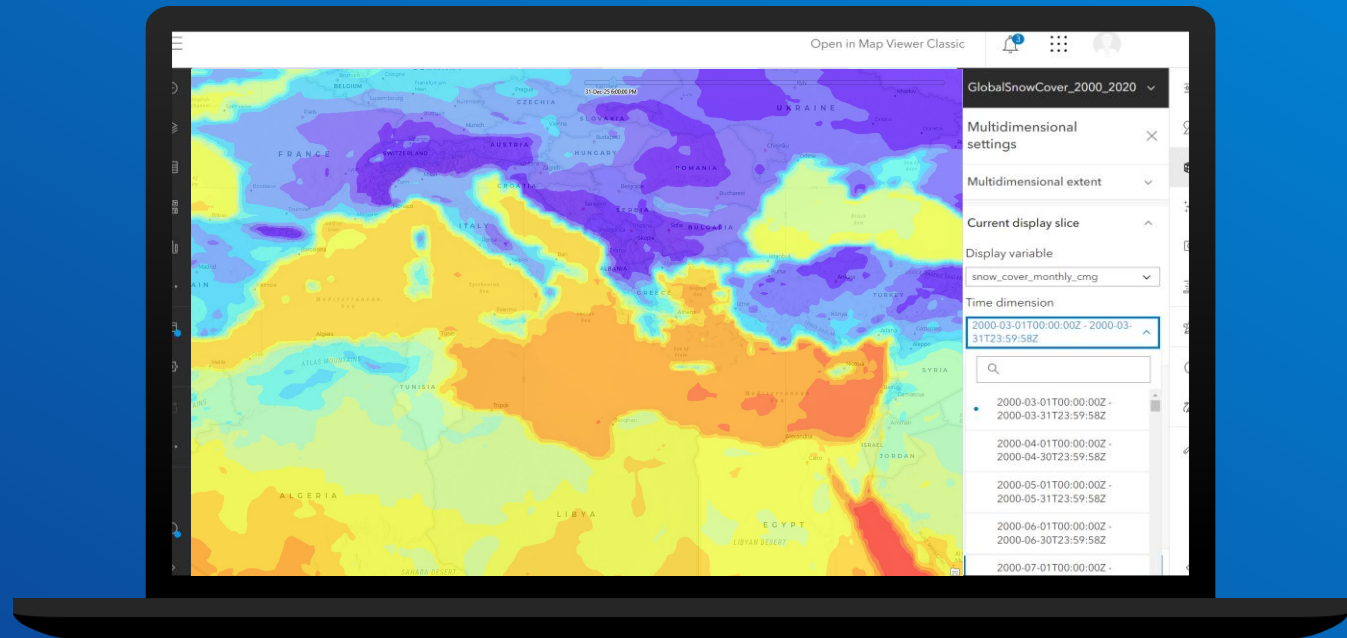
- 4D+ support
- Symbology per variable
- Surface Profile



Visualizing multidimensional imagery layer

Multidimensional raster in the web

- Use ArcGIS Pro as a client
- Web Map Viewer
 - Multidimensional tool on layer panel
 - Dimension slider
 - Time slider

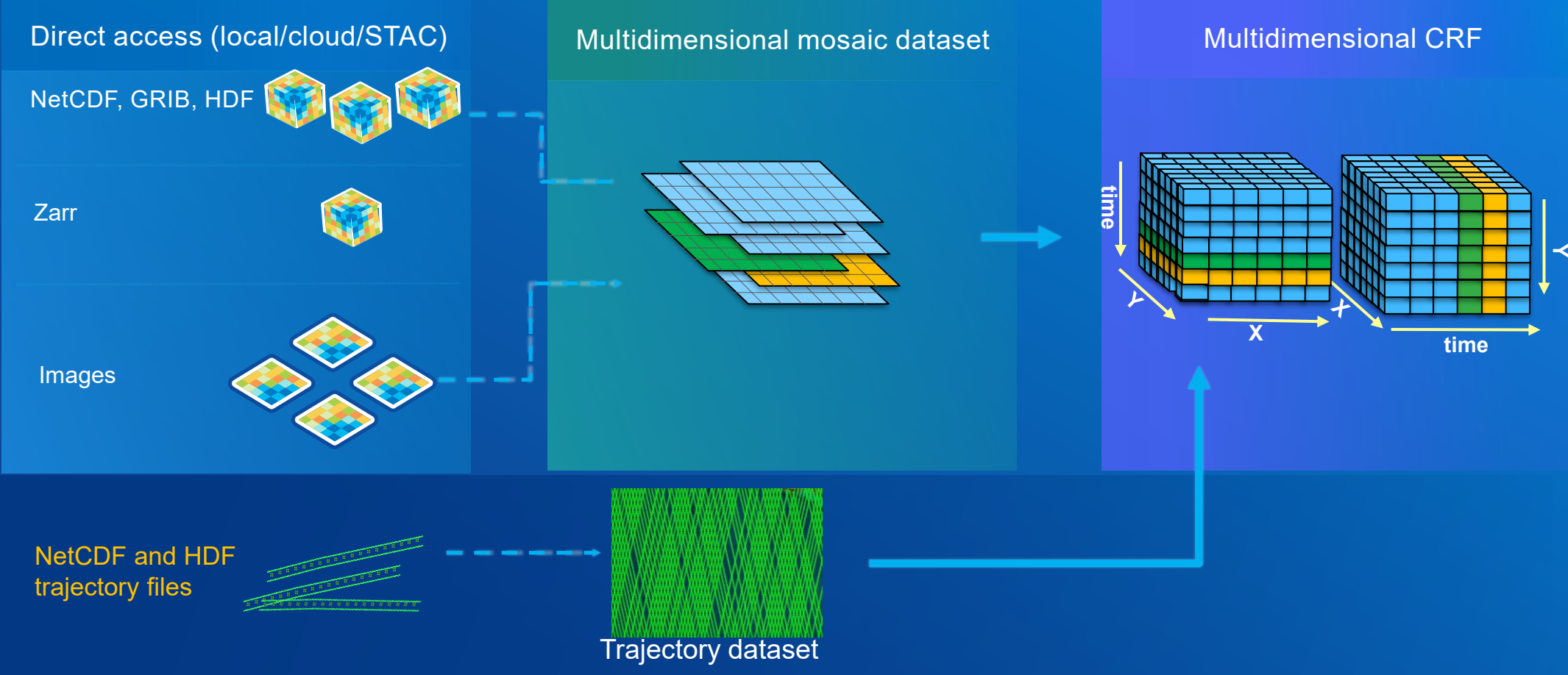


Create Multidimensional Raster



Create Multidimensional Raster

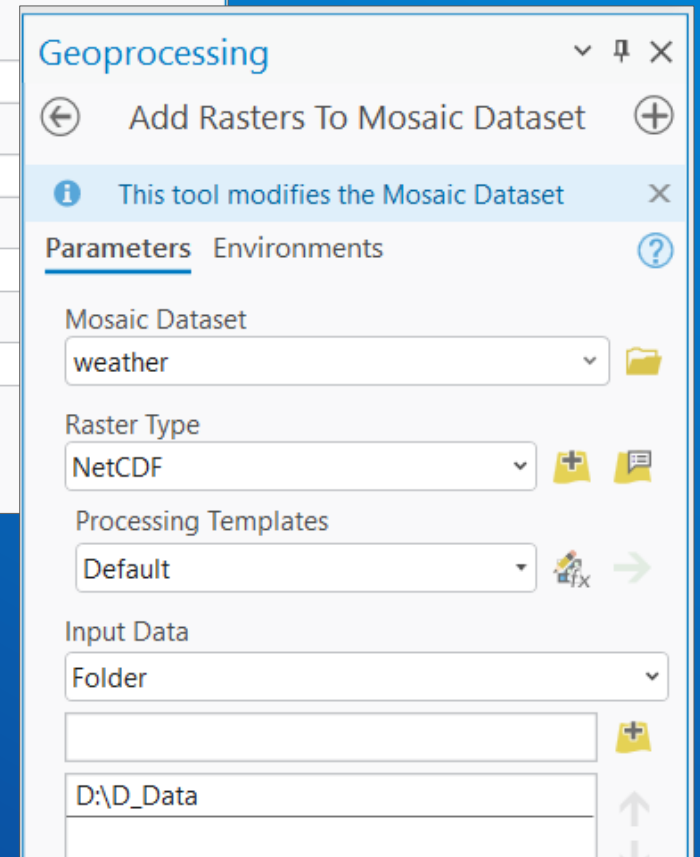
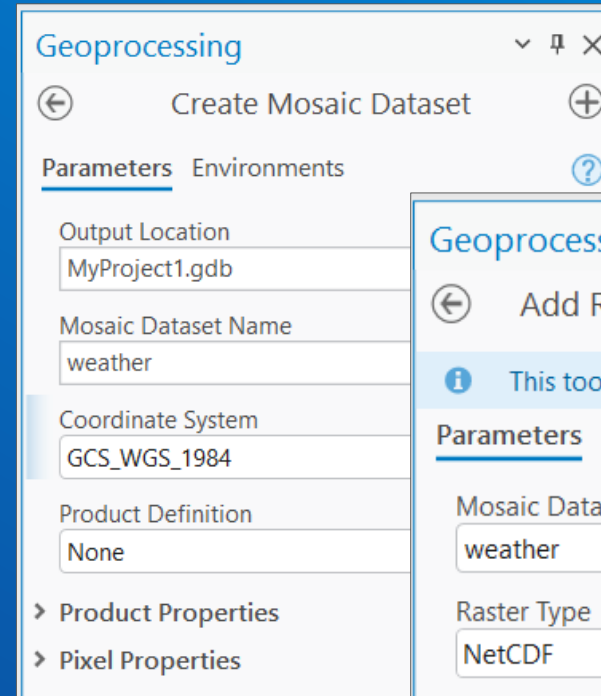
Multidimensional raster data models



Create Multidimensional Raster

From multidimensional raster formats

- Create a mosaic dataset
 - Use the *Create Mosaic Dataset* geoprocessing tool
- Add data to the mosaic dataset
 - Use the *Add Rasters To Mosaic Dataset* tool
 - Use *NetCDF*, *HDF*, or *GRIB* raster type
- Optional, Create a multidimensional CRF
 - Use *Copy Raster* tool



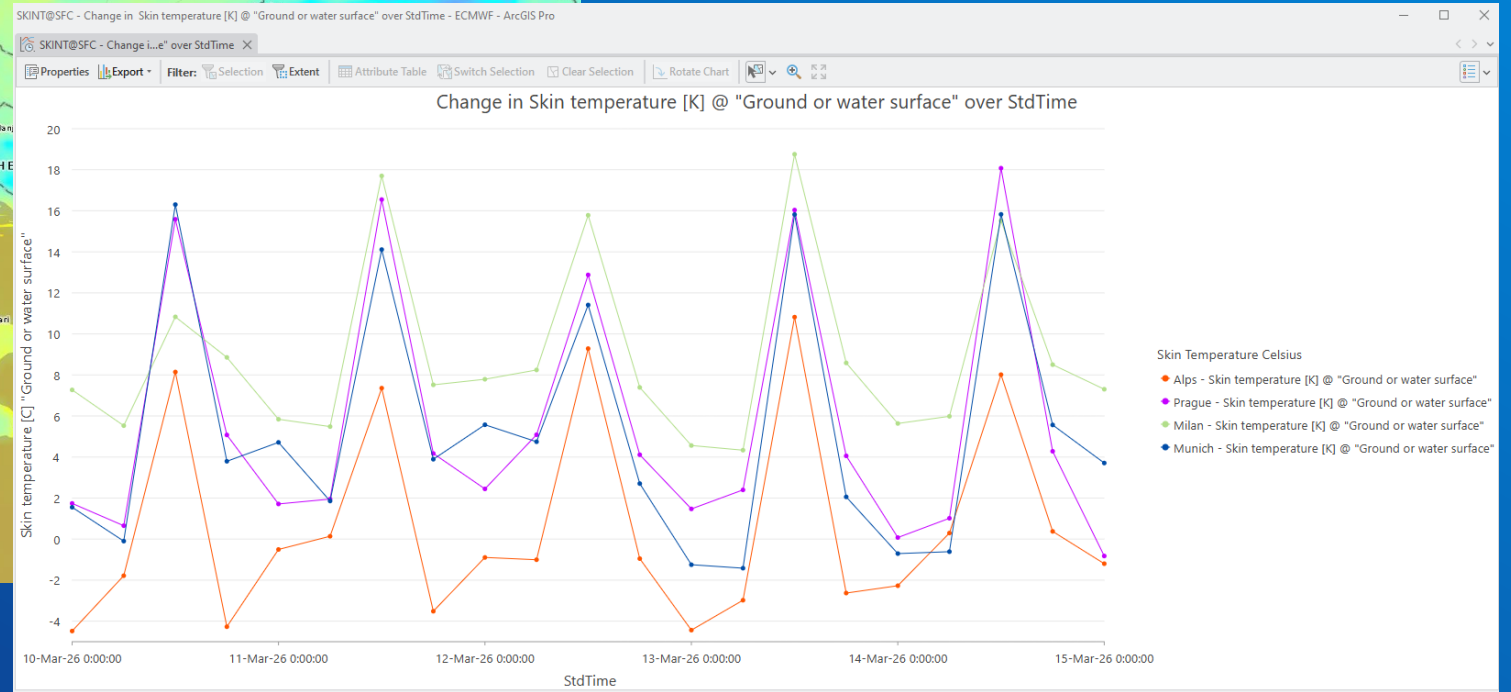
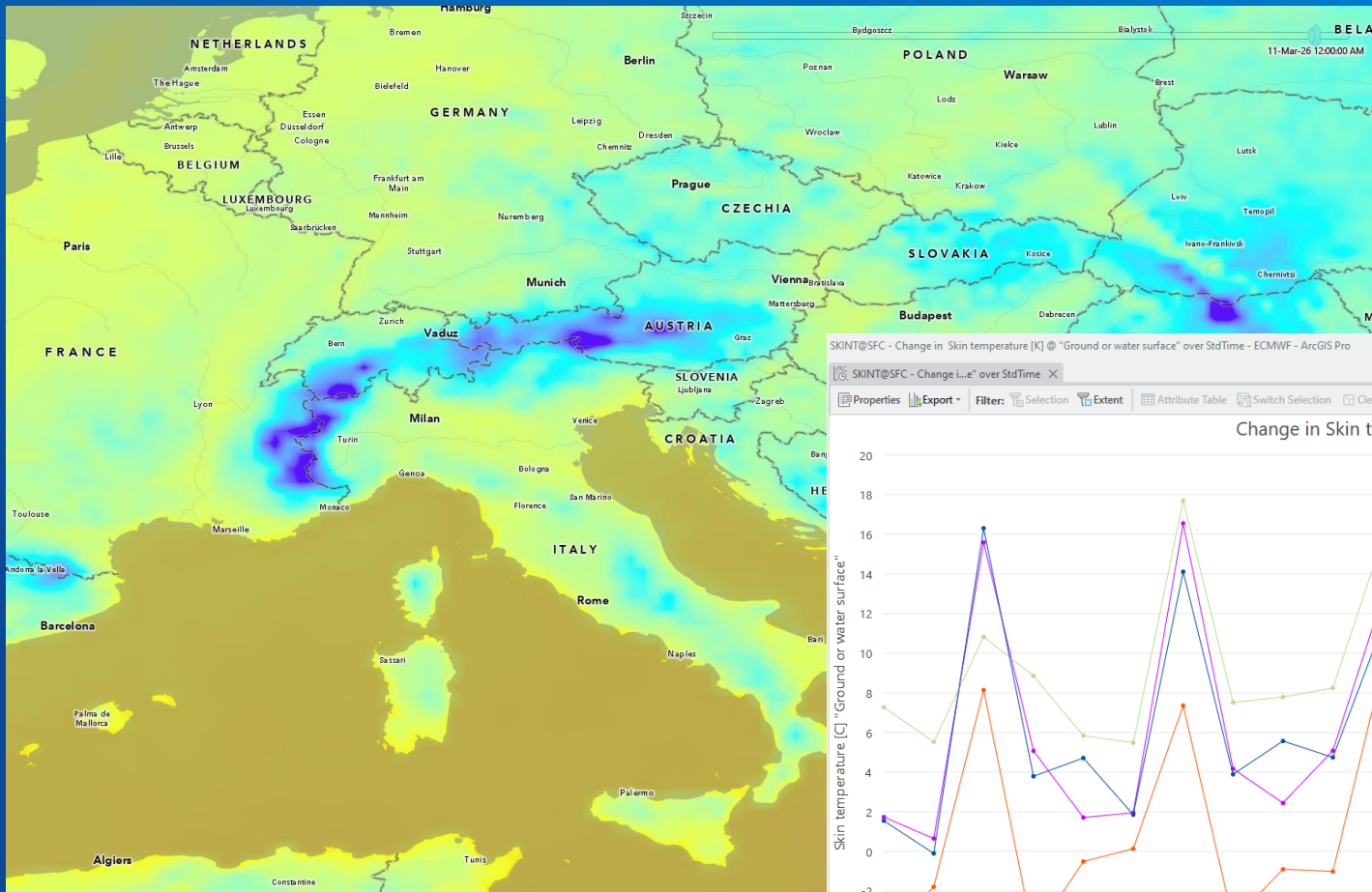
Create Multidimensional Raster (2)

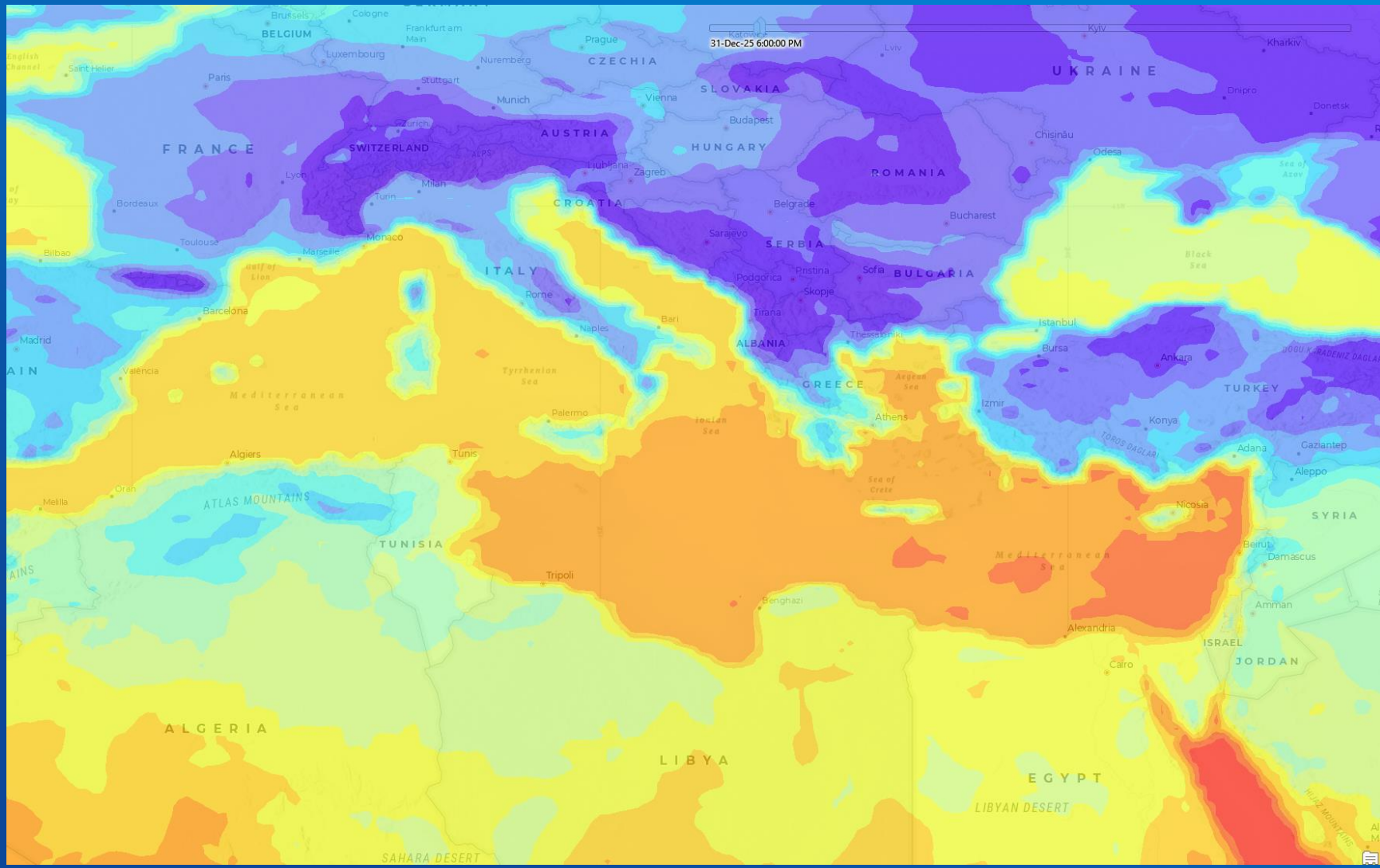
From time series image data

- Create a mosaic dataset
 - Use Landsat, sentinel, or other raster types
- Add rasters to the mosaic dataset
 - Use *Build Multidimensional Info* tool
 - Use *Process Raster Collection* Function to aggregate
- Create from STAC search
- Example
 - <https://www.esri.com/arcgis-blog/products/arcgis-pro/imagery/create-image-cubes/>

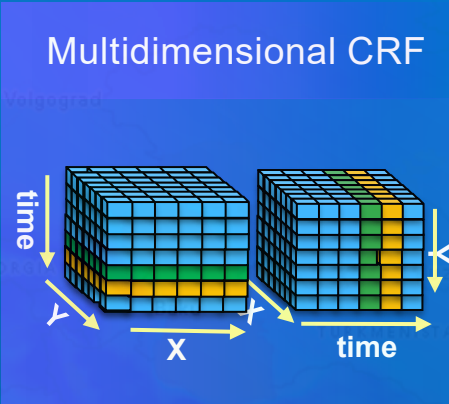
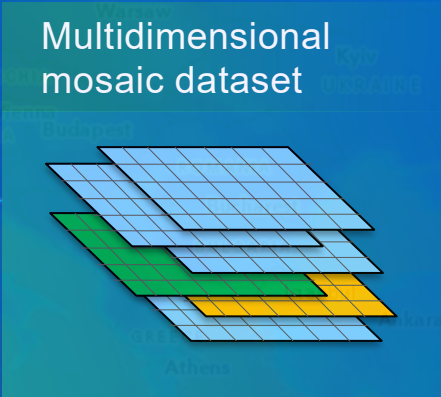
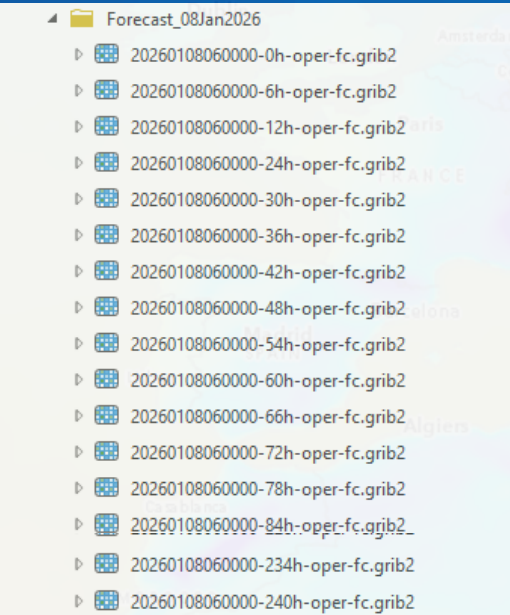


Exploring a grib Time Series dataset





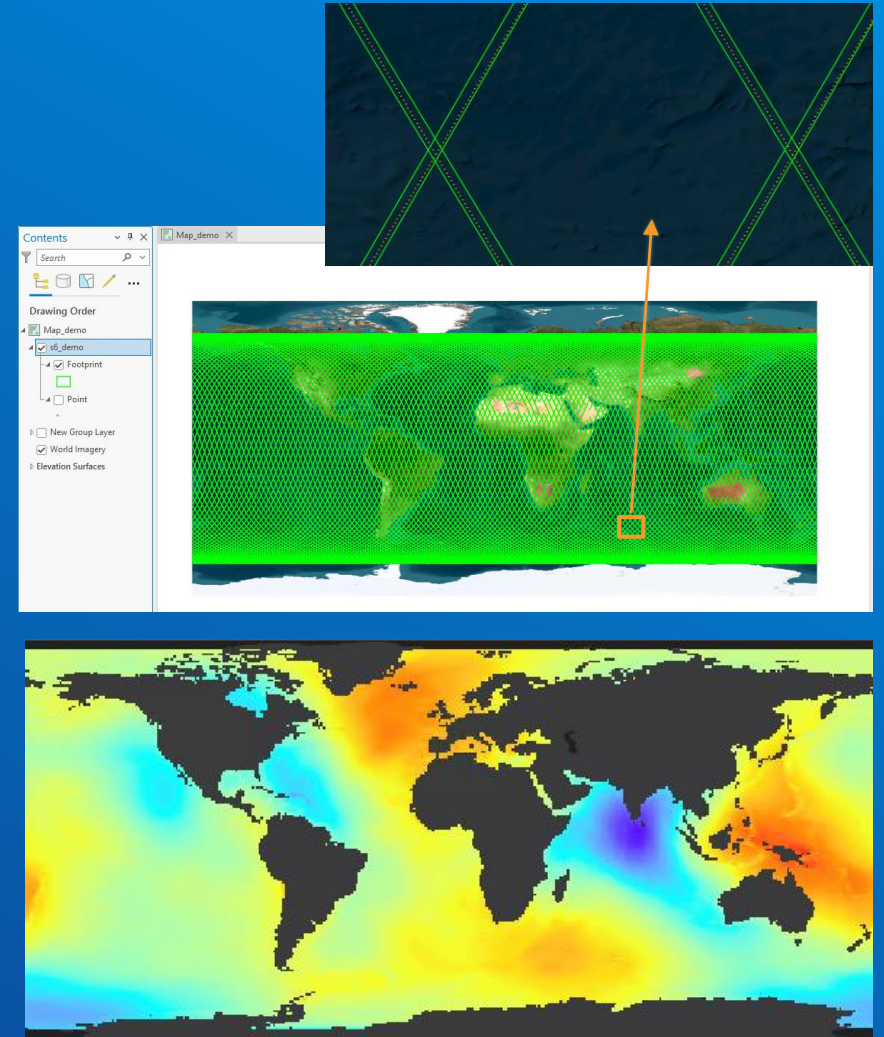
Build a Time Series from slices (single time)



Create Multidimensional Raster (3)

From altimetry data

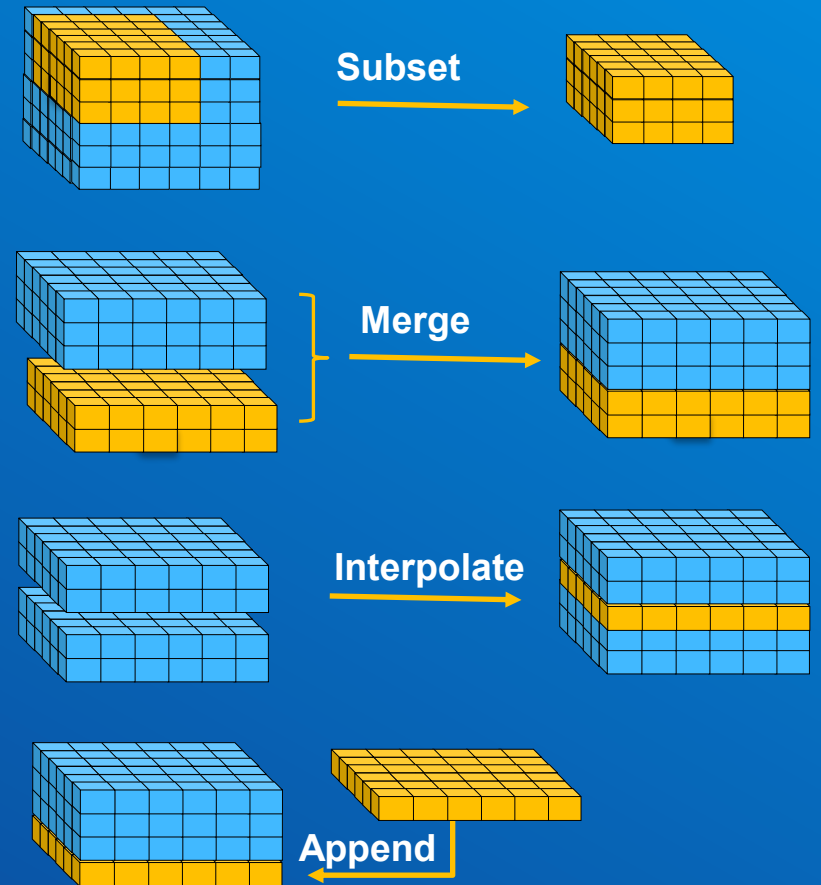
- Create Trajectory Dataset
- Add Data to Trajectory Dataset
 - Sentinel-6, Sentinel-3, IceSat-2, CryoSat-2,
 - Jason-2, Jason-3, GEDI, SWOT
- Interpolate From Spatiotemporal Points tool



Process multidimensional rasters

Subset, merge, interpolate, append, update

- **Subset Multidimensional Raster** tool
- **Merge Multidimensional Raster** tool
- **Interpolate By Dimension** raster function
- **Manage Multidimensional Raster** tool
- Smoothing
 - **Statistics** raster function
 - **Dimensional moving statistics** raster function



Share multidimensional raster

Enterprise and ArcGIS Online

- Create a multidimensional imagery layer in Enterprise

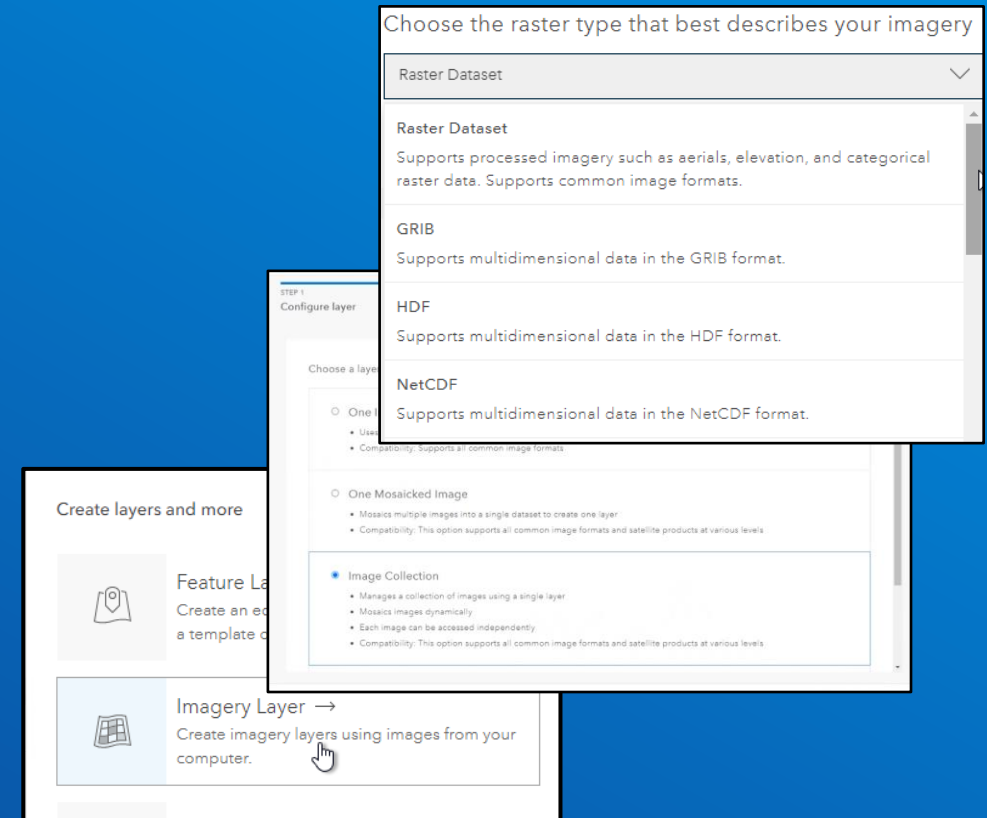
- Publish using ArcGIS Pro's Share As Web Layer
- Web Create Imagery Layer wizard

- Create a multidimensional imagery layer in AGOL

- Web Create Imagery Layer wizard
- ArcGIS Pro's Create Hosted Imagery wizard

- Help topics

- <https://pro.arcgis.com/en/pro-app/latest/help/data/imagery/web-image-layer.htm>
- <https://doc.arcgis.com/en/arcgis-online/manage-data/publish-imagery-layers.htm>
- <https://pro.arcgis.com/en/pro-app/latest/help/sharing/overview/publish-hosted-imagery-layers.htm>



Analyze Multidimensional Raster



Multidimensional analysis – slice by slice

Using raster function

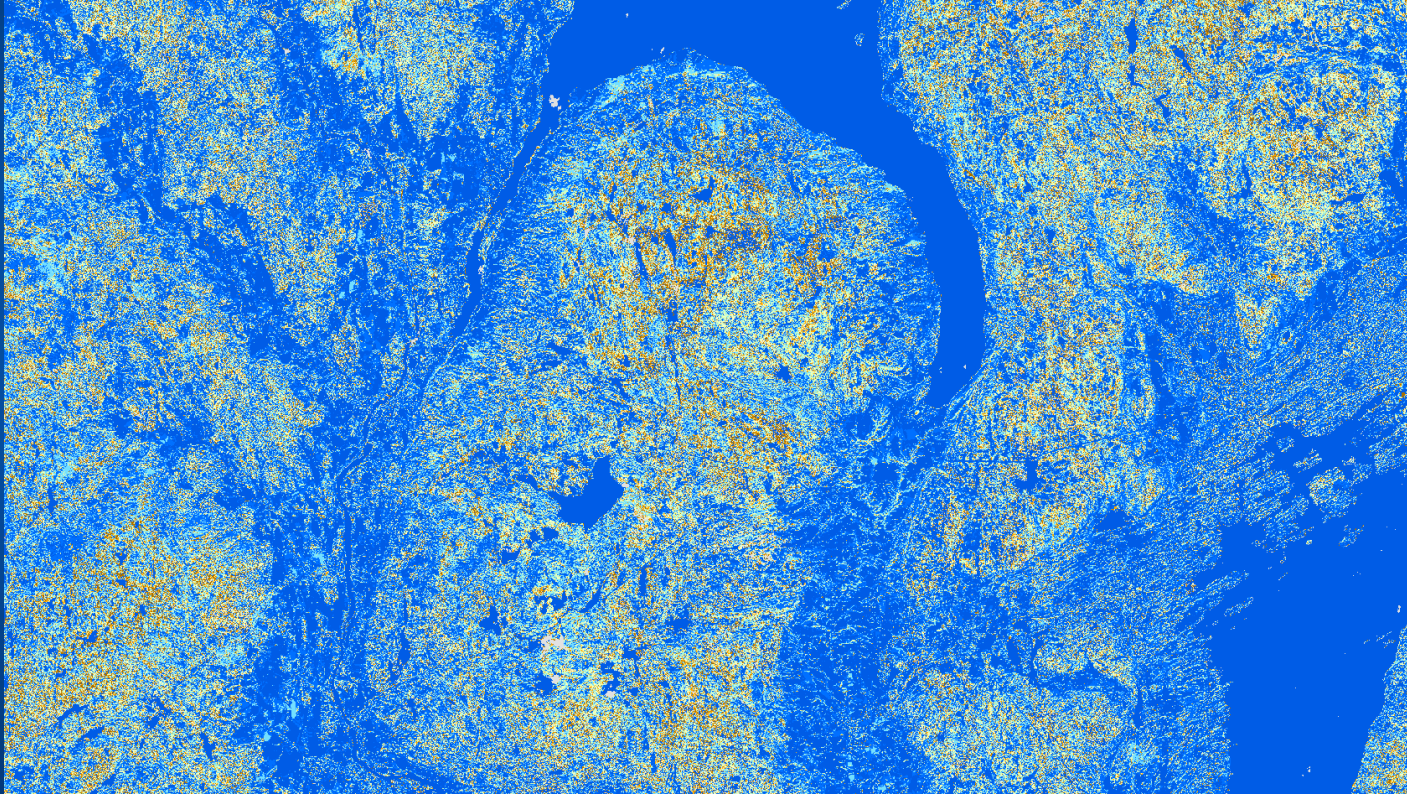
- Dimension-aware raster functions



- Dimension-aware map algebra and operators



The screenshot shows the "Raster Functions" dialog box in ArcGIS. It includes a search bar, tabs for "Project", "System", and "Custom", and a list of analysis tools such as Binary Thresholding, CCDC Analysis, Compute Change, Detect Change Usi..., Generate Trend, Heat Index, Kernel Density, LandTrendr Analysis, NDVI, NDVI Colorized, Predict Using Trend, Process Raster Colle..., Tasseled Cap (Kauth-Tho..., Weighted Overlay, and Weighted Sum. A workflow diagram on the right shows a sequence of tools: Solar Energy, Temperature Zonal Remap, Soil Moisture Zonal Remap, and Precipitation Zonal Remap, all leading to Cell Statistics, which then leads to an Attribute Table.



Examples

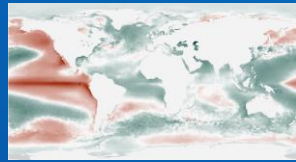
Using Time Series from Sentinel-2

Multidimensional analysis – reducing dimensions

Geoprocessing tools



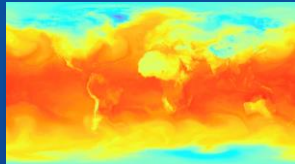
Trend & predictive analysis



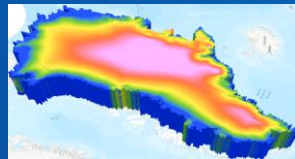
PCA pattern identification



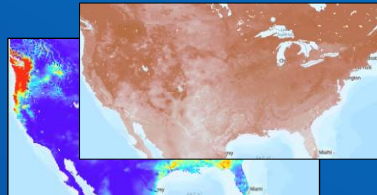
Change Detection



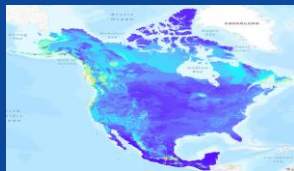
Data aggregation



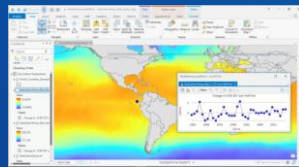
Interpolation



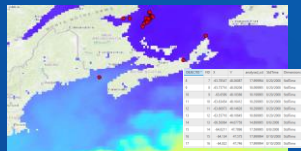
Variable Correlation



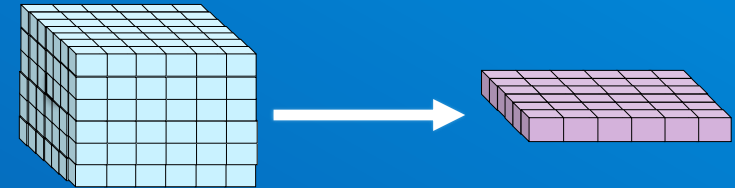
Find when and where



Anomaly detection



Data Enrichment



- Multidimensional Analysis
 - Aggregate Multidimensional Raster
 - Dimensional Moving Statistics
 - Find Argument Statistics
 - Generate Multidimensional Anomaly
 - Generate Trend Raster
 - Multidimensional
 - Multidimensional
 - Predict Using
 - Summarize Ca
- Change Detection
 - Analyze Changes Using CCDC
 - Analyze Changes Using LandTrendr
 - Compute Change Raster
 - Detect Change Using Change Analysis Raster

Trend and predictive analysis

- Generate Trend Raster tool

- Algorithms

- Linear, Polynomial, Harmonic

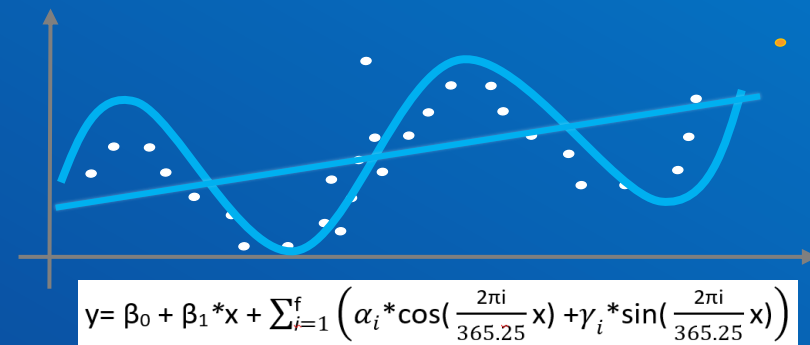
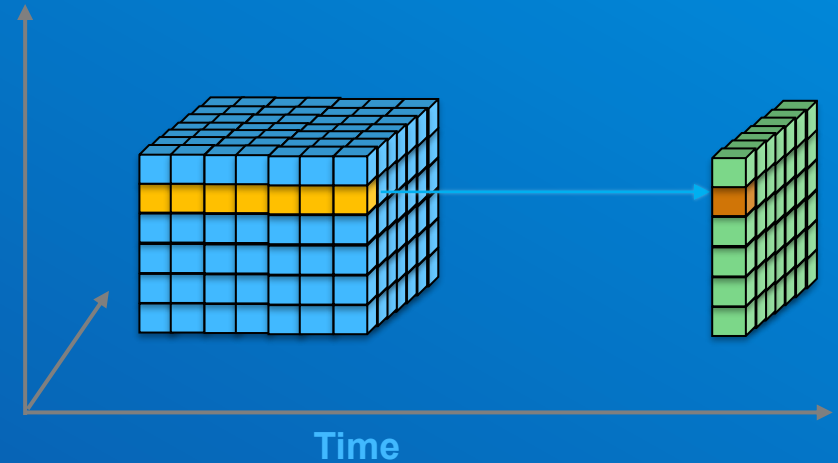
- Mann-Kendal and Season-Kendal trend tests

- Output trend Raster

- Multiband storing model coefficients

- Predict Using Trend Raster tool

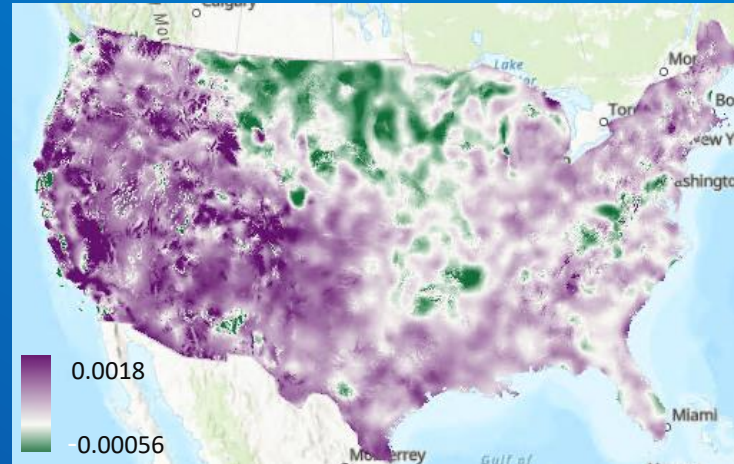
- Predict value raster for unknown time stamps



Visualize trend raster

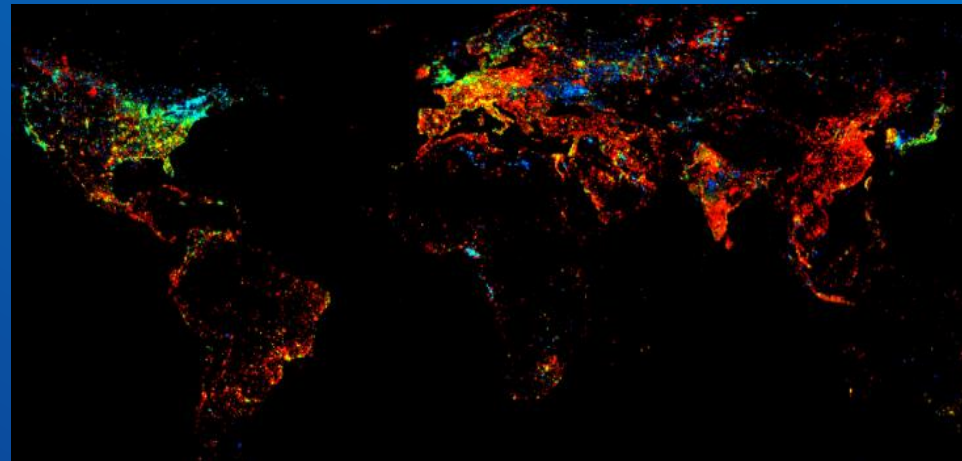
Trend maps

- Slope band



Temperature trend using slope

- Trend to RGB function

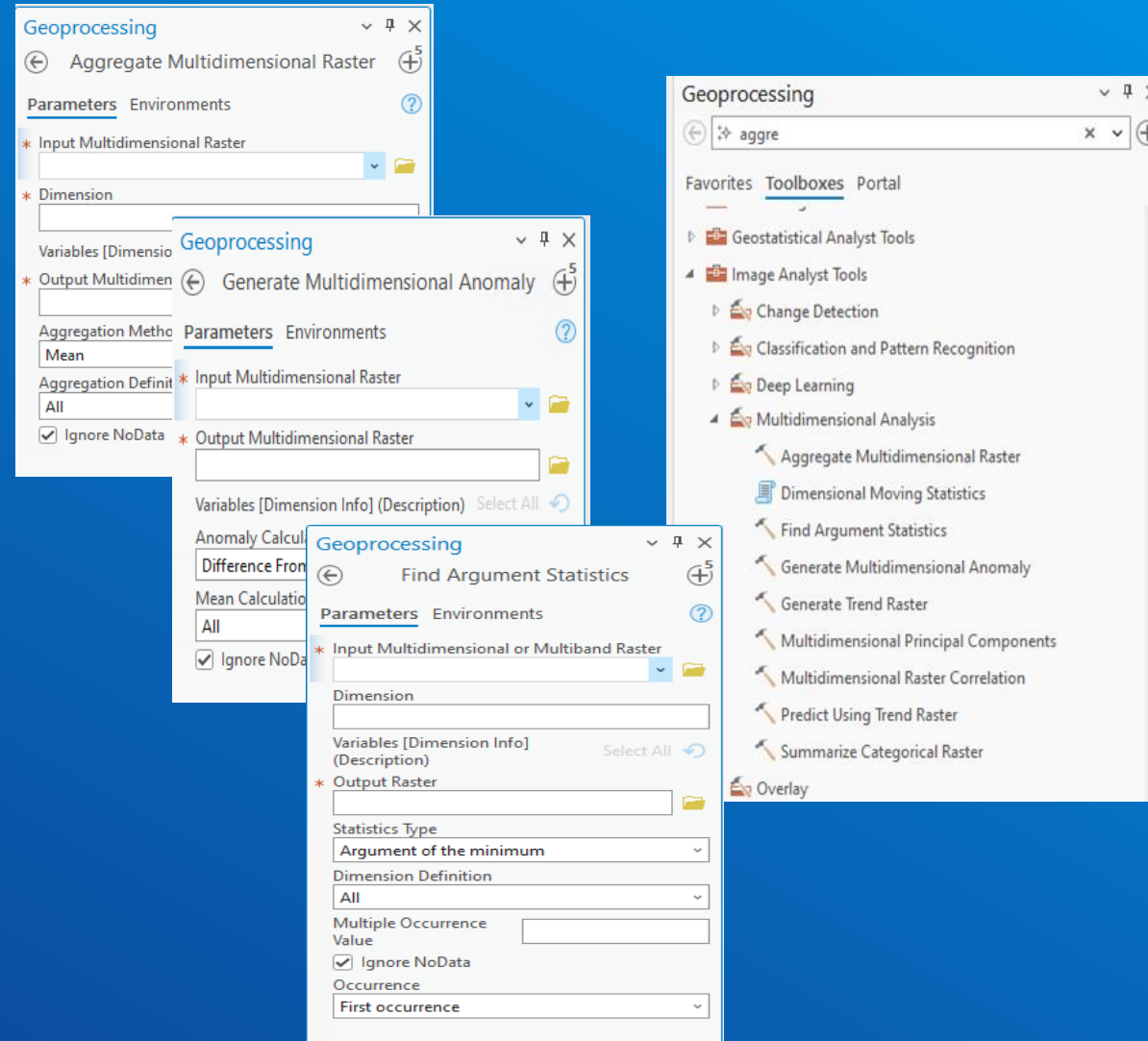


Trend of nighttime lights

More tools for analyzing patterns

Aggregate and anomaly

- **Aggregate Multidimensional Raster**
 - Quarterly, yearly, monthly, weekly, daily
 - Min, max, mean, median, sum, majority, std, percentile
- **Generate Multidimensional Anomaly**
 - Calculation interval, all, yearly, monthly, daily
 - Calculated mean, median, z-score
- **Find Argument Statistics**
 - Date and duration when reaching max, mean, median, and specific value

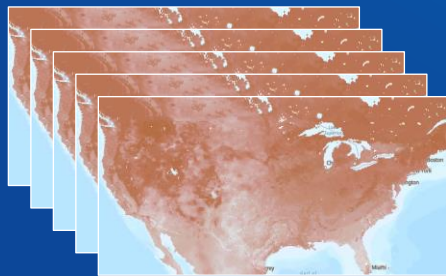


Compute correlations between two variables

Multidimensional Raster Correlation tool

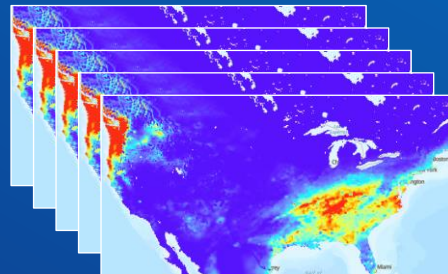
- Quantify correlation, similarity, and synchronization

- Pearson, Spearman, Kendall
- Support lag
- Cross correlation



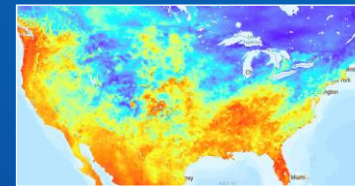
Monthly soil moisture

+



Monthly precipitation

→



Correlation raster

Geoprocessing

← Multidimensional Raster Correlati... →

Parameters Environments ?

* Input Multidimensional Raster 1
[Folder icon]

Dimension Name of Raster 1
[Text box]

Variable 1
[Text box]

* Input Multidimensional Raster 2
[Folder icon]

Dimension Name of Raster 2
[Text box]

Variable 2
[Text box]

Correlation Method
Pearson [Dropdown]

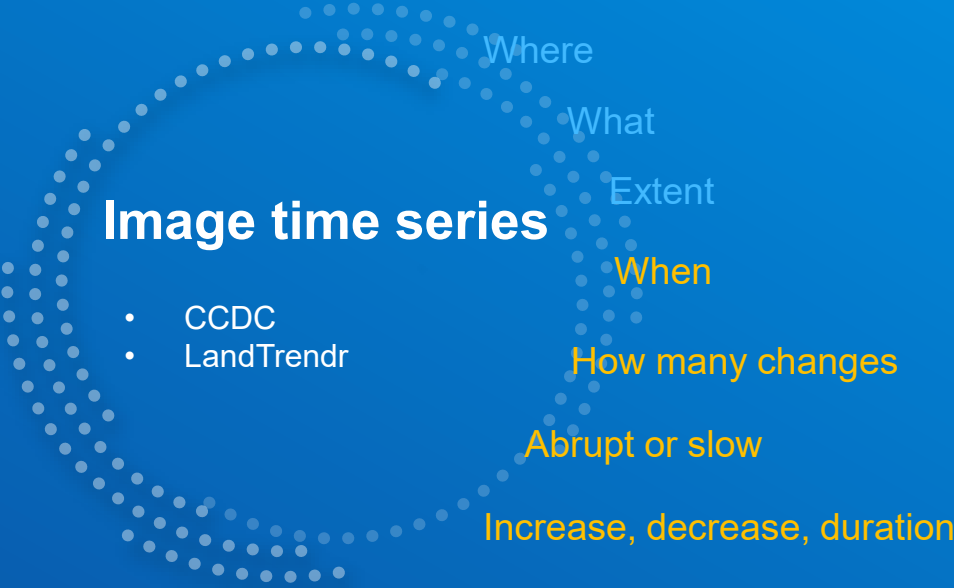
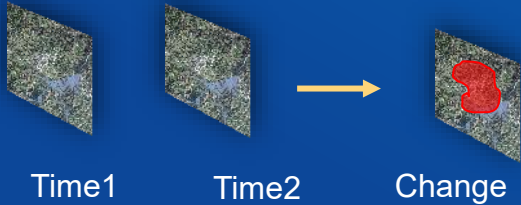
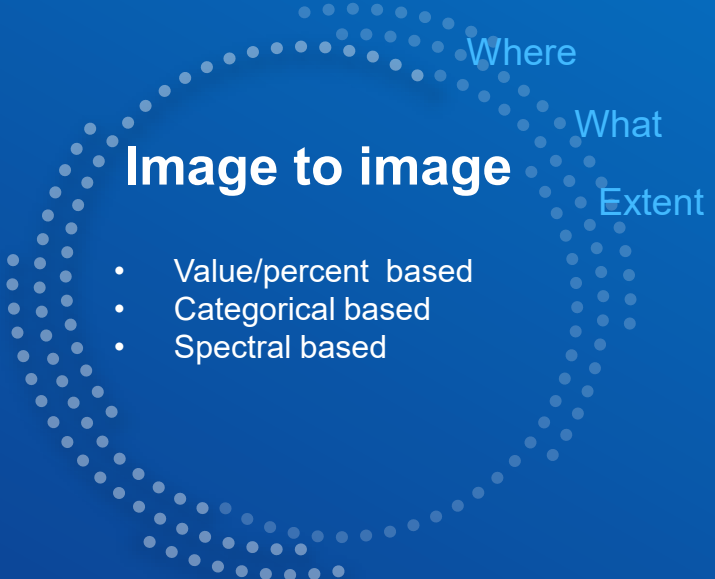
Lag [Text box] 0

Calculate Cross Correlation at Lags

Calculate P-value

* Output Raster
[Folder icon]

Change Detection



Change detection of time series imagery

CCDC and LandTrendr

LandTrendr (Landsat-based Detection of Trends and Disturbances)

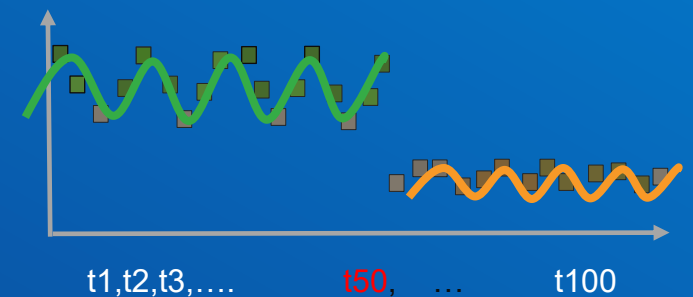
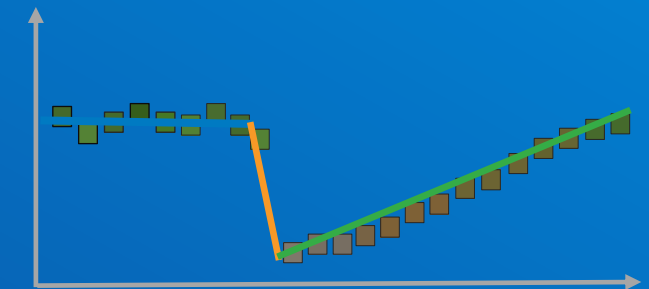
- Linear, temporal segmentation
- Yearly data

• CCDC (Continuous Change Detection and Classification)

- Harmonic regression
- Accounts for seasonality
- Dense image time series



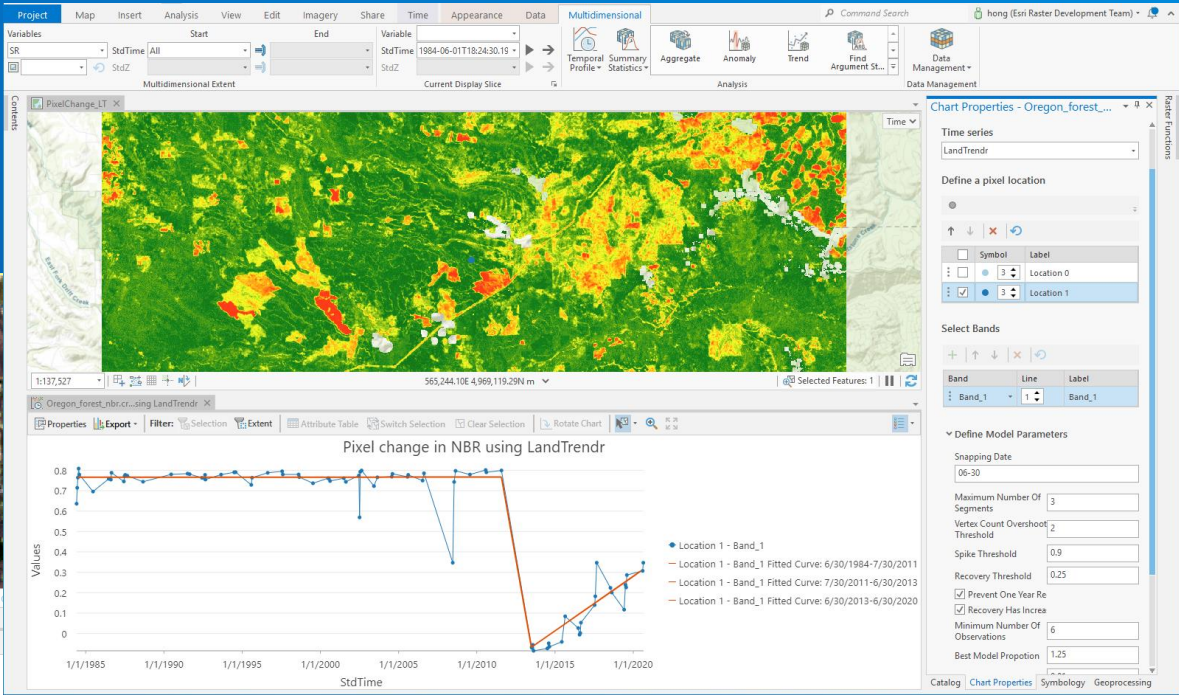
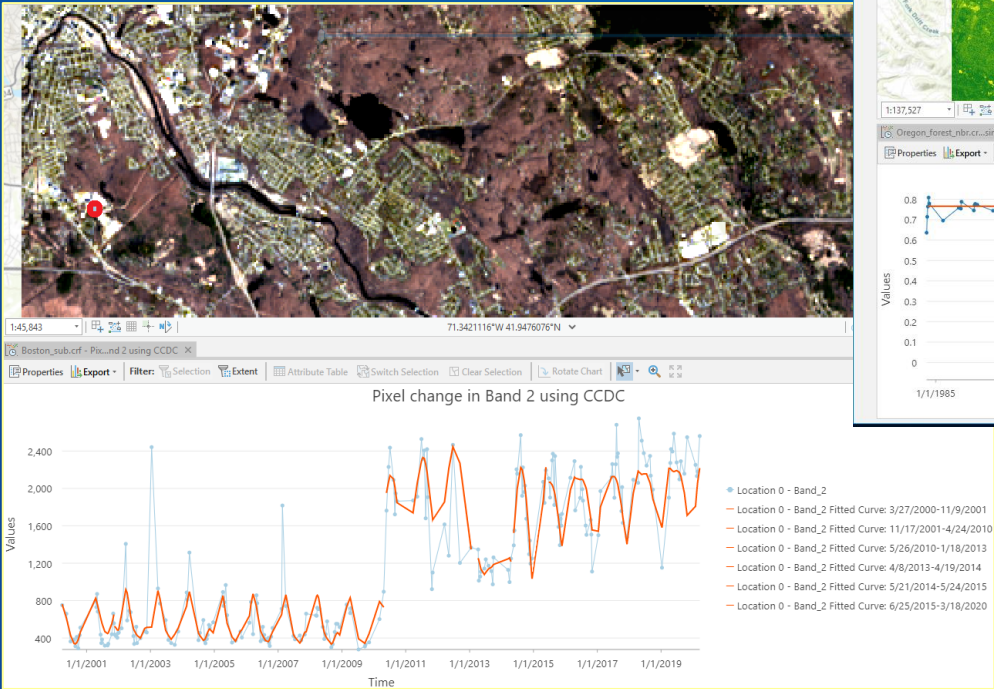
Input time series



Change detection of time series imagery

Pixel time series change explorer in ArcGIS Pro

- Detect and explore change for a pixel across time



Change detection of time series imagery

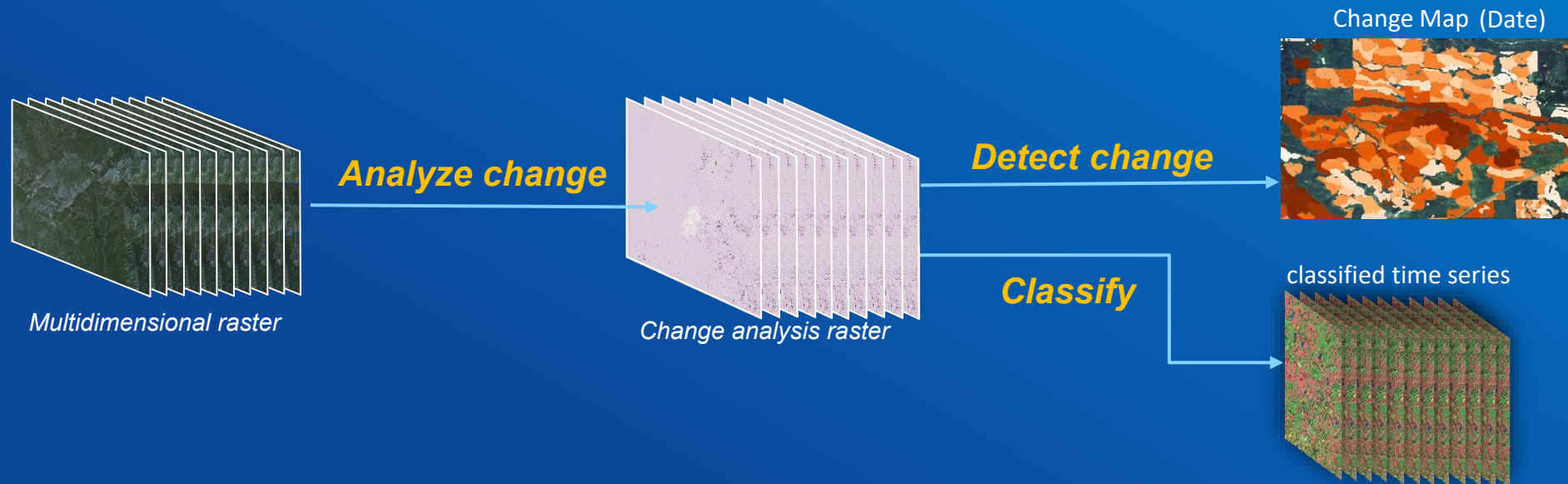
Tools and functions

- Analyze Change

- Analyze Change Using LandTrendr tool
- Analyze Change Using CCDC tool

- Detect Change

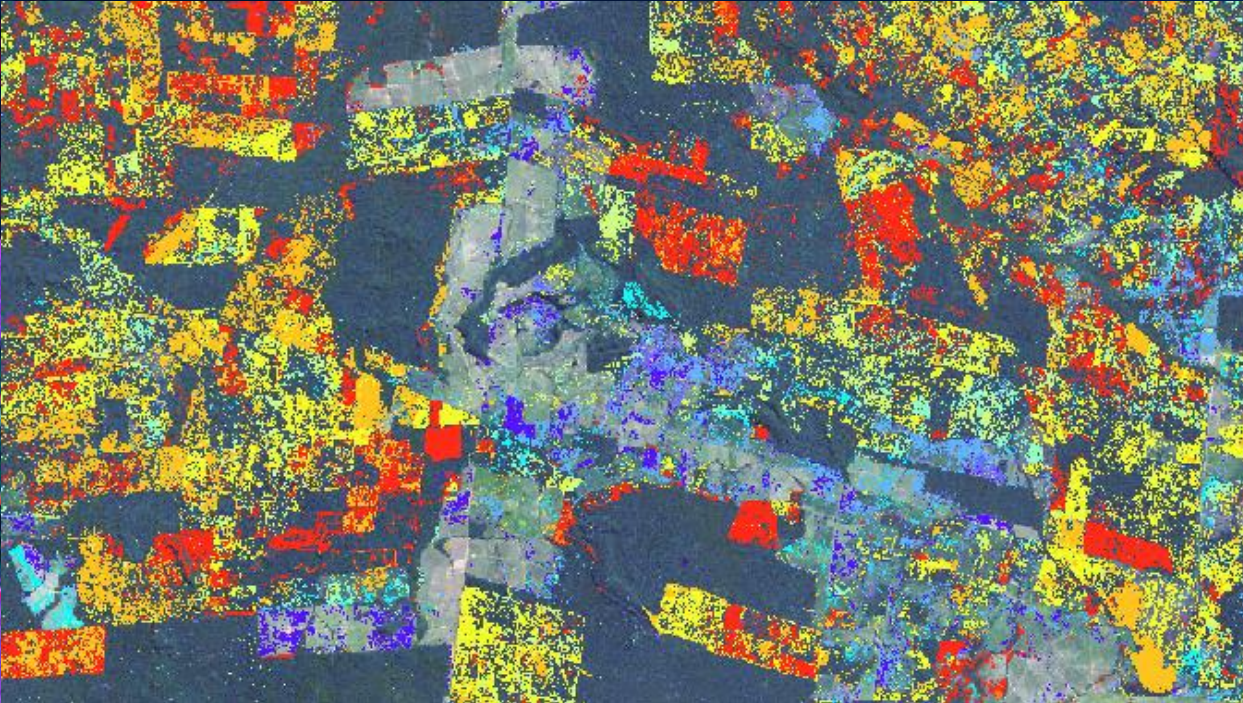
- Detect Change Using Change Analysis tool





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Deforestation in the Brazilian Amazon Rainforest

Hong

Multidimensional analysis in web map viewer

- Raster functions
- Multidimensional service tools

The image displays a web map viewer interface with a heatmap of the United States. The heatmap shows a color gradient from blue (low values) to yellow and orange (high values), indicating a spatial distribution of data. The interface includes a menu on the left with the following options:

- Use multidimensional analysis
- Aggregate Multidimensional Raster
- Find Argument Statistics
- Generate Multidimensional And
- Generate Trend Raster
- Multidimensional Principal Components
- Predict Using Trend Raster

Below the menu, there is a function editor window titled "My Map > Function Editor" with the function name "RFT_daymet_monthly_trendpredic". The editor shows a workflow with the following steps:

```
graph LR; tmin_ --> Generate Trend; Generate Trend --> Predict Using Trend;
```

The function editor also displays a list of items with their respective icons and update dates:

- Generate Trend (by esri_en, Updated: 11/15/18)
- Predict Using Trend (by esri_en, Updated: 11/15/18)
- Trend To RGB (by esri_en, Updated: 11/15/18)

The main map area shows a heatmap of the United States, with a legend on the right side. The legend includes the following items:

- Trended raster using RFT daymet monthly trendpredic
- Interpolated by field
- Interpolated by field
- Topographic

Additional Imagery and Remote Sensing Resources

Help and Tutorials

AMPC Documentation

- <https://doc.arcgis.com/en/microsoft-planetary-computer>
- <https://github.com/esri/arcgis-for-mpc>

Learn lessons and blogs

- [Monitor forest change over time](#)
- [Biomass Mapping using Landsat and GEDI Data](#)
- [Mapping Greenland ice changes using altimetry data](#)
- [Change Detection in Amazon floodplains](#)
- [Climate impact on wine using multidimensional analysis](#)

Keep Learning about Imagery and Remote Sensing in ArcGIS

Discover Imagery at the 2024 Esri User Conference

- [Esriurl.com/UCImageryEvents](https://esriurl.com/UCImageryEvents)

Find Case Studies, On-Demand Learning, & Pre-Made Workflows

- go.esri.com/ImageryAndRemoteSensingResources

Sign up for an Instructor-Led Courses

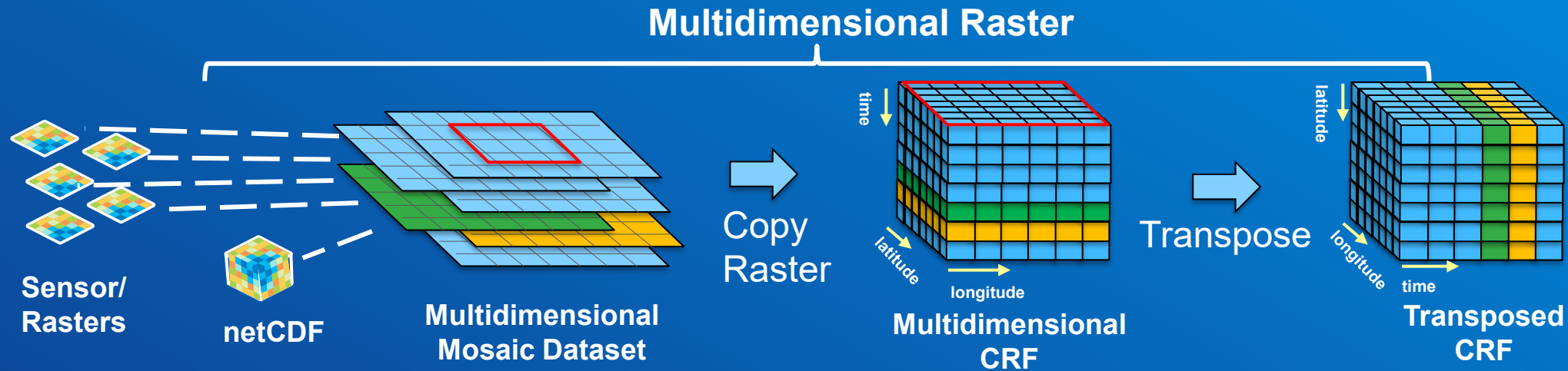
- go.esri.com/Imagery_Learning

Read Blogs about All Things Imagery and ArcGIS

- go.esri.com/Imagery_Blog

Multidimensional Raster

Increasing Demand to handle large scientific datasets, deep temporal data stacks, Image Cube, Data Cubes



Projection:	Variable	Fixed
Pixel Size:	Variable	Fixed
Number of bands:	Unlimited	Unlimited
Number of variables:	Unlimited	Unlimited
Time/Dimension:	Variable	Fixed
Update with new Data:	Yes	YES (append since 2.8)
Optimized for:	Flexibility	Performance
Directly access in ArcGIS Pro	Yes	Yes
Server as Image Services	Yes	Yes

Fast Temporal Profile
Aggregate, etc

CRF is optimum format for
Raster Analytics

Multidimensional Rasters

Increasing Demand to handle large scientific datasets, deep temporal data stacks, Image Cubes, Data Cubes

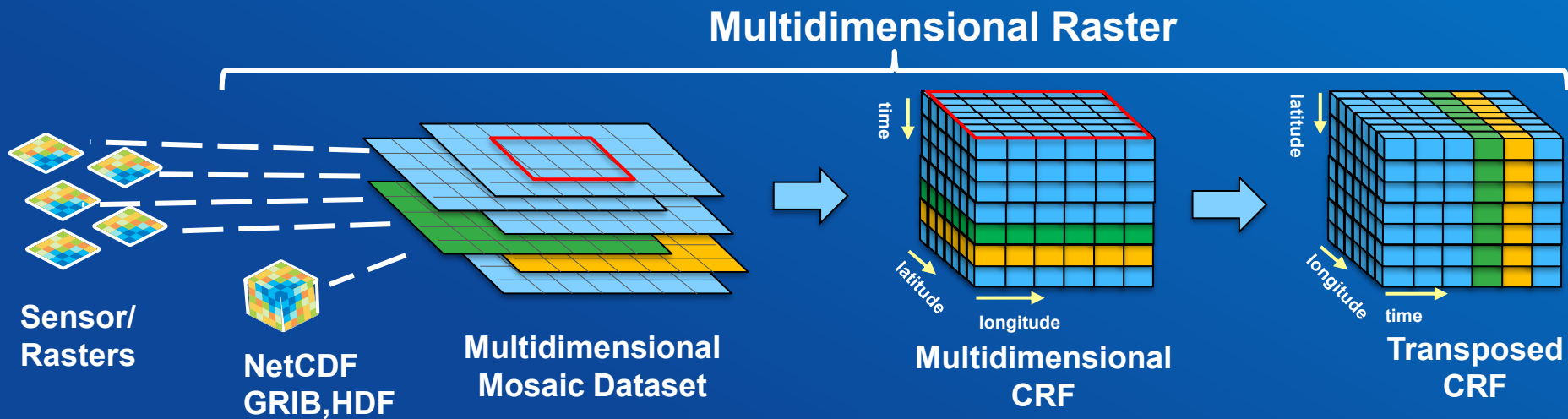
Mosaic Dataset

Multidimensional Mosaic Dataset

CRF – Optimized for cloud storage and processing – Output for Raster Analytics

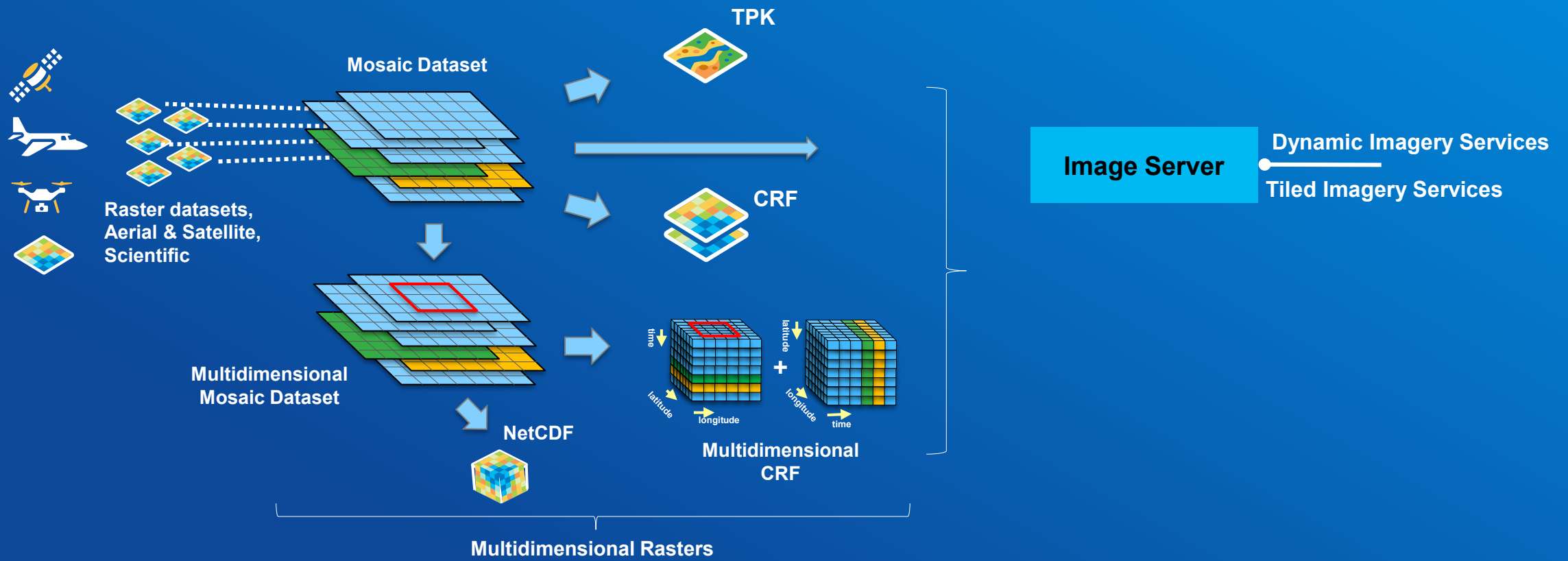
Multidimensional CRF – Optimize for multiple variables/dimensions

Transposed CRF – Enable rapid dimension access and analysis



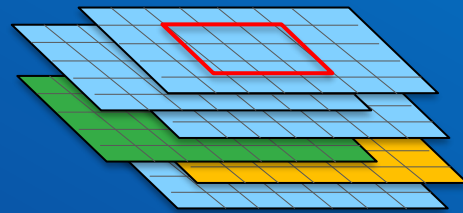
Optimized Data Models

Manage all form of imagery and rasters

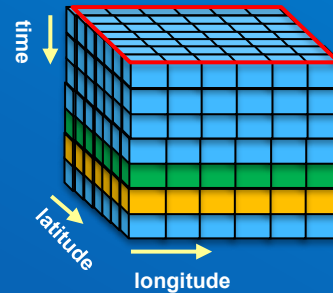


Multidimensional Raster for Analysis

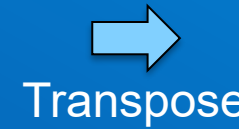
Decision depends on Analytical task, frequency, need to update, ...



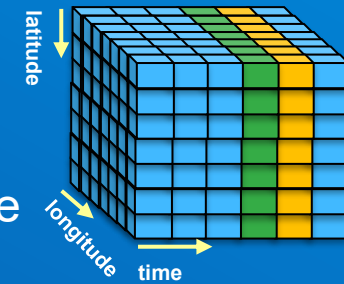
Multidimensional Mosaic Dataset



Multidimensional CRF



Transpose



Transposed CRF

Fast Temporal Profile Aggregate, etc

Projection:	Variable	Fixed
Pixel Size:	Variable	Fixed
Number of bands:	Unlimited	Unlimited
Number of variables:	Unlimited	Unlimited
Time/Dimension:	Variable	Fixed
Update with new Data:	Yes	YES (append since 2.8)
Optimized for:	Flexibility	Performance
Directly access in ArcGIS Pro	Yes	Yes
Server as Image Services	Yes	Yes

1. The ArcGIS Pro Multidimensional Toolbar

The screenshot displays the ArcGIS Pro Multidimensional Toolbar, which is part of the 'Multidimensional' ribbon. The toolbar includes several tool groups and individual tools:

- Configure Extent**: A tool to set the spatial extent of the data.
- Extent**: A tool to view the current extent.
- Current Display Slice**: A section for configuring the current slice, including:
 - Variable**: Set to 'thetao'.
 - StdTime**: Set to '2023-01-01T00:00:00'.
 - StdZ**: Set to '-9.572997093200684'.
- Temporal Profile**: A tool to view the temporal profile of the data.
- Summary Statistics**: A tool to calculate summary statistics for the data.
- Aggregate**: A tool to aggregate data across slices.
- Anomaly**: A tool to identify anomalies in the data.
- Trend**: A tool to analyze trends in the data.
- Find Argument St...**: A tool to find argument statistics.
- Data Management**: A tool to manage the data.
- Zonal Statistics**: A tool to calculate zonal statistics.
- Analyze Changes Usi...**: A tool to analyze changes in the data.
- More Tools...**: A button to access more tools.
- Make Multidimensional Raster Layer**: A tool to create a new multidimensional raster layer from the selected layer.
- Subset**: A tool to extract slices of multidimensional data by specifying slicing criteria.
- Minority**: A tool to calculate the minority value of a pixel across all slices in the interval.
- Range**: A tool to calculate the range of values that occurred most frequently for a pixel in the interval.
- Variety**: A tool to calculate the variety of a pixel's values across all slices in the interval.

The 'Classification Tools' dropdown menu is open, showing the following tools:









- Classification Tools**
- Deep Learning Tools**
- Segmentation**: Group neighboring pixels together based on their similarity, to create objects that are then used in image classification.
- Training Samples Manager**: Create and manage training samples for supervised classification.
- Classify**: Categorize pixels into classes.

The 'Geoprocessing' dialog box is open, showing the 'Manage Multidimensional Raster' tool. The parameters are:






- Target Multidimensional Raster**: [Empty]
- Variables**: [Select All]
- Manage Mode**: Append Slices
- Input Multidimensional Rasters**: [Empty]
- Update Statistics**: [Checked]
- Update Transpose**: [Checked]

2. Multidimensional Raster Functions






▼ Analysis

							
CCDC Analysis	Compute Change	Detect Change Usi...	Generate Trend	Gradient	LandTrendr Analysis	Predict Using Trend	Process Raster Colle...

▼ Classification

				
Classify	Linear Spectral Un...	ML Classify	Predict Using Regression	Segment Mean Shift

▼ Data Management

				
Interpolate Raster By D...	Aggregate Multidimen...	Multidimen...	Multidimen...	Geometric Median