Time Series & Multidimensional Definitions

Alberto Meroni

Session agenda

Introduction to multidimensional raster

Visualization

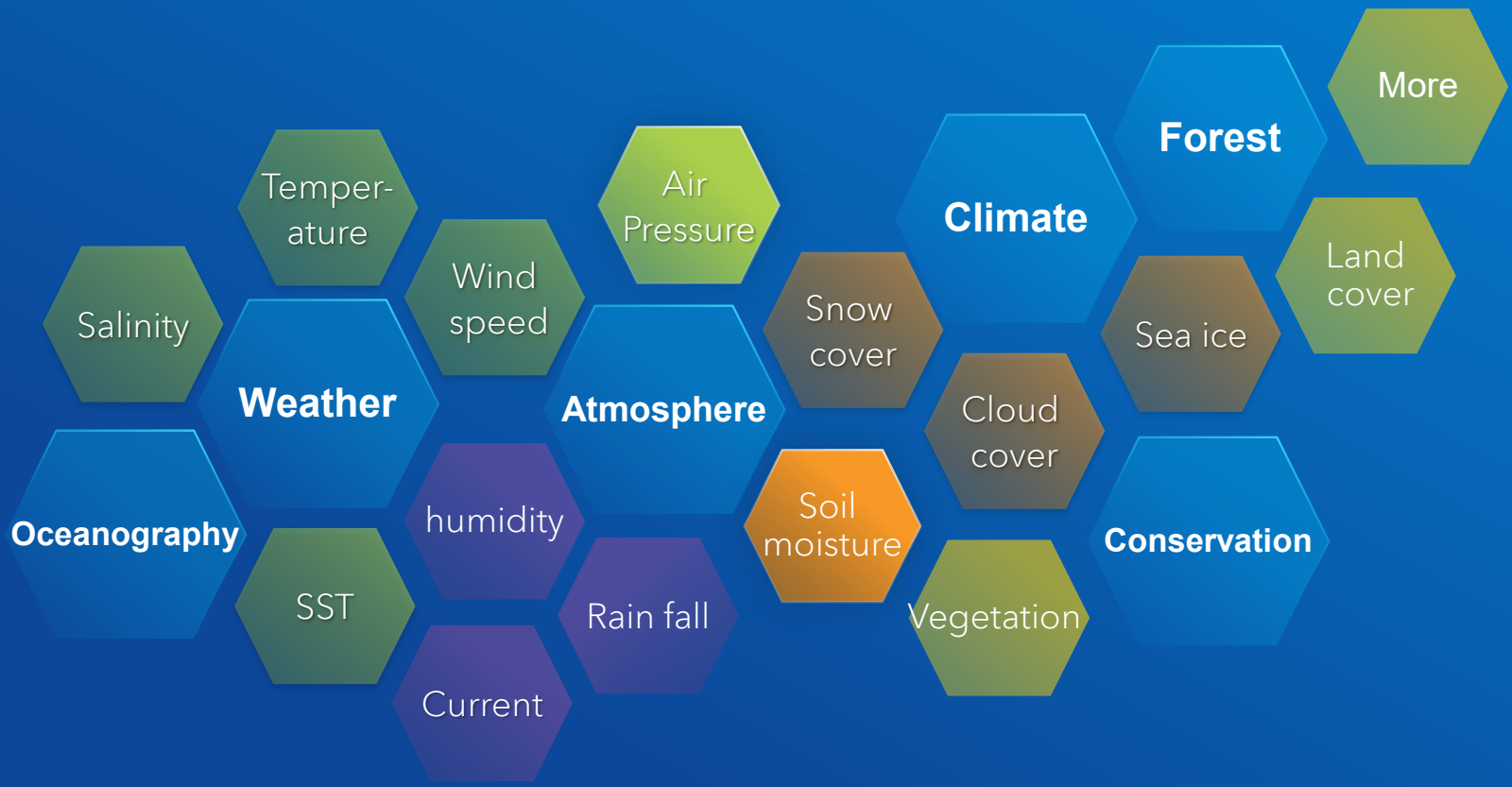
Creating Data cubes

Analysis

Q&A

What is multidimensional data?

Geospatial data of our earth over time



Detect changes

Find anomalies

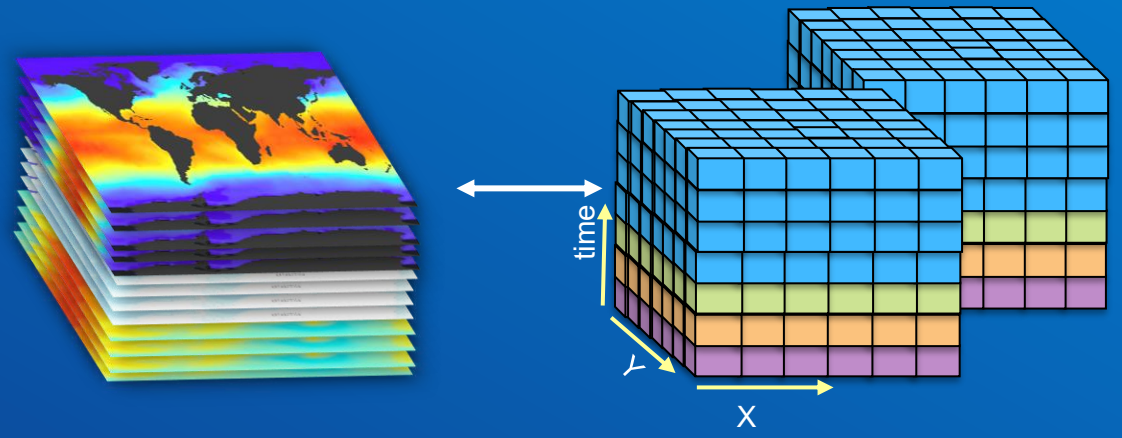
Explore trends

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

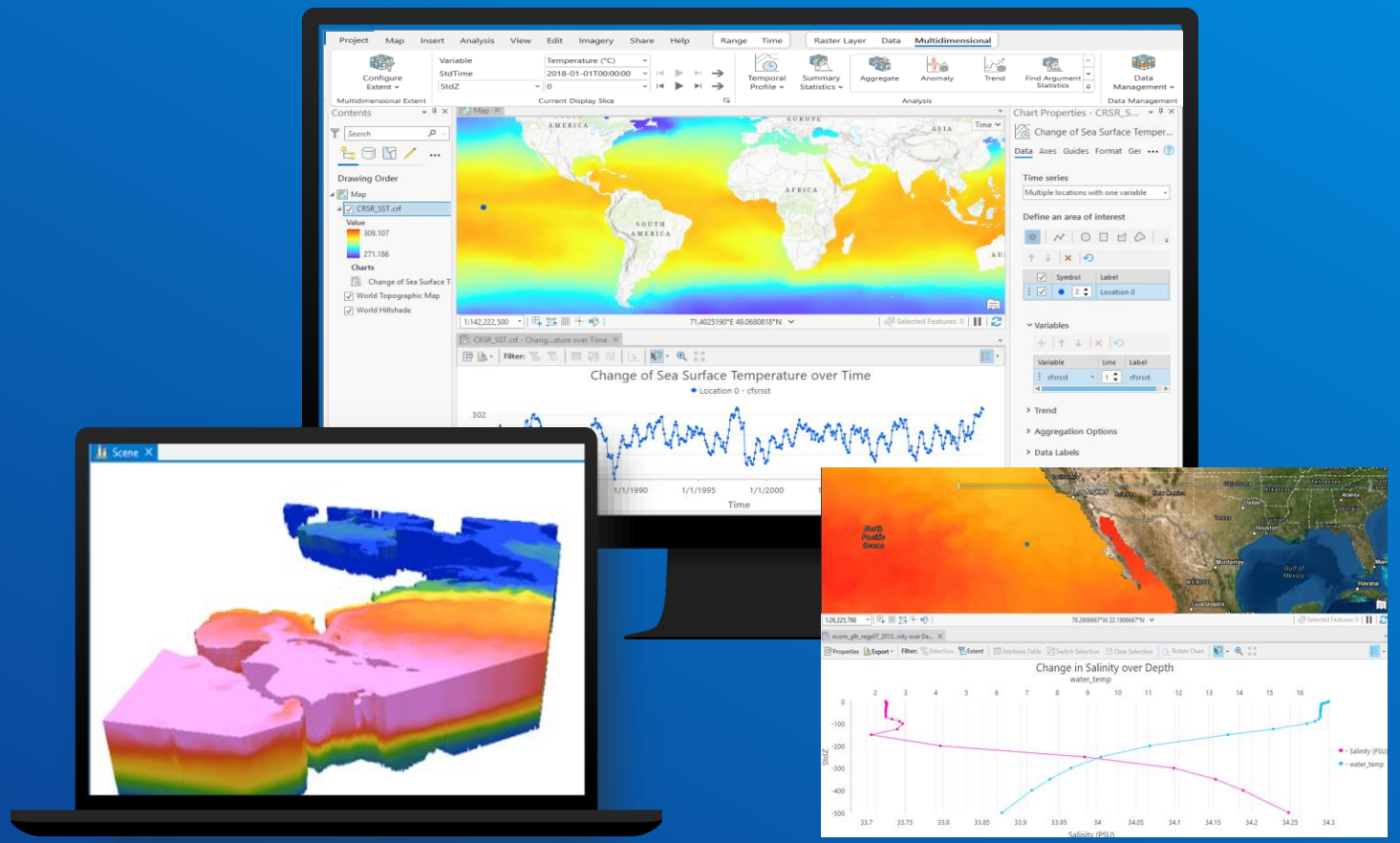
Visualization and Exploration

Multidimensional raster visualization in ArcGIS Pro

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

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

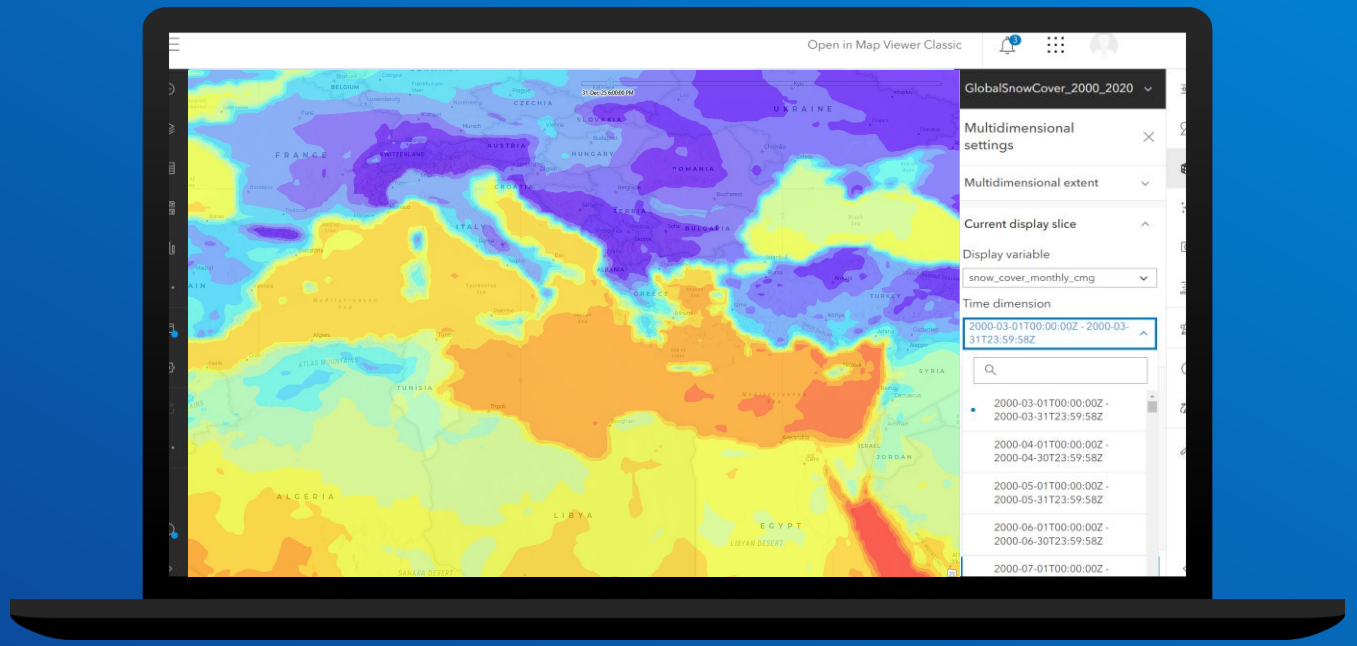
- 4D+ support
- Symbology per variable
- Surface Profile



Visualizing multidimensional imagery layer

Multidimensional raster in the web

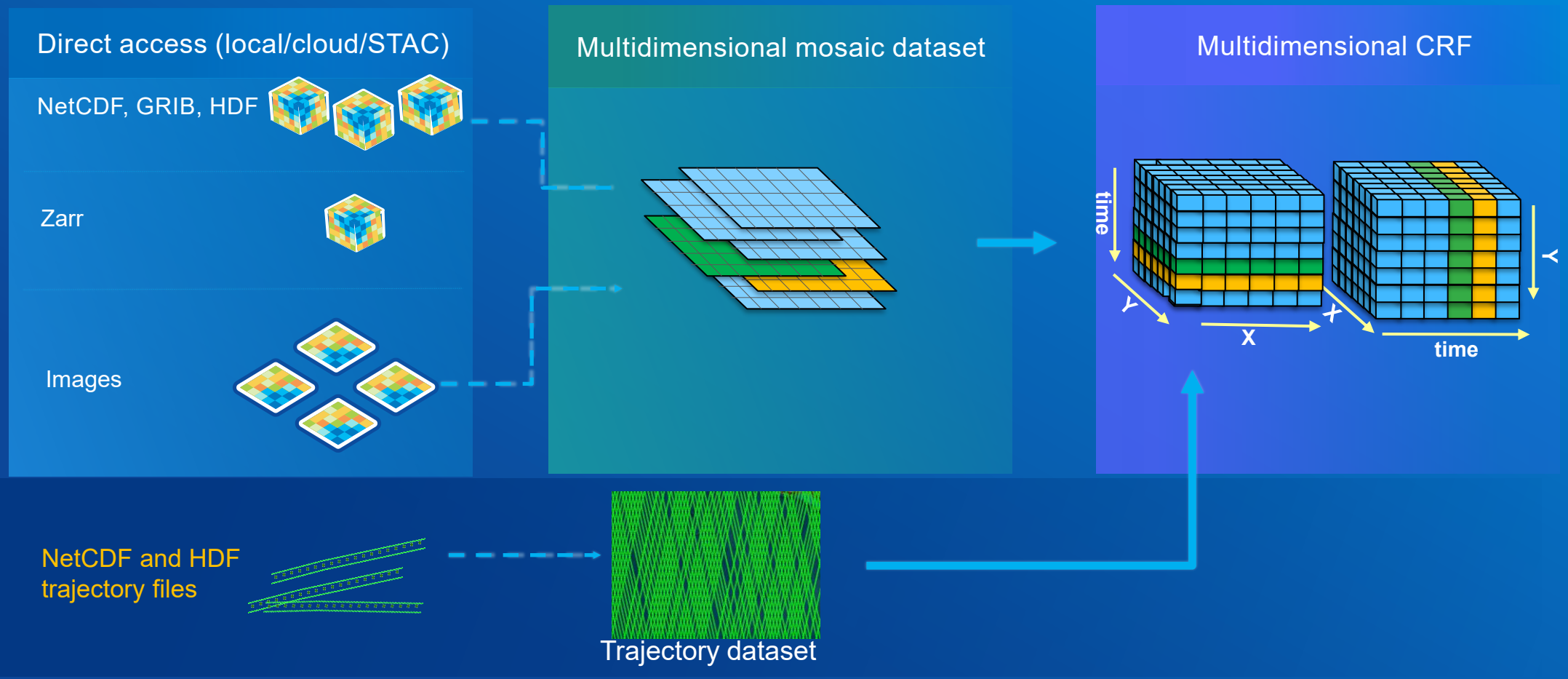
- Use ArcGIS Pro as a client
- Web Map Viewer
  - Multidimensional tool on layer panel
  - Dimension slider
  - Time slider



Create Multidimensional Raster

Create Multidimensional Raster

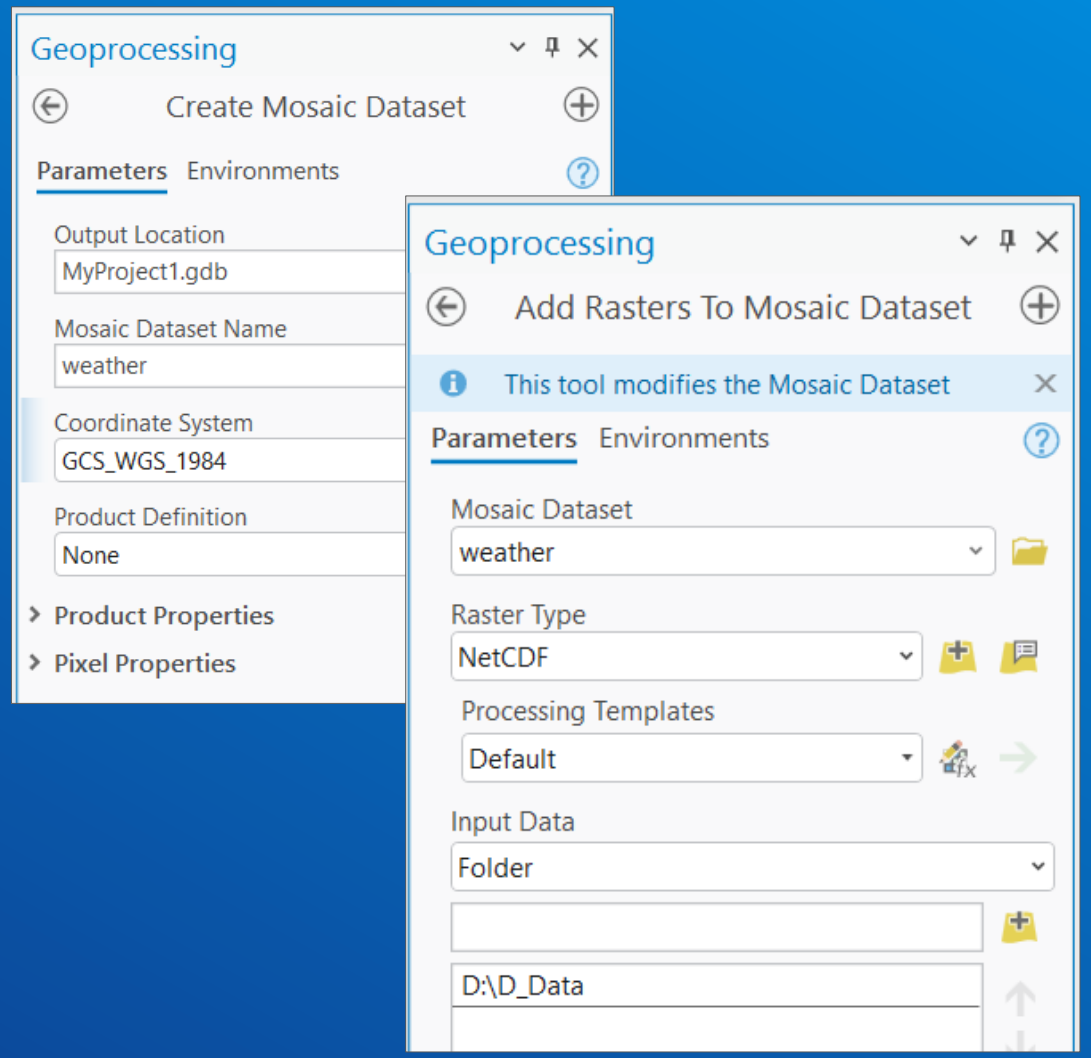
Multidimensional raster data models



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

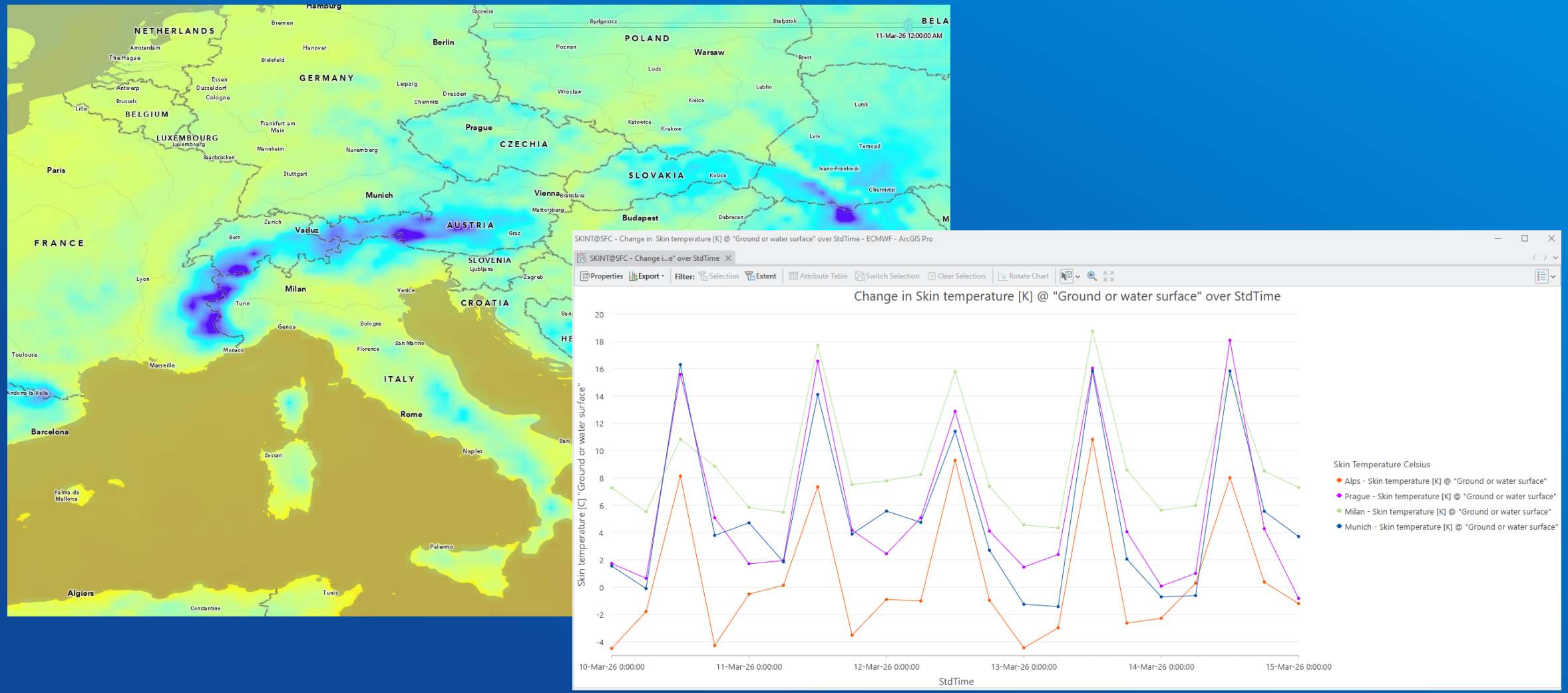


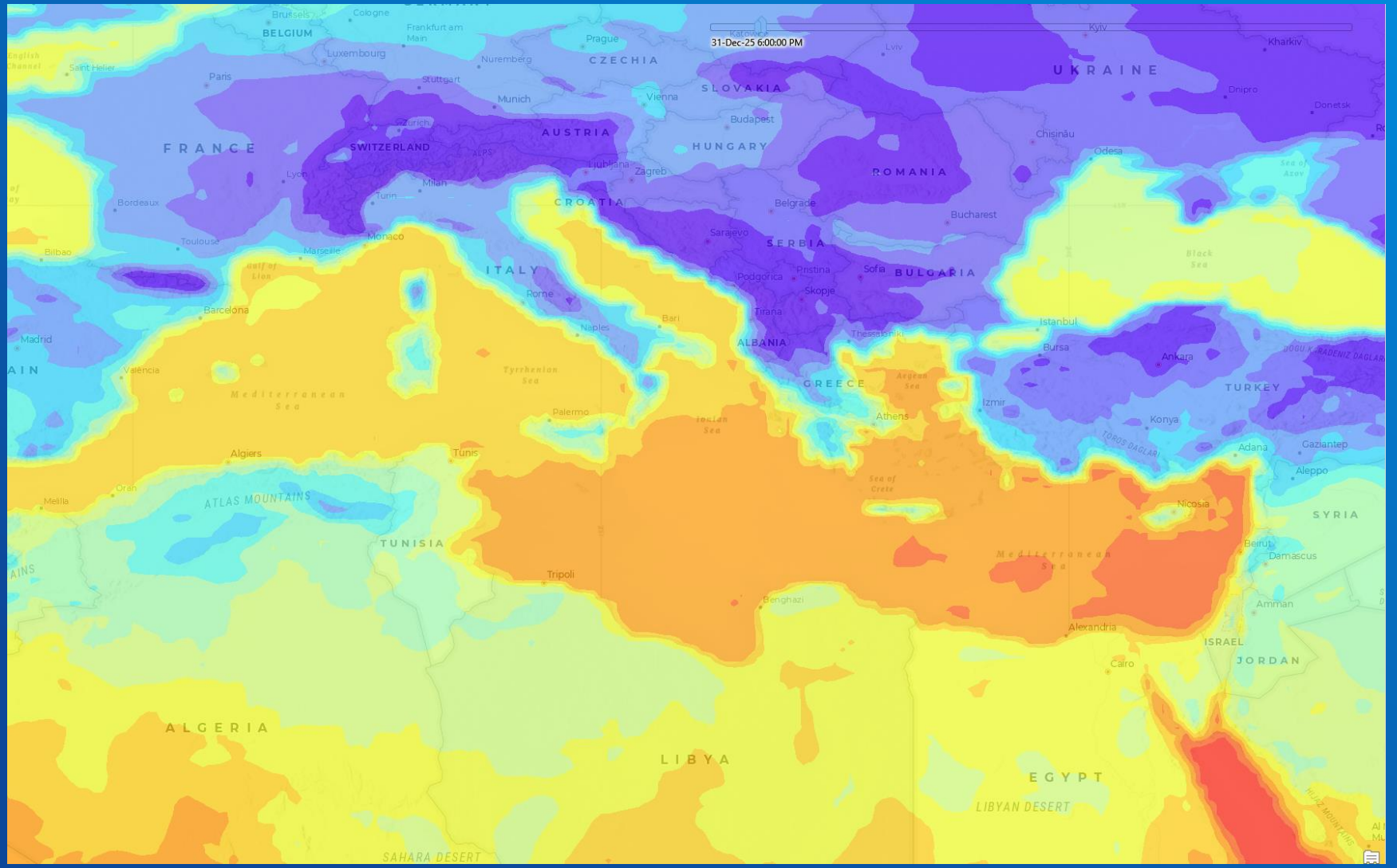
Create Multidimensional Raster (2)

From time series image data

- Create a mosaic dataset
- Add rasters to the mosaic dataset
  - Use Landsat, sentinel, or other raster types
- Make it multidimensional
  - 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




31-Dec-25 6:00:00 PM
BELGIUM
Brussels
Cologne
Frankfurt am Main
Luxembourg
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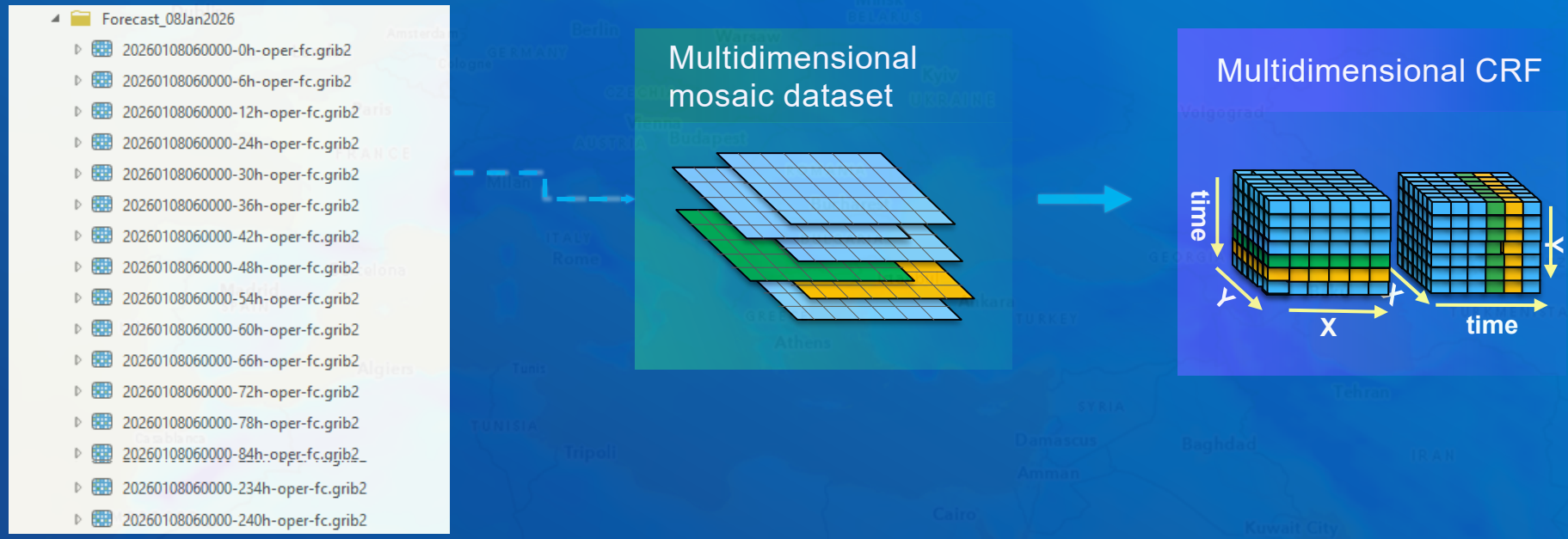
Prague
CZECHIA
Saint Helier
Paris
Stuttgart
Munich
Vienna
SLOVAKIA
Budapest
UKRAINE
Kyiv
Kharkiv
Dnipro
Donetsk
FRANCE
SWITZERLAND
AUSTRIA
HUNGARY
Chisinău
Odesa
ROMANIA
Zagreb
Ljubljana
Milan
Turin
Lyon
Bordeaux
CROATIA
Belgrade
Bucharest
Sarajevo
SERBIA
Toulouse
Monaco
Marseille
Bilbao
ITALY
Pristina
Sofia
BULGARIA
Podgorica
Skopje
Rome
Tirana
Barcelona
Istanbul
Bari
Naples
Thessaloniki
ALBANIA
Madrid
Bursa
Ankara
Valencia
GREECE
TURKEY
Izmir
Athens
Palermo
Konya
Adana
Gaziantep
Aleppo
Algiers
Tunis
Oran
Melilla
ATLAS MOUNTAINS
Nicosia
SYRIA
TUNISIA
Beirut
Damascus
Tripoli
Benghazi
Amman
Alexandria
ISRAEL
JORDAN
Cairo
ALGERIA
LIBYA
EGYPT
LIBYAN DESERT
SAHARA DESERT
Mediterranean Sea
Tyrrhenian Sea
Ionian Sea
Aegean Sea
Sea of Crete
Black Sea
Sea of Azov
Gulf of Lion

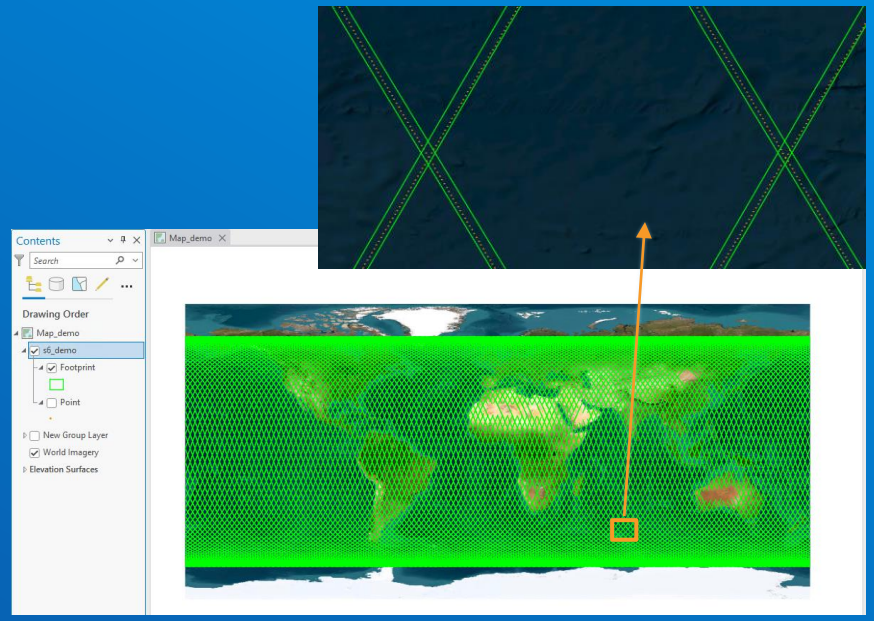
Build a Time Series from slices (single time)

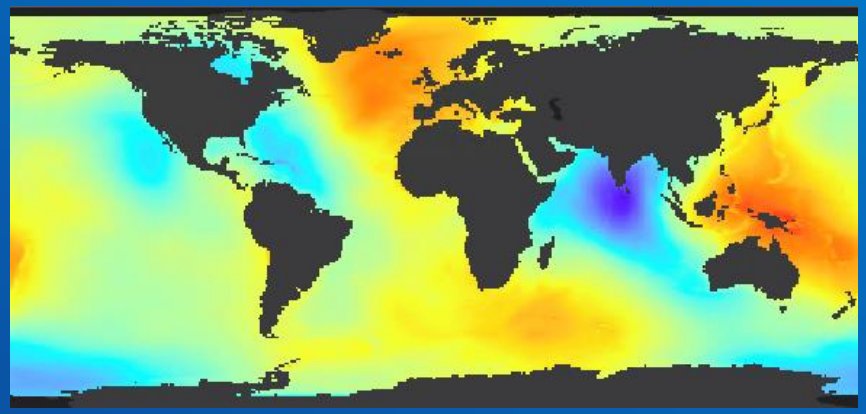


Create Multidimensional Raster (3)

From altimetry data

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

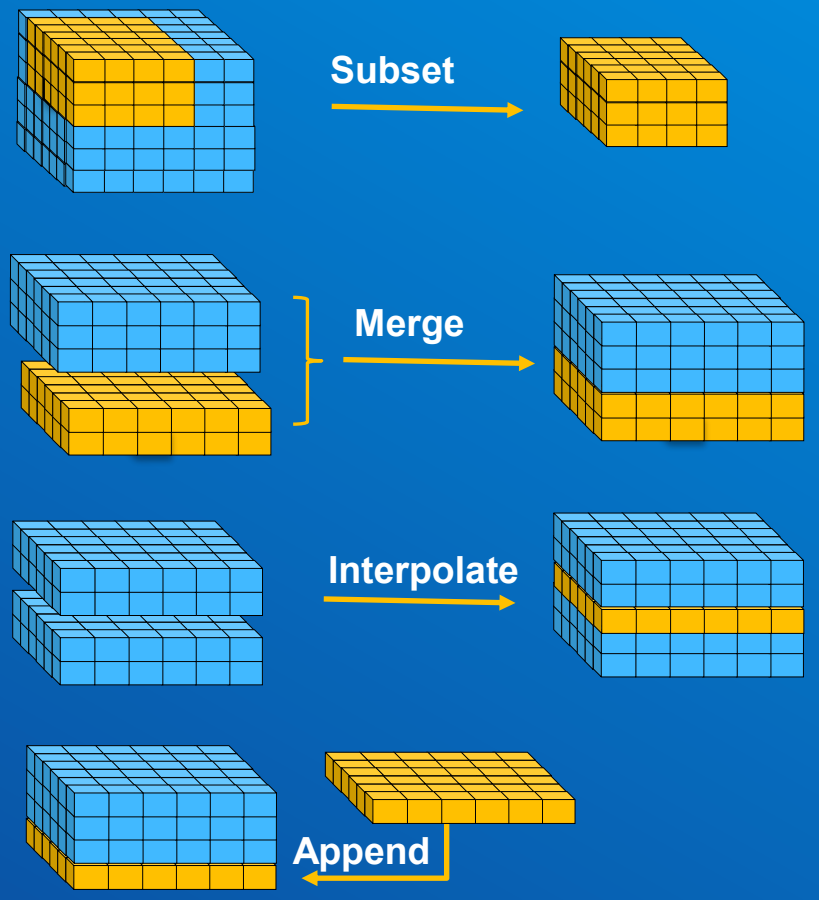




Process multidimensional rasters

Subset, merge, interpolate, append, update

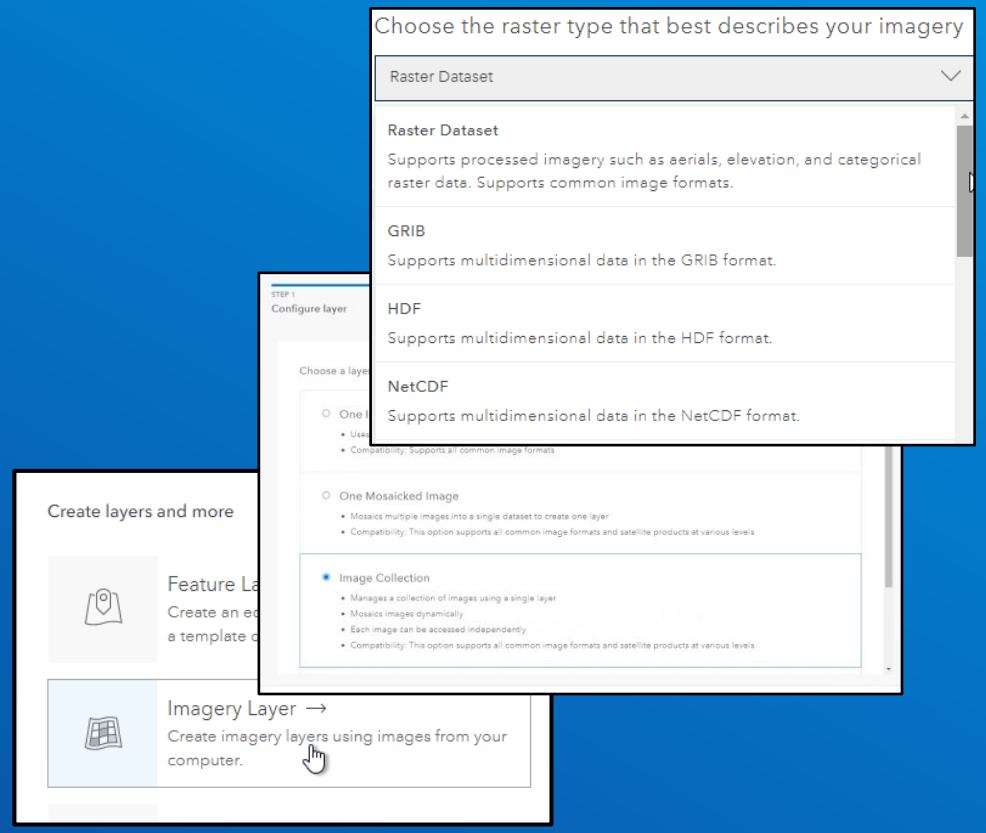
- **Subset Multidimensional Raster** tool
- **Merge Multidimensional Raster** tool
- **Interpolate By Dimension** raster function
- **Manage Multidimensional Raster** tool
- Smoothing
  - **Statistics** raster function
  - **Dimensional moving statistics** raster function



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



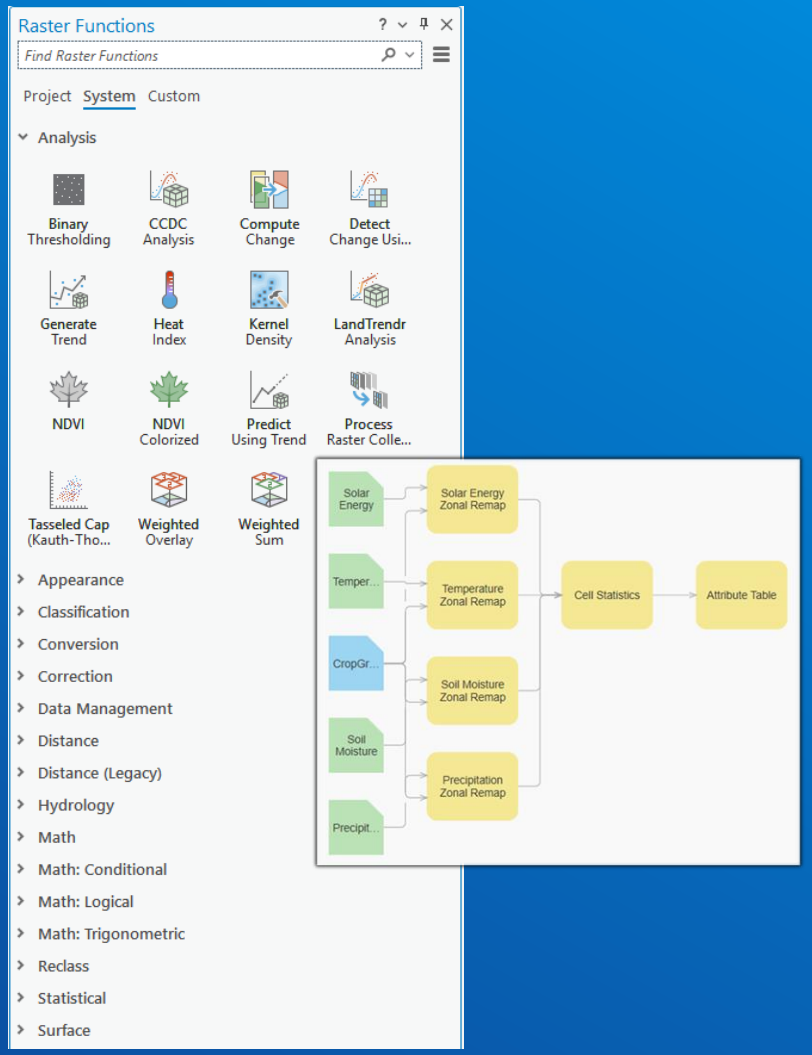
Analyze Multidimensional Raster

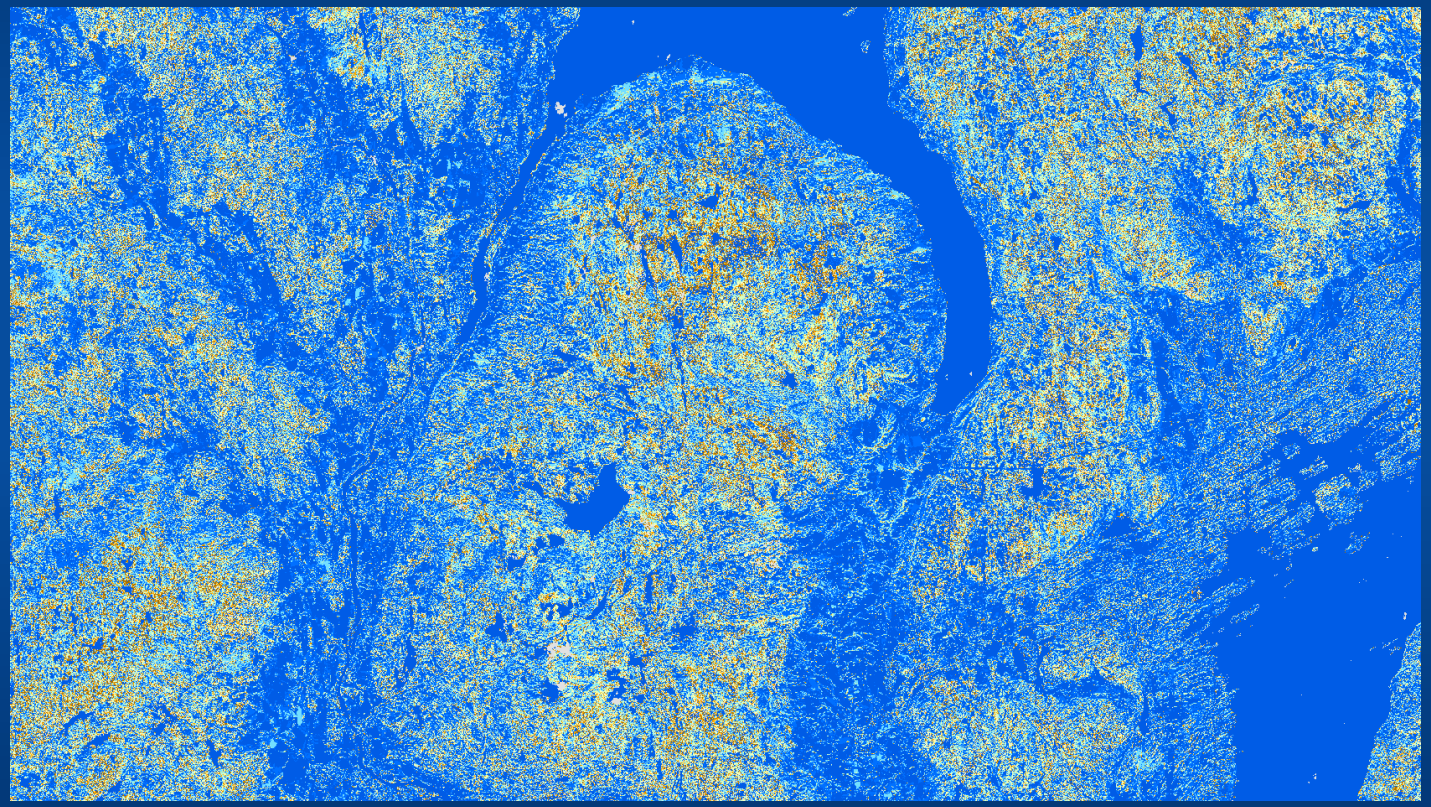
Multidimensional analysis – slice by slice

Using raster function

- Dimension-aware raster functions

- Dimension-aware map algebra and operators





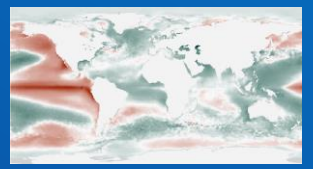
Examples

Using Time Series from Sentinel-2

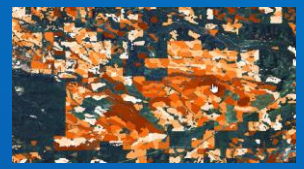
Multidimensional analysis – reducing dimensions

Geoprocessing tools

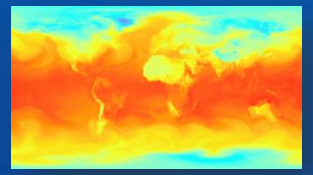
Trend & predictive analysis



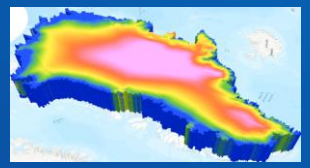
PCA pattern identification



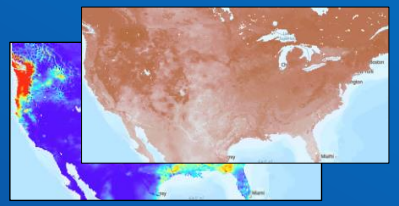
Change Detection



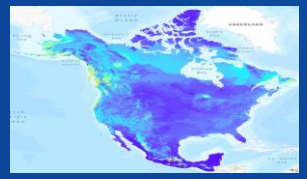
Data aggregation



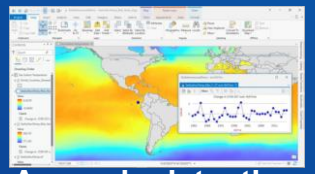
Interpolation



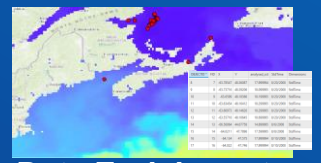
Variable Correlation



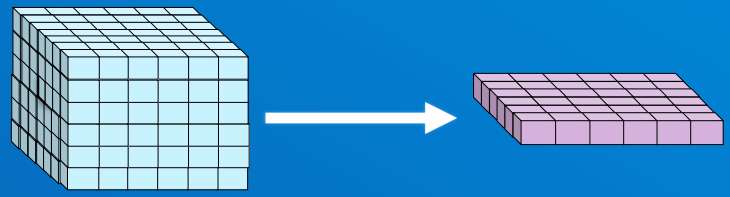
Find when and where

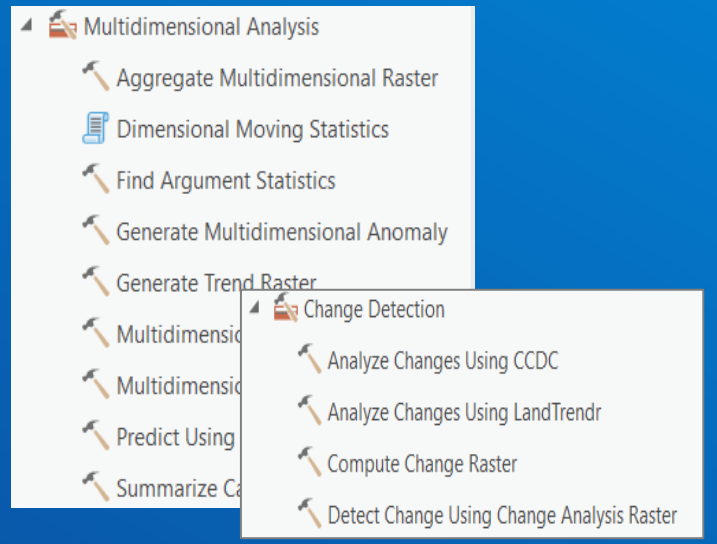


Anomaly detection



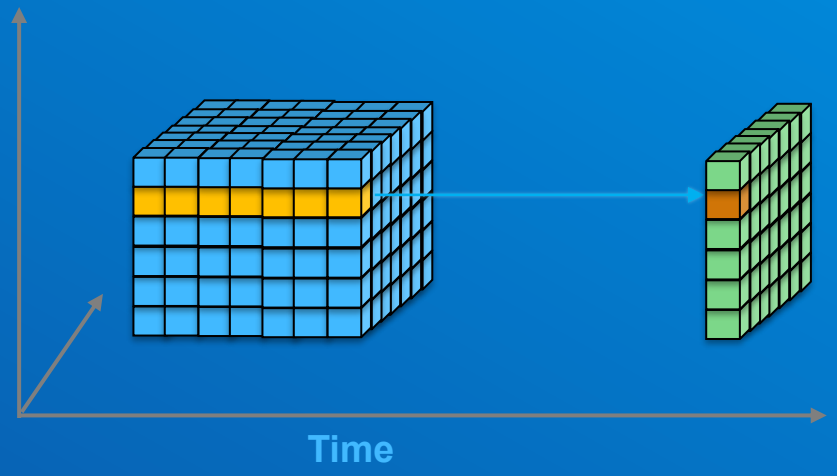
Data Enrichment



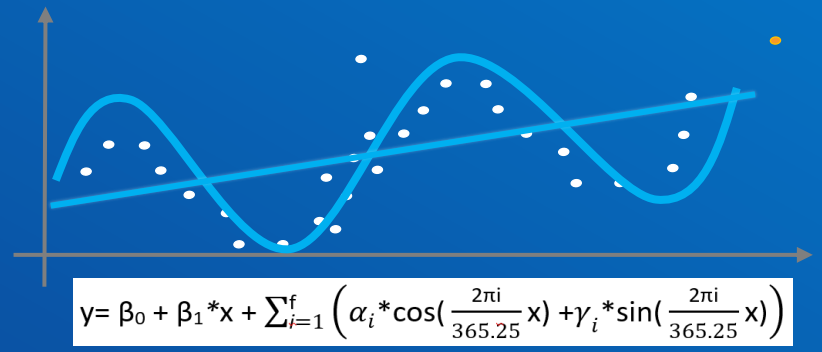


Trend and predictive analysis

- 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

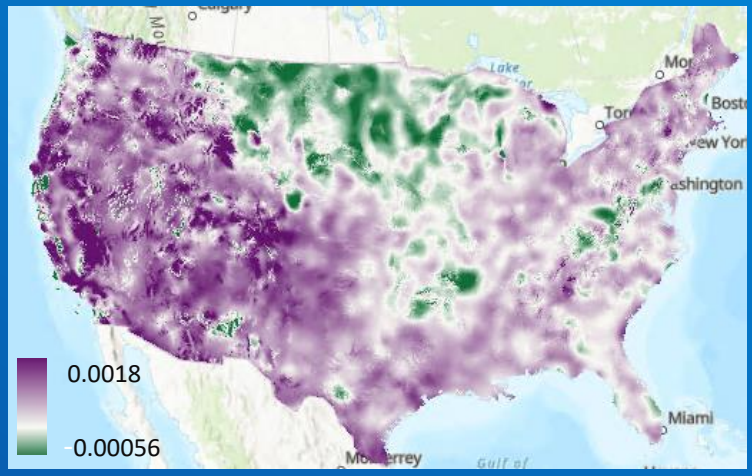


$$y = \beta_0 + \beta_1 * x + \sum_{i=1}^{f} \left(\alpha_i * \cos\left(\frac{2\pi i}{365.25} x\right) + \gamma_i * \sin\left(\frac{2\pi i}{365.25} x\right) \right)$$

Visualize trend raster

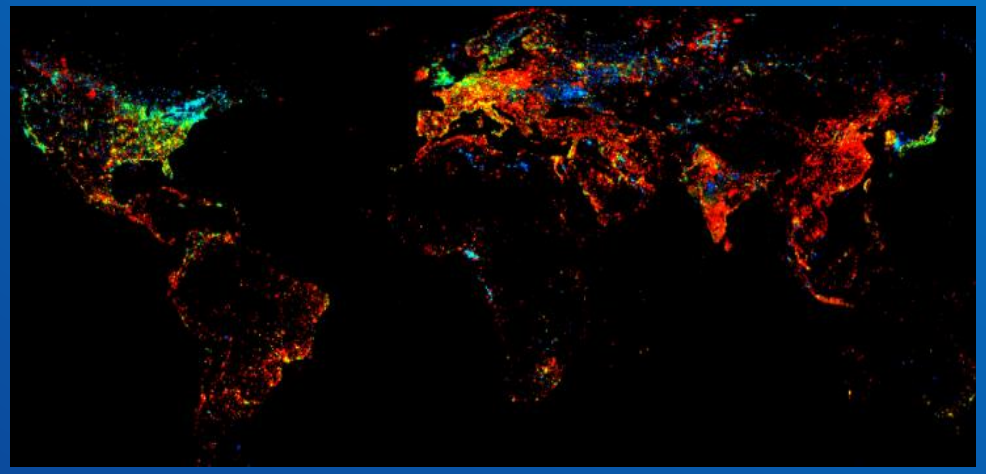
Trend maps

- Slope band



Temperature trend using slope

- Trend to RGB function



Trend of nighttime lights

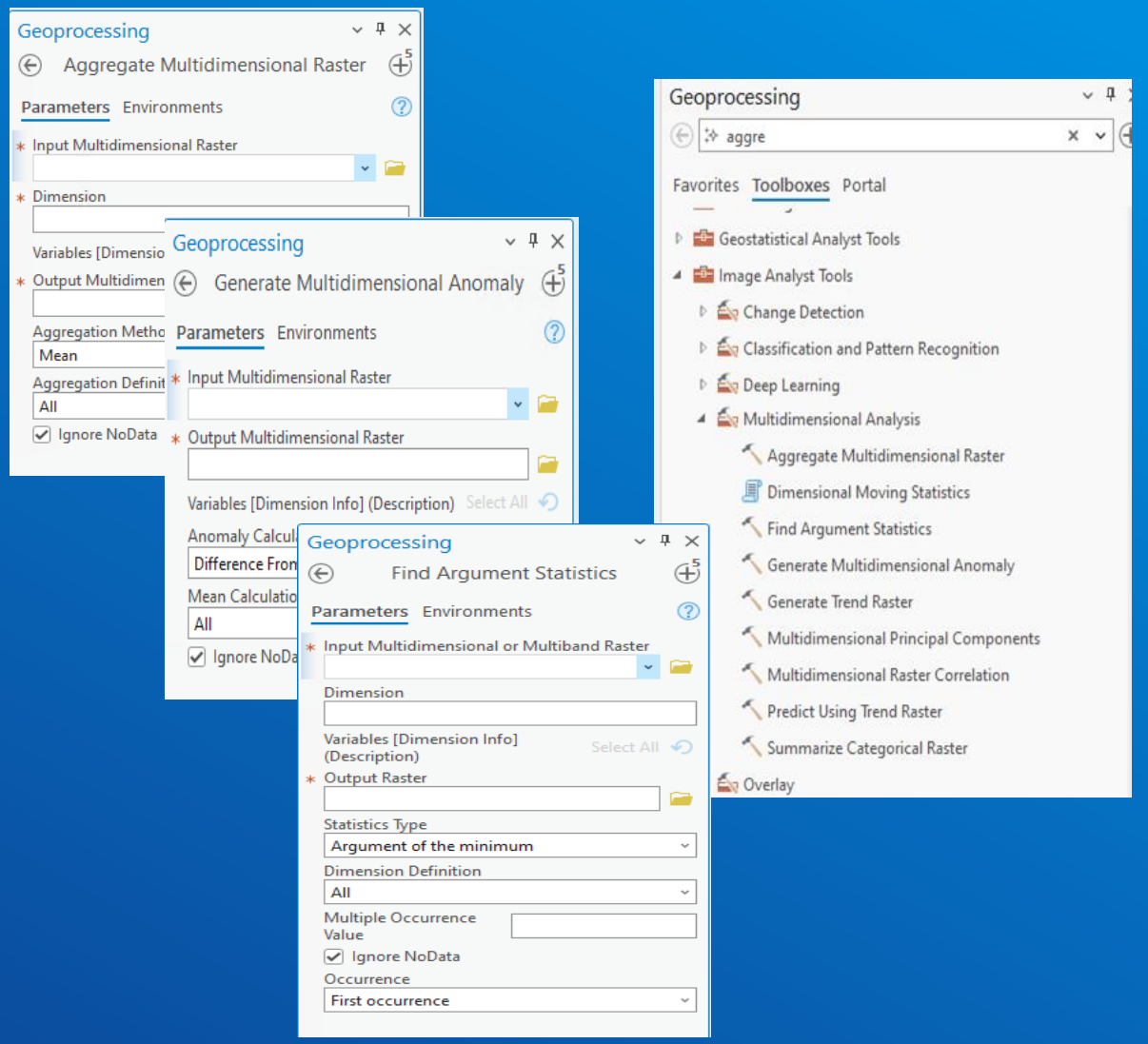
More tools for analyzing patterns

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

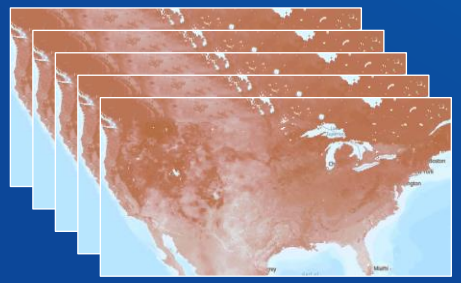
- **Find Argument Statistics**
  - Date and duration when reaching max, mean, median,
  - and specific value



Compute correlations between two variables

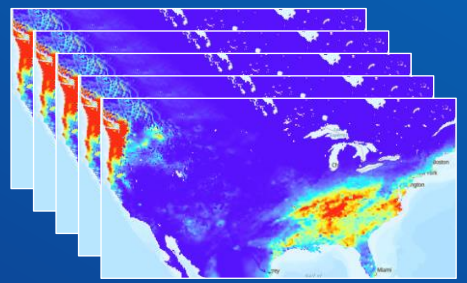
Multidimensional Raster Correlation tool

- Quantify correlation, similarity, and synchronization
  - Pearson, Spearman, Kendall
  - Support lag
  - Cross correlation



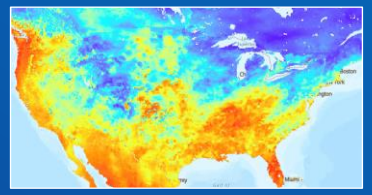
Monthly soil moisture

+

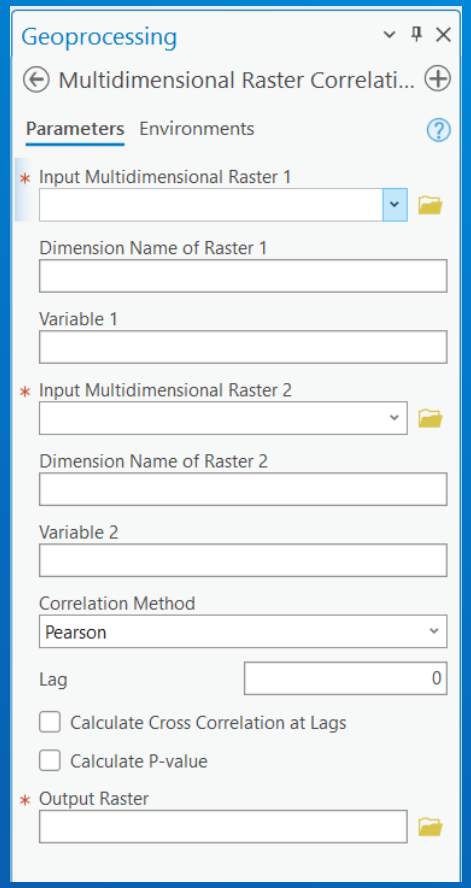


Monthly precipitation

→



Correlation raster



Change Detection

Where

What

Extent

Image to image

- Value/percent based
- Categorical based
- Spectral based

Time1 Time2 Change

Where

What

Extent

When

How many changes

Abrupt or slow

Increase, decrease, duration

Image time series

- CCDC
- LandTrendr

Change detection of time series imagery

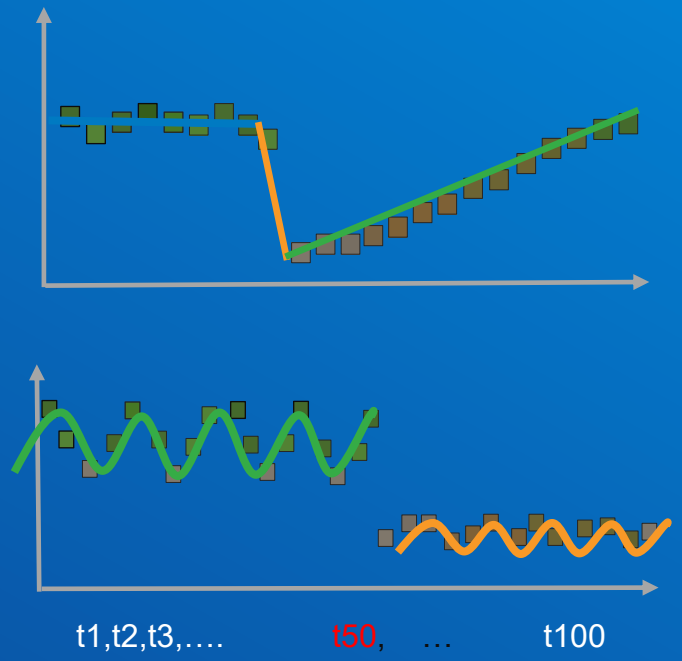
CCDC and LandTrendr

Input time series

LandTrendr (Landsat-based Detection of Trends and Disturbances)

- Linear, temporal segmentation
- Yearly data

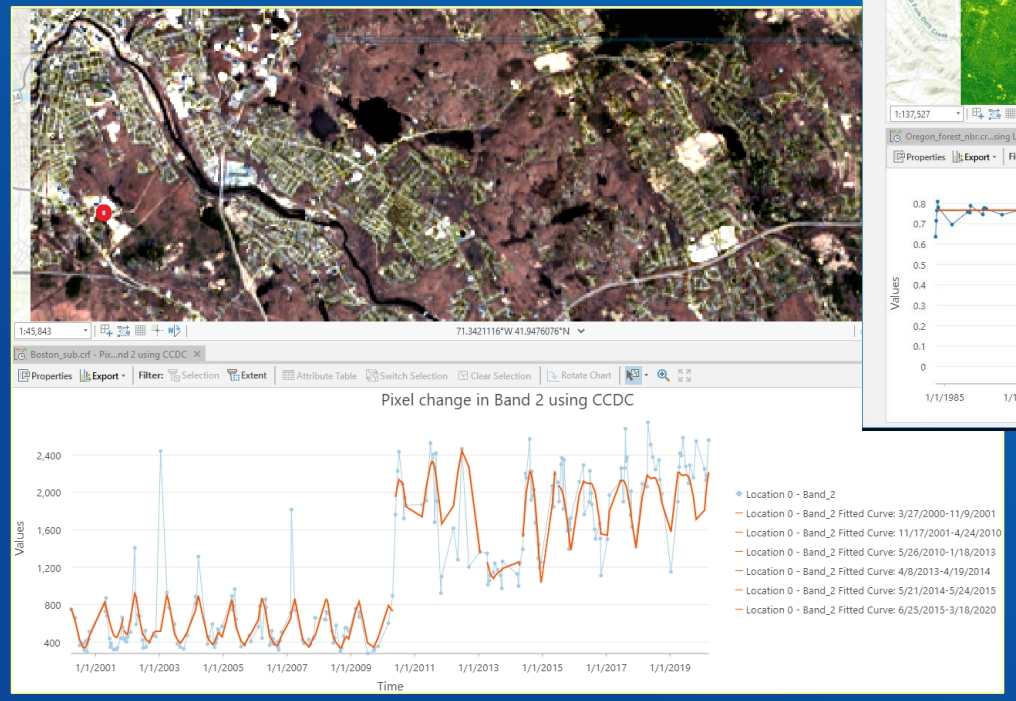
- CCDC (Continuous Change Detection and Classification)
  - Harmonic regression
  - Accounts for seasonality
  - Dense image time series

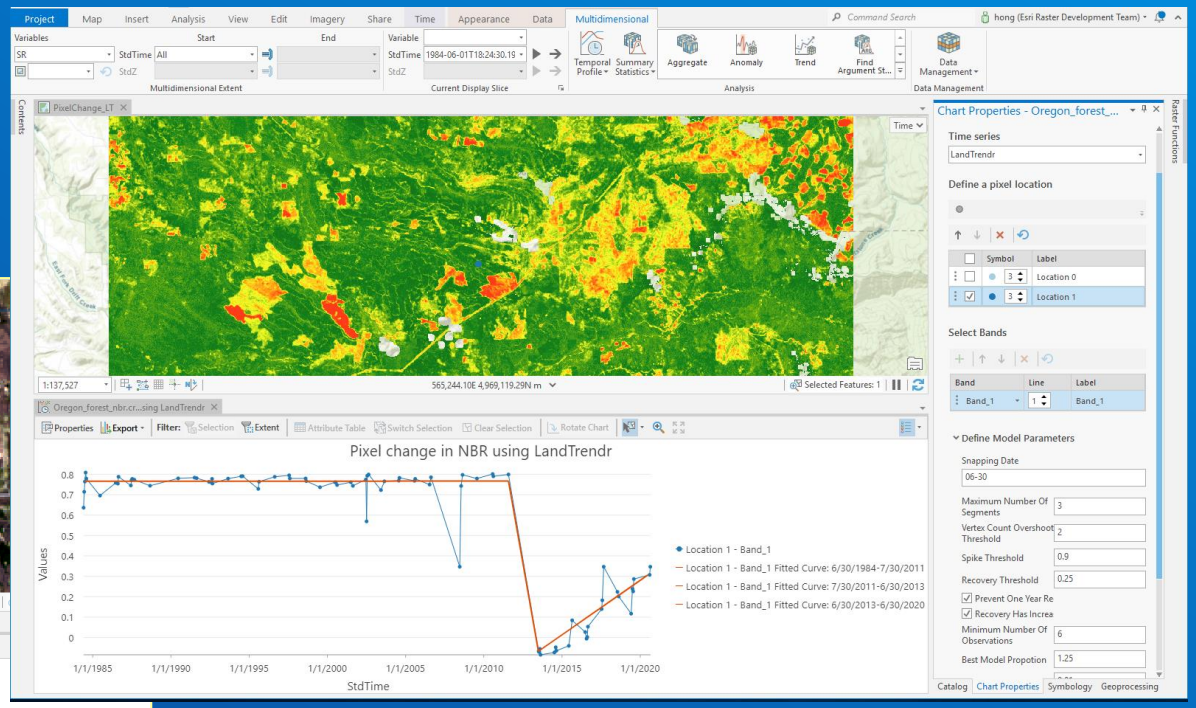


Change detection of time series imagery

Pixel time series change explorer in ArcGIS Pro

- Detect and explore change for a pixel across time

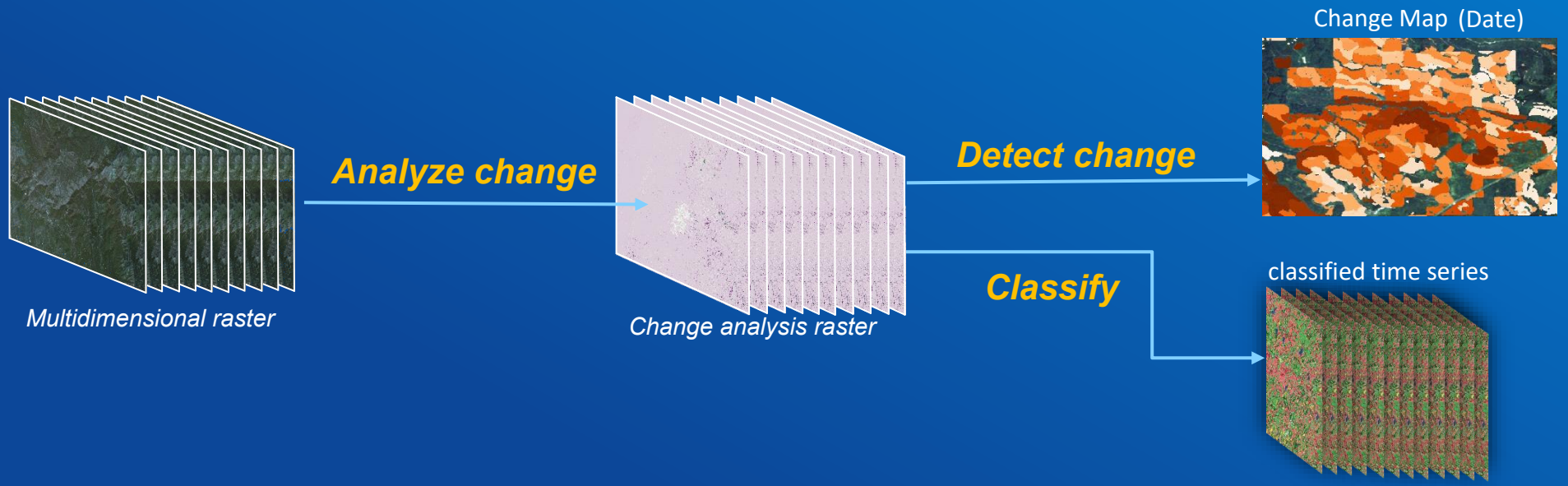




Change detection of time series imagery

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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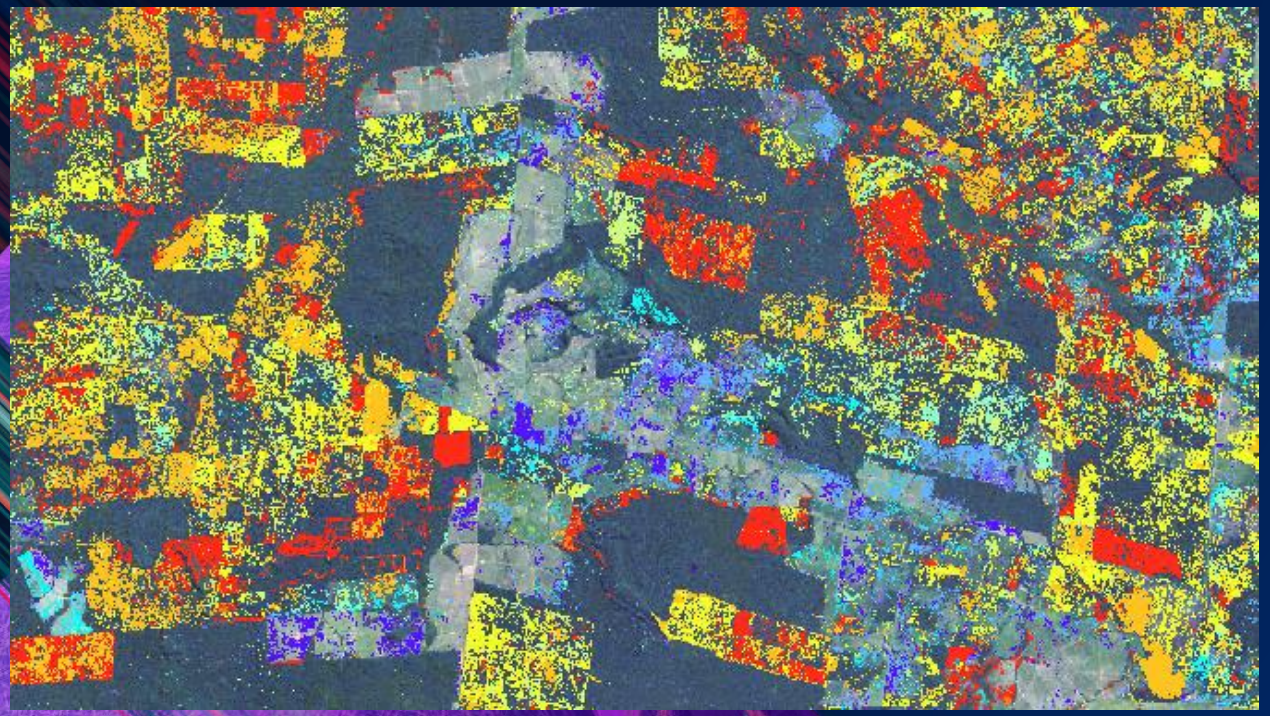
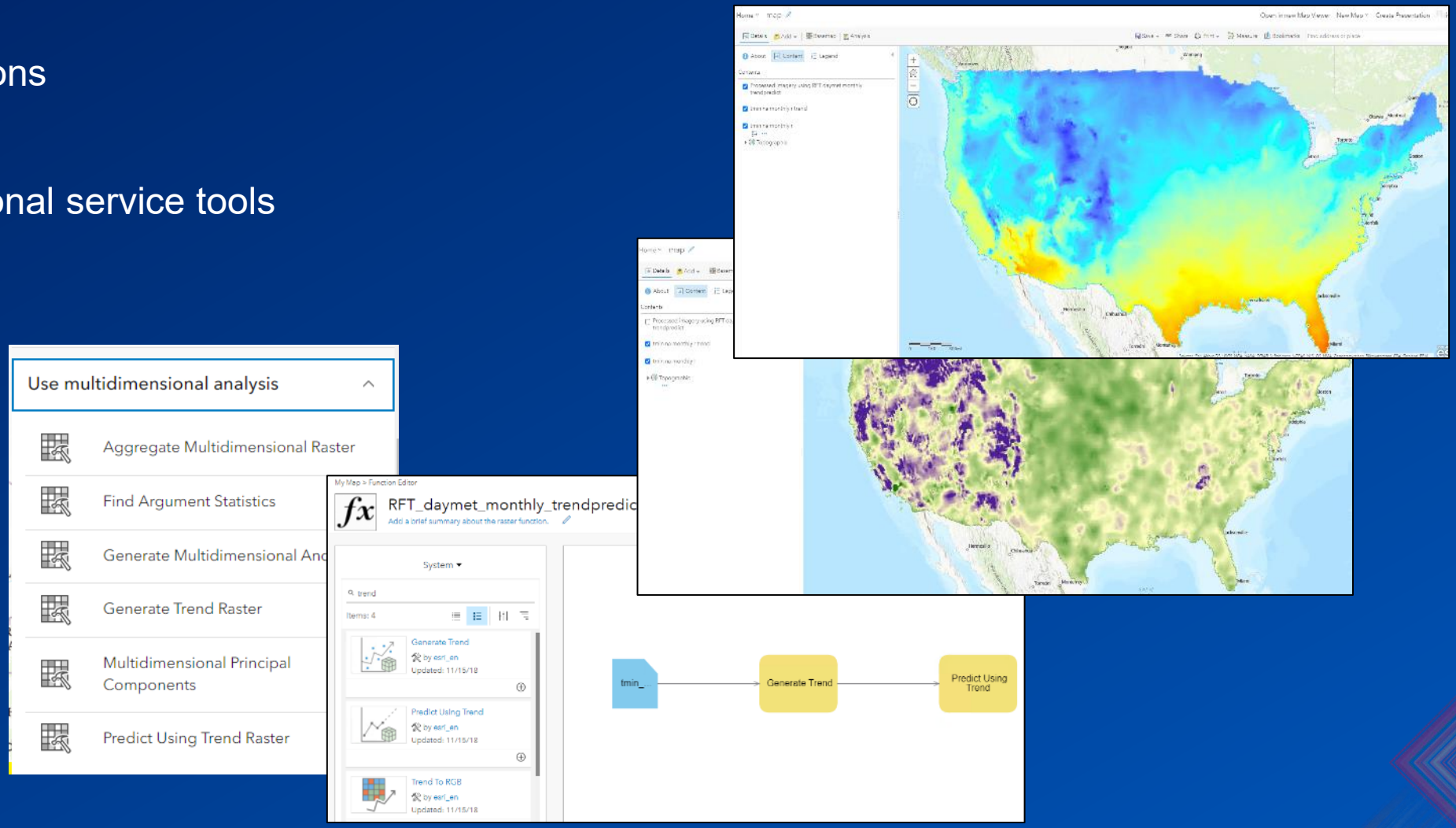


Deforestation in the Brazilian Amazon Rainforest

Hong

Multidimensional analysis in web map viewer

- Raster functions
- Multidimensional service tools



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

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

- go.esri.com/ImageryAndRemoteSensingResources

Sign up for an Instructor-Led Courses

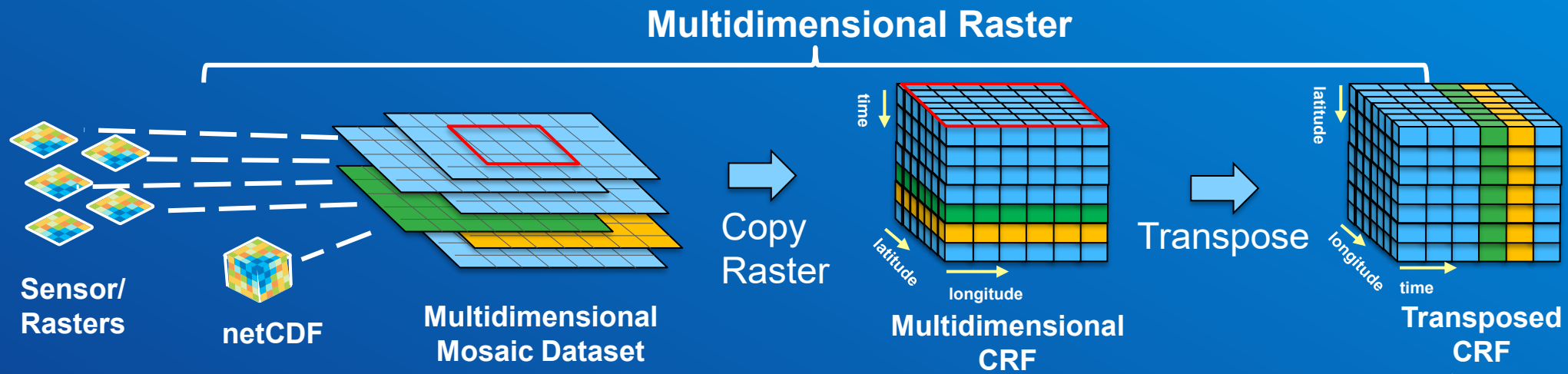
- go.esri.com/Imagery_Learning

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

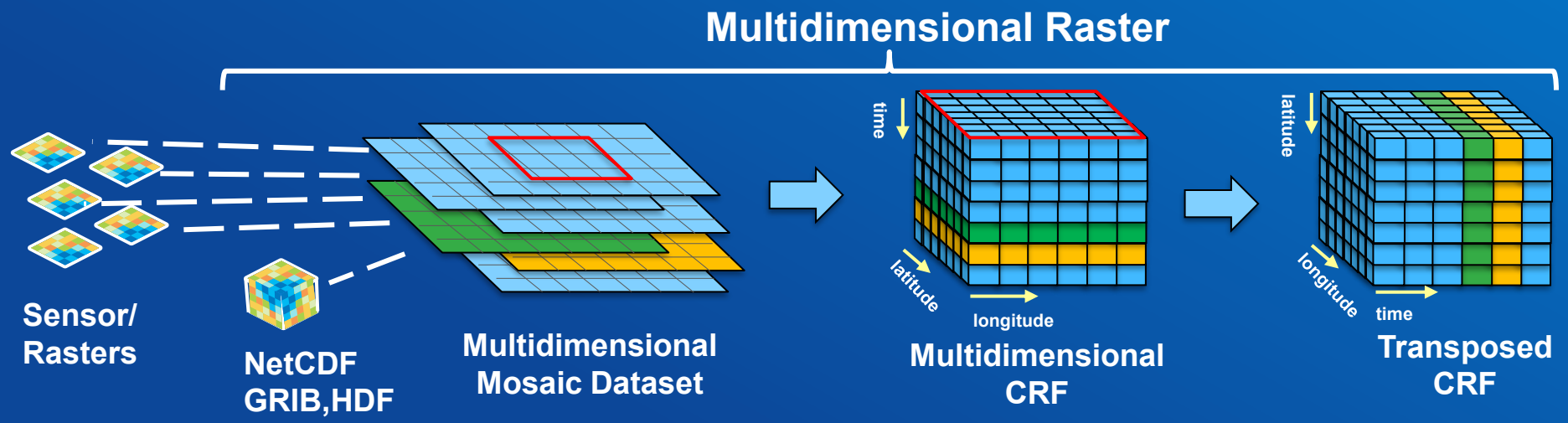
Mosaic Dataset

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

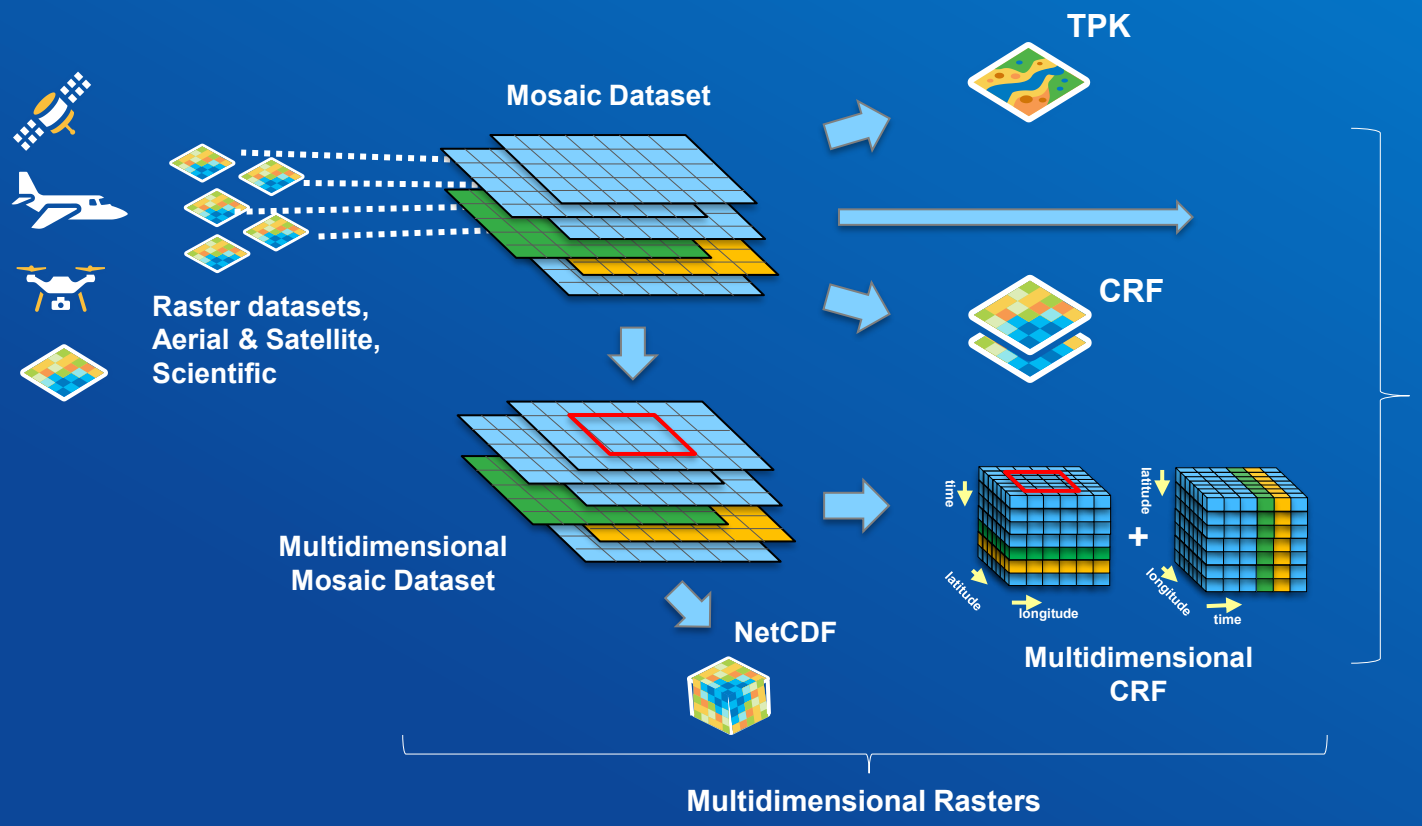
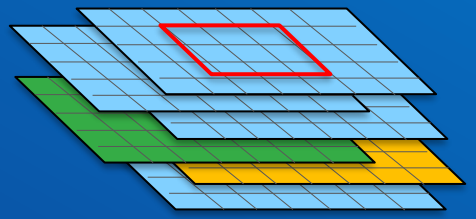


Image Server

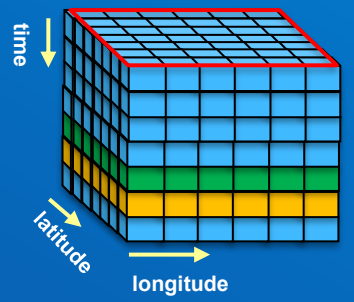
- Dynamic Imagery Services
- Tiled Imagery Services

Multidimensional Raster for Analysis

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

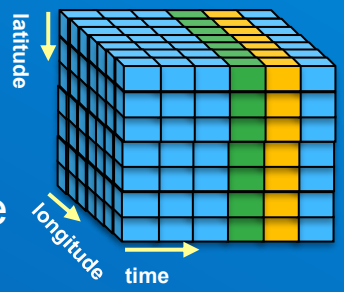


Multidimensional Mosaic Dataset



Multidimensional CRF

Transpose

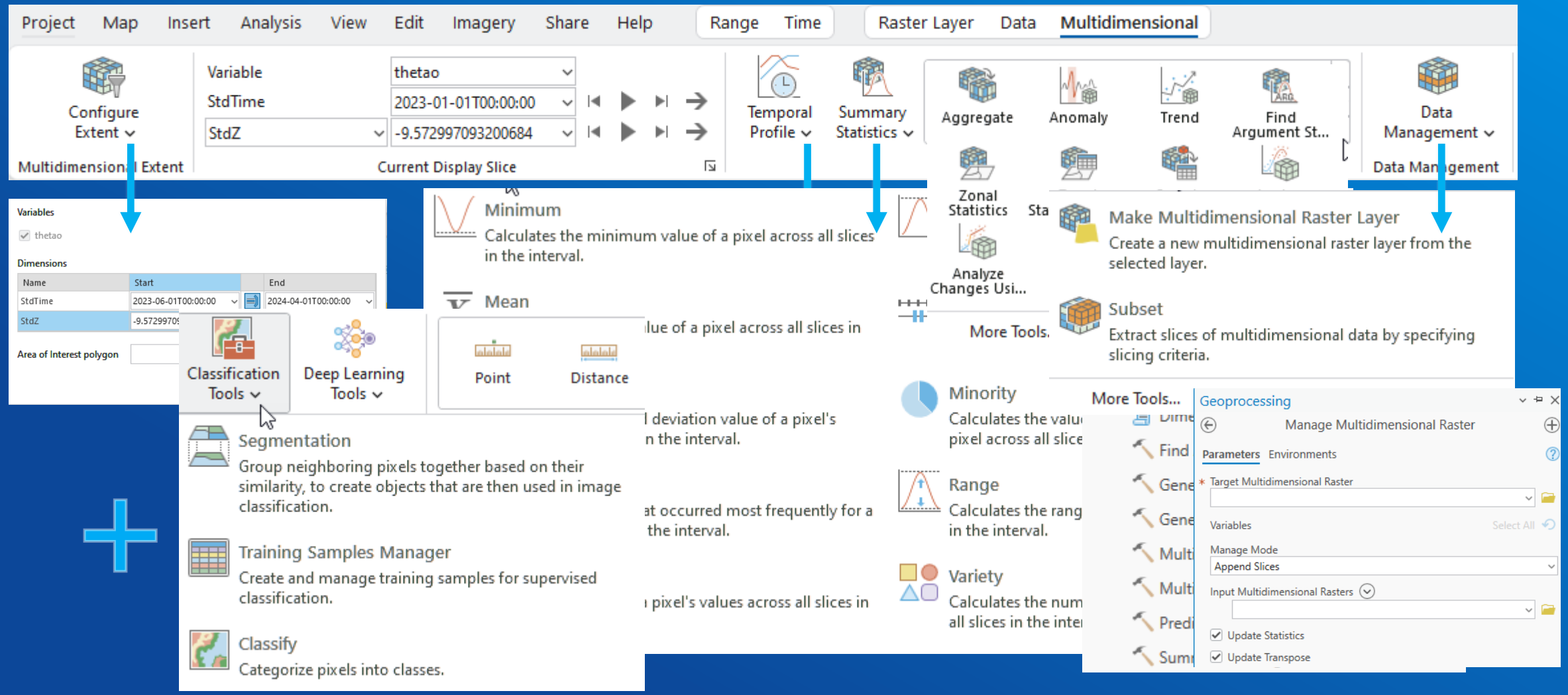


Transposed CRF

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



2. Multidimensional Raster Functions