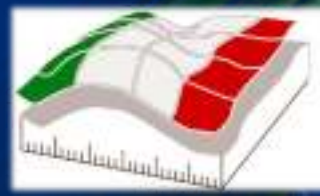
Geomorphometry in the Cloud: New Capabilities and Future Directions of ArcGIS

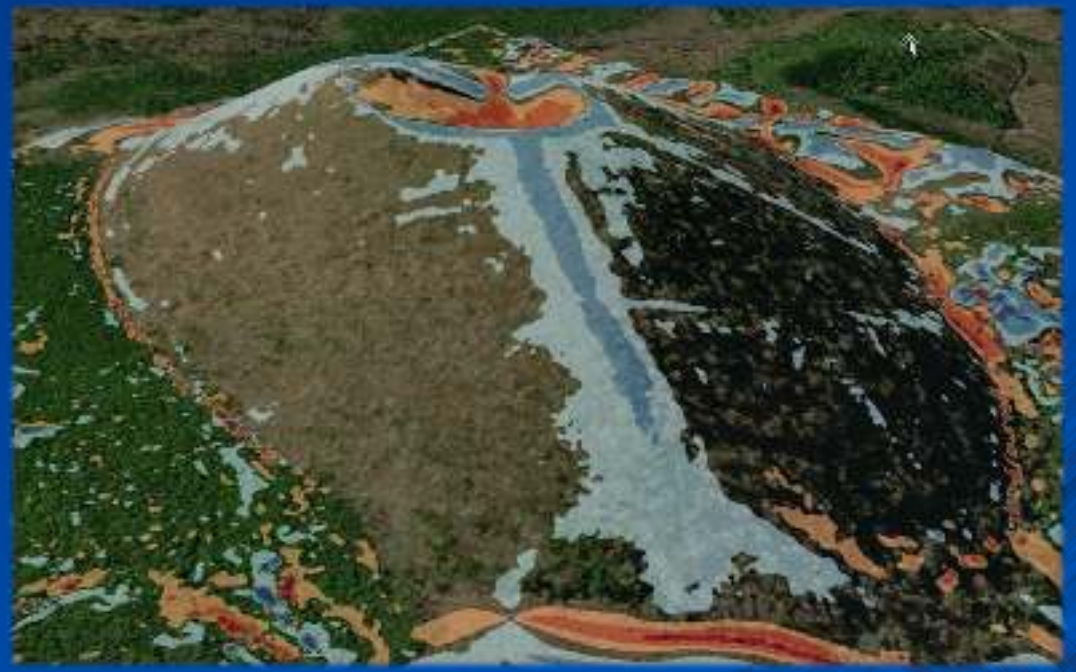
Nawajish Noman, Steve Kopp, Tania Lopez-Cantu



GEO MORPHOMETRY
PERUGIA ITALY
2025
JUNE 9-13

Agenda

- ArcGIS
- Living Atlas and Elevation Services
- Analysis in the Cloud
- Advancements in Raster Analysis
- Extending Analytical Capability



ArcGIS A Geospatial Enterprise Analytics System

Driving data insights and supporting decision making

Users

Knowledge Workers

Data Scientists

GIS Analysts

Experiences

BROWSER NOTEBOOKS MODELS DESKTOP APIs

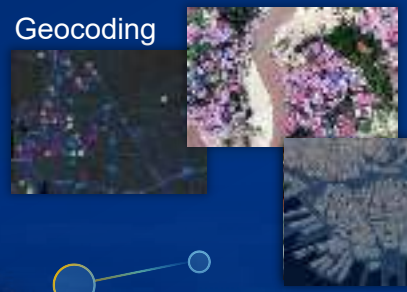
Open Science Integrations

R PROJECT MATPLOTLIB
ANACONDA PANDAS PYTORCH
GDAL SCIKIT LEARN
PYTHON JUPYTER FAST.AI

Analytics

Geocoding

GeoAI



Spatiotemporal Statistics

Network

Big Data

Graph

3D

Imagery & Raster

Overlays

GeoEnrichment

Real-Time

ArcGIS

Data

Relational Database

Vector

Unstructured

Graph Database

Geodatabase

Tabular

Multi-dimensional

Lidar / Point Cloud

Raster

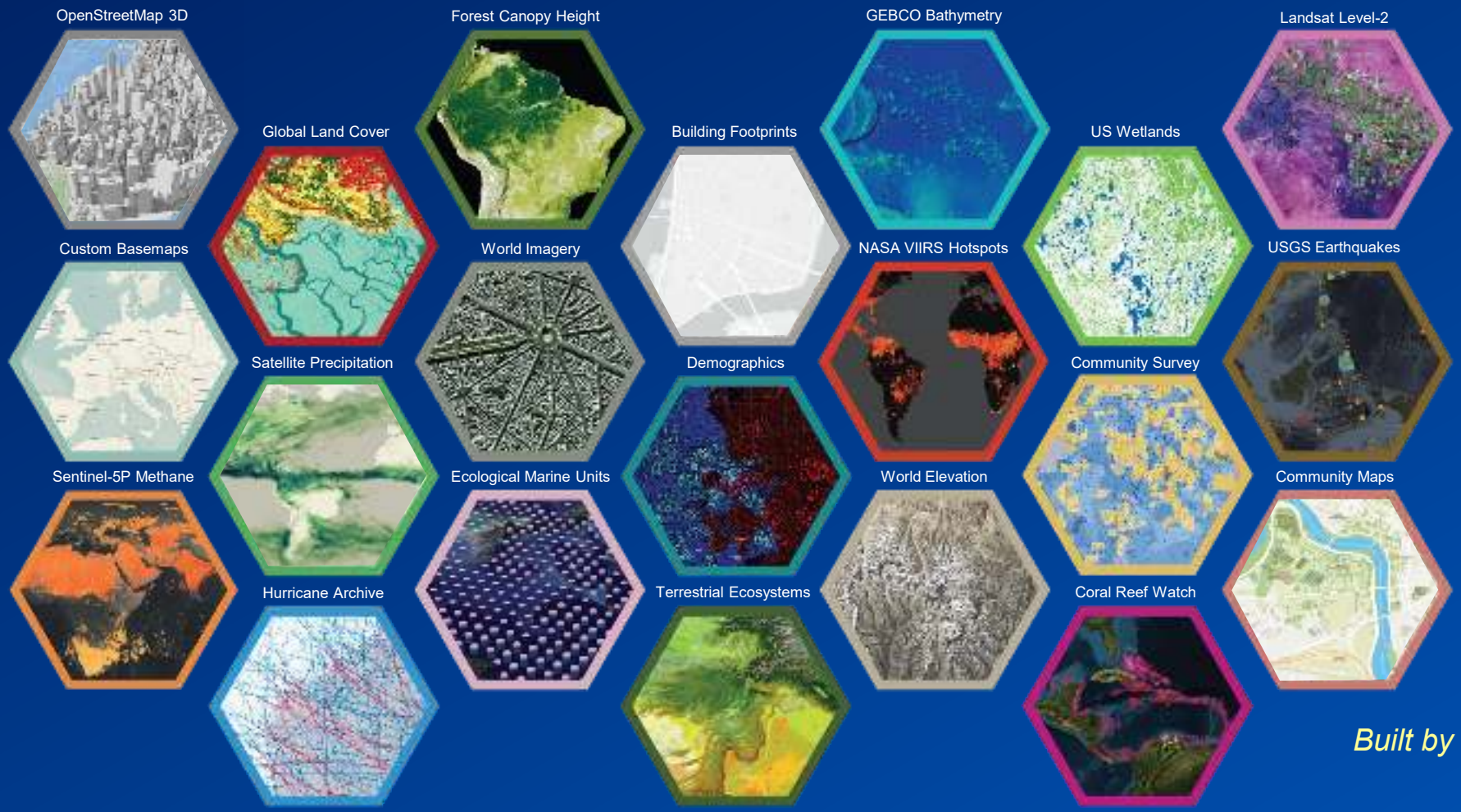
Data Warehouse

ArcGIS Living Atlas

An open ecosystem for science

ArcGIS includes the Living Atlas of the World

Esri Curated Collection of Ready-to-Use Maps, Layers, and Apps



- 10,000+ Quality Items
- Wide Variety of Topics

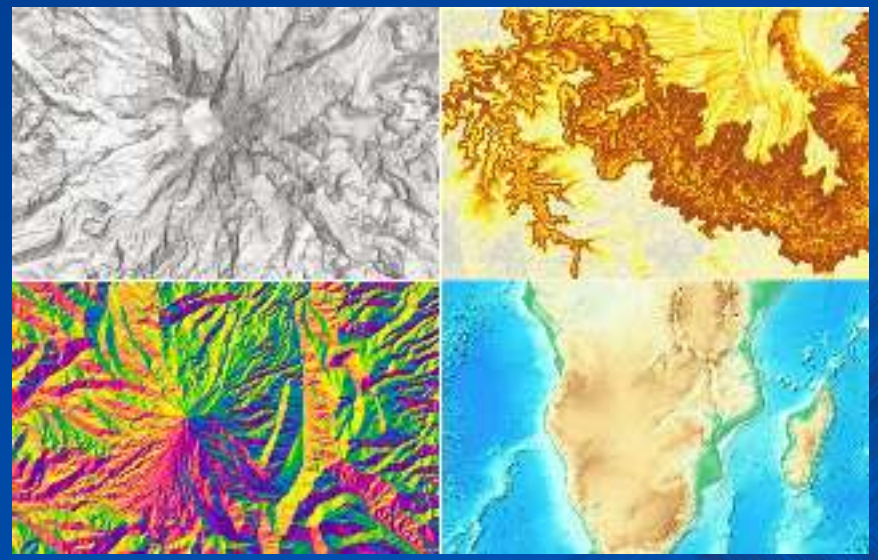
- Updated Continuously
- Billions of Requests Daily

- Accessible Across ArcGIS
- Available to All User Types

Built by and for the ArcGIS Community

Overview of world elevation layers

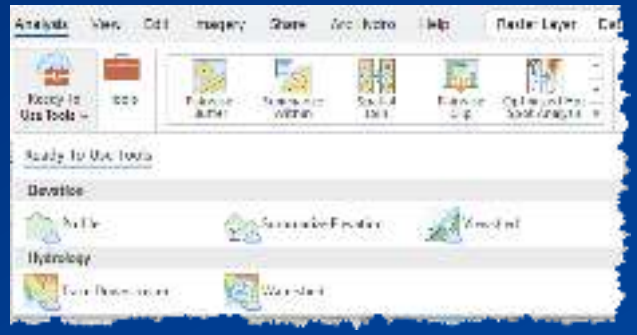
- Global collection of multi-resolution & multi-source
  - 1000 meters to 0.25 meters
  - ~ 188,000 rasters (~ 8 TB, LERC compressed MRF's)
- Best public, commercial and community data
  - USGS, SwissTopo, Ordnance Survey, Geoscience Australia, NASA, etc
  - Airbus DS, Maxar
  - 50 authoritative data providers and growing …
- Ready to use layers, maps and tools
  - Analysis and Visualization
  - 2D and 3D visualizations



Ready To Use – Hydrology and Elevation Analysis Tools

Analytics and input data in a hosted service

- Hydrology
  - Trace Downstream
  - Watershed
- Elevation
  - Profile
  - Viewshed
  - Summarize elevation
- Available in Pro, Online, and API



Why perform analysis in ArcGIS Online?

- Cloud-based solution that you can access from anywhere
- Access layers and services from your organization, Esri, and users around the world
- Quickly share results and maps with your organization, and easily integrate with apps

Analysis in ArcGIS Online using the Map Viewer

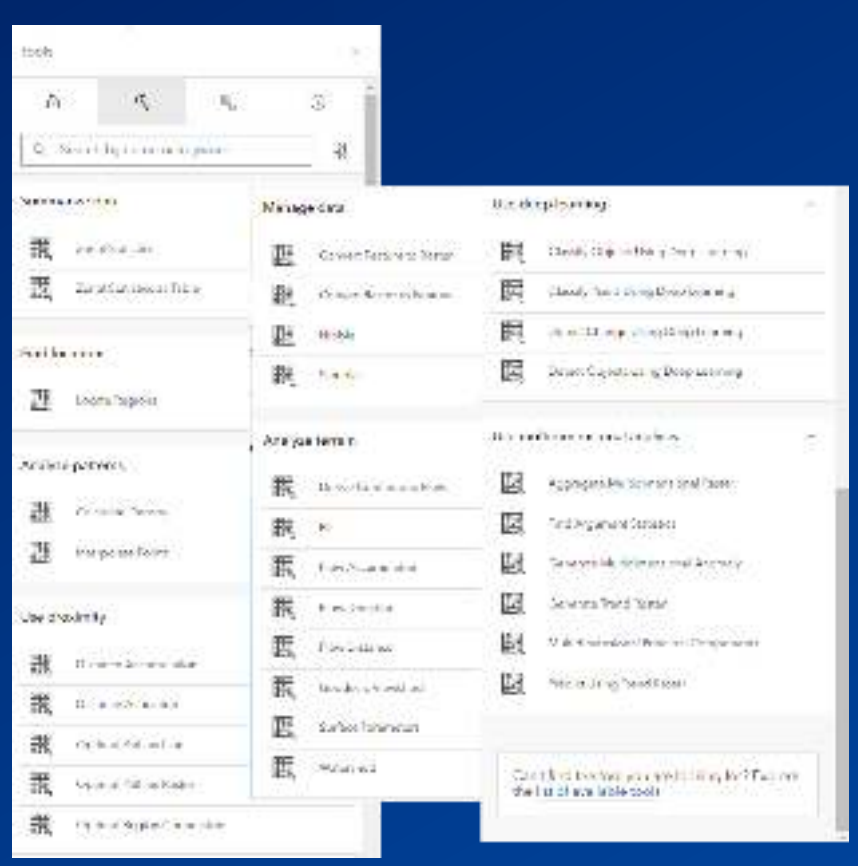
The Analysis pane (home) currently provides the following options:

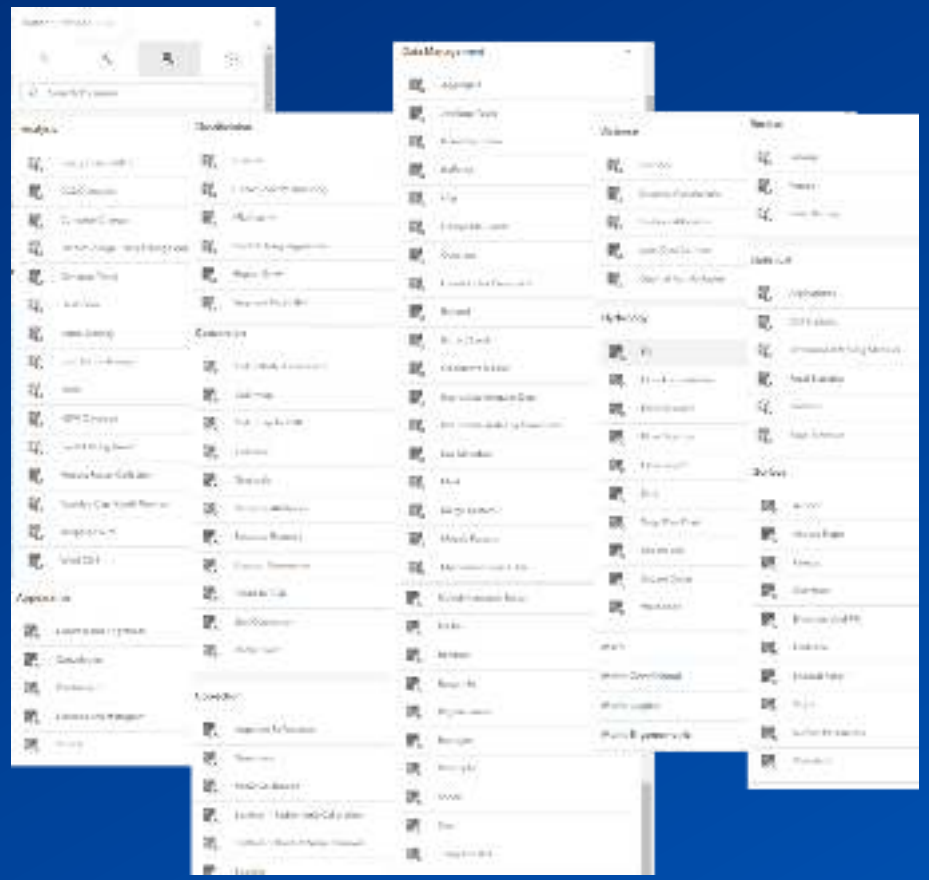
1. Tools
2. Raster Functions, Raster Function Editor
3. History
4. Analysis settings
5. Charting

Working on the Model Builder and Notebooks support.

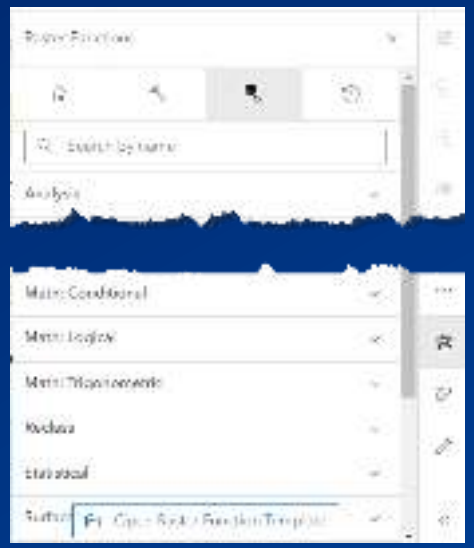
Raster Analysis Tools and Raster Functions

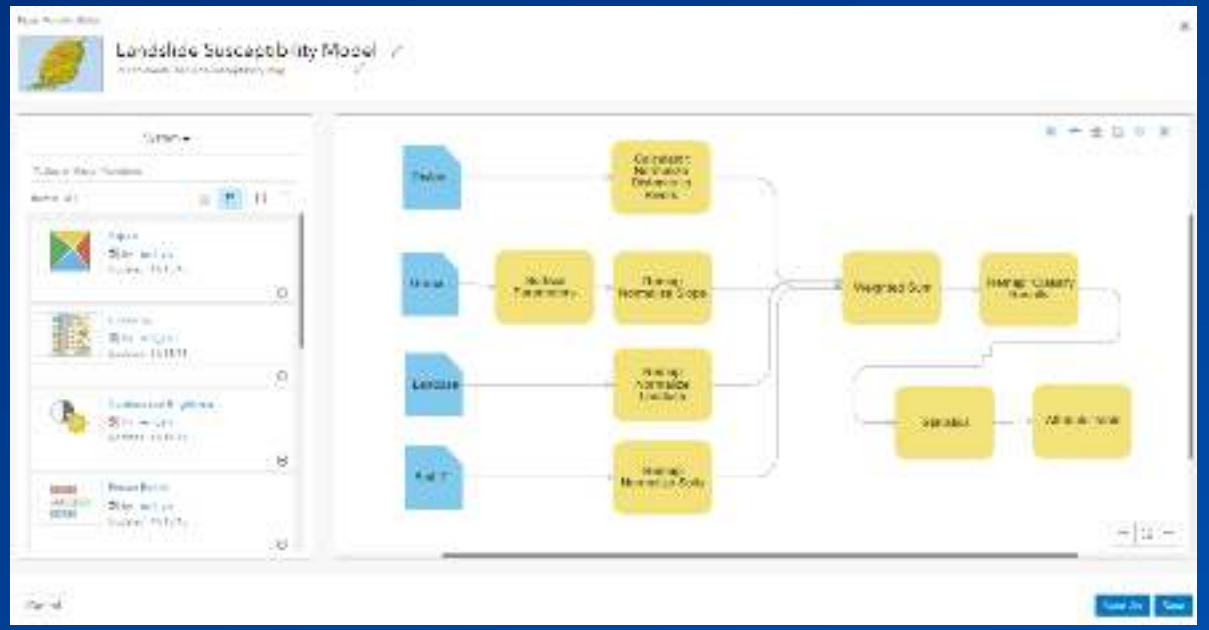
- 37 Raster Analysis Tools
- 164 Raster Functions

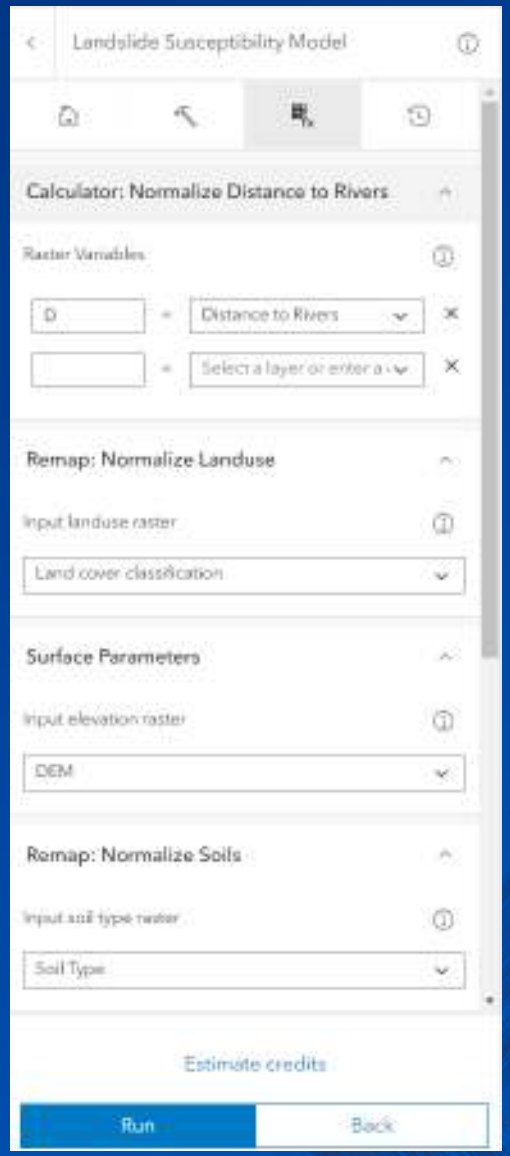




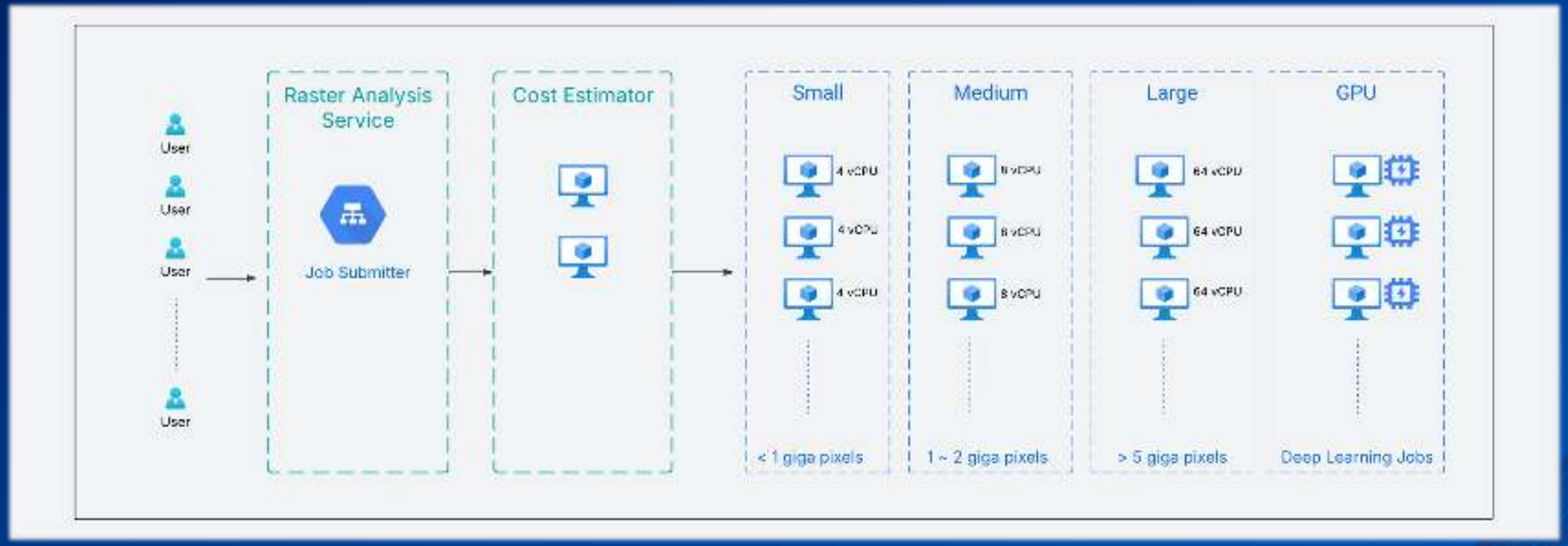
Raster Function Editor





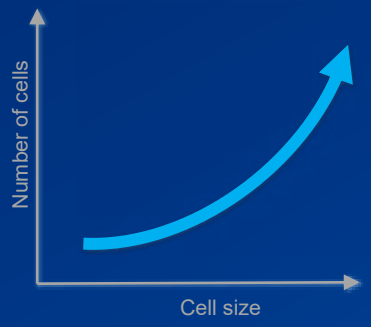


Raster Analysis in Online: Scaling



Scaling and Performance Improvement Challenges

Hydrologic Unit Codes (HUCs)



Large

- HUC2: 22 regions
- HUC4: 245 subregions
- HUC6: 405 basins
- HUC8: ~2,400 subbasins
- HUC10: ~19,000 watersheds
- HUC12: ~105,000 subwatersheds

Small

Redlands is in HUC8 1808001
~718 sq miles or ~1,860 sq km

- CS 60 m: ~0.5 million cells
- CS 30 m: ~2.1 million cells
- CS 10 m: 18.6 million cells
- CS 1 m: 1.86 billion cells

Approaches

- Parallel computation
  - Reading of the inputs
  - Writing of the outputs
  - Analysis
- GPU computation
- Distributed computation

GPU Computation

- Slope, Aspect
- Geodesic Viewshed
- Feature Preserving Smoothing
- Raster Solar Radiation
- Feature Solar Radiation
- Multiscale Surface Deviation
- Multiscale Surface Difference
- Multiscale Surface Percentile

Scalability and Performance Improvements

Raster analysis for GIS analysts and professionals

Execution Time Improvements

- Many tools now run faster
- Distance: Complex analysis 10x-50x faster, some cases are 350x faster.
- Locate Regions: 3.5x to 7x faster
- Hydrology tools: up to 90x faster
  - Basin, Flow Accumulation, and Snap Pour Point benefited the most
  - Fill, Flow Distance, Flow Length, and Stream order improved up to 1.7x
- Raster To Polygon: 1.6x to 2x faster, some cases are 40x faster

Use Cases in ArcGIS Pro

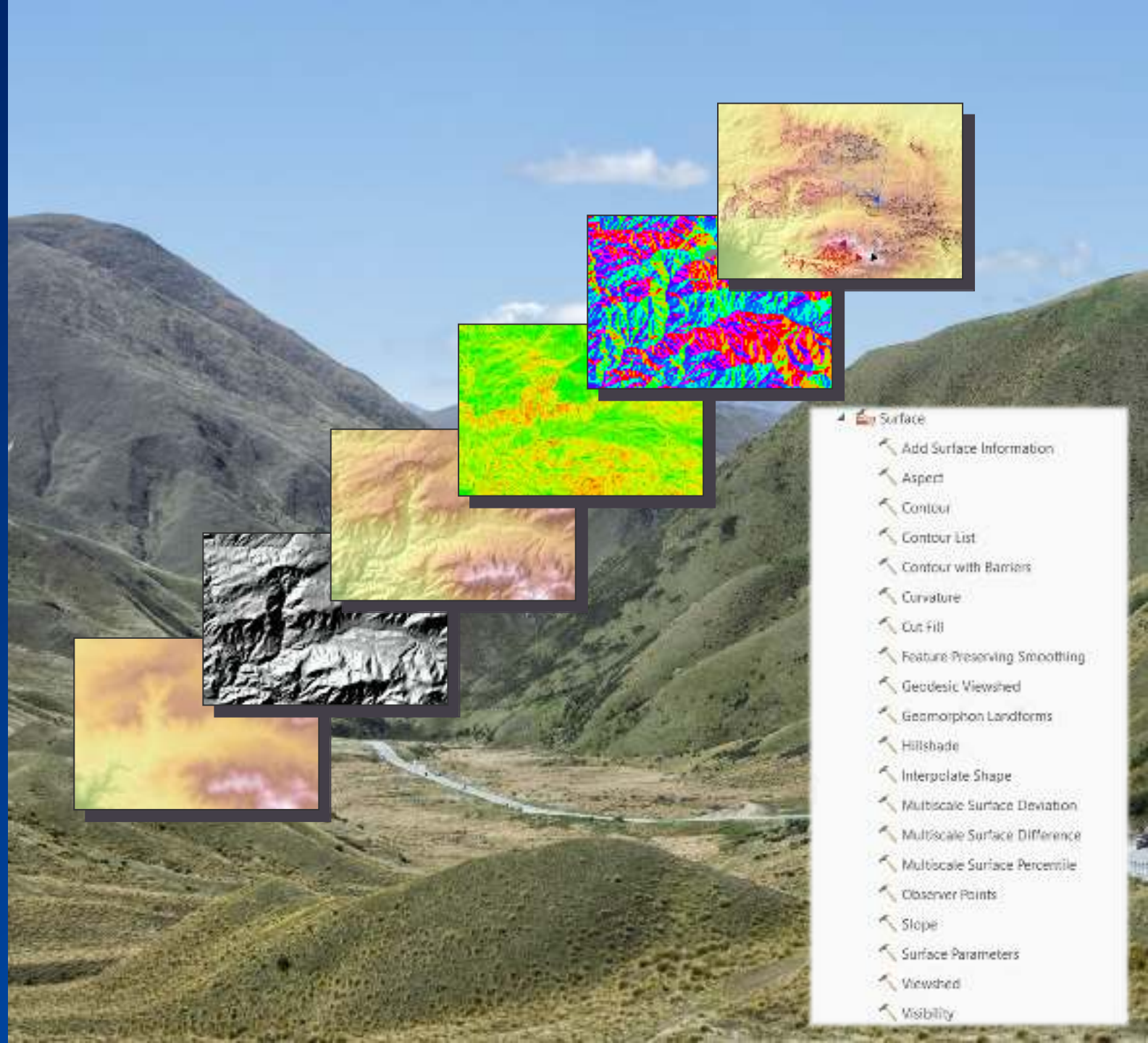
- Snap 1/2 million points to a 7 billion cell raster
  - Before: 5 hours 31 min
  - Now: 7 min 29 secs (improvement 44x)
- 13.3 billion cells raster converted to 14.2 million polygons
  - Before: 14.5 hours
  - Now: 20 minutes (improvement 44x)
- USGS application to determine the optimal hiking route in the Black Canyon
  - Before: 30 hours
  - Now: 5 min (improvement 360x)

Cloud vs ArcGIS Pro

- Tested 4 trillion cells with 400 CPUs
- Flow direction of Global 30m DEM, 540+ billion cells
  - Single processor: 14 days
  - K8s: 40 nodes/200 pods: 4.4 hours
- Hydrology workflow for Guadiana Catchment in Spain-Portugal, DEM ~ 39 billion cells
  - ArcGIS Pro (12 processors): 31 hrs 15 mins
  - Cloud (3 workers, 24 processors): 3 hours 52 minutes. Improvement ~ 8x

Surface Analysis

- Surface Parameters
  - Slope
  - Aspect
  - Curvature (Profile, Tangential, Plan, Contour geodesic torsion, Gaussian, Casorati)
- Geomorphon Landforms
- Feature Preserving Smoothing
- Multiscale Surface Deviation
- Multiscale Surface Difference
- Multiscale Surface Percentile
- Many more…



Hydrologic Analysis

- Create watersheds and stream networks from DEMs
  - Derive Continuous Flow, Derive Stream As Line
  - Flow Direction, Flow Accumulation
  - Watershed Delineation
  - Flow Length, Flow Distance
  - Stream Order, Stream Link
  - Sink, Fill
- Flow Direction tool supports D8, Dinf, and MFD
- Large collection of free workflow and productivity tools available in Arc Hydro tools

Flood Simulation

Improving urban design and emergency response

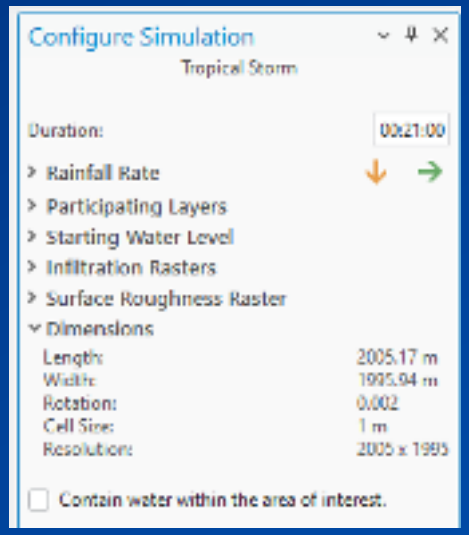
Rainfall rate and duration
DEM and landscape variables

→

Water surface elevation
Time series animation

What If Scenarios

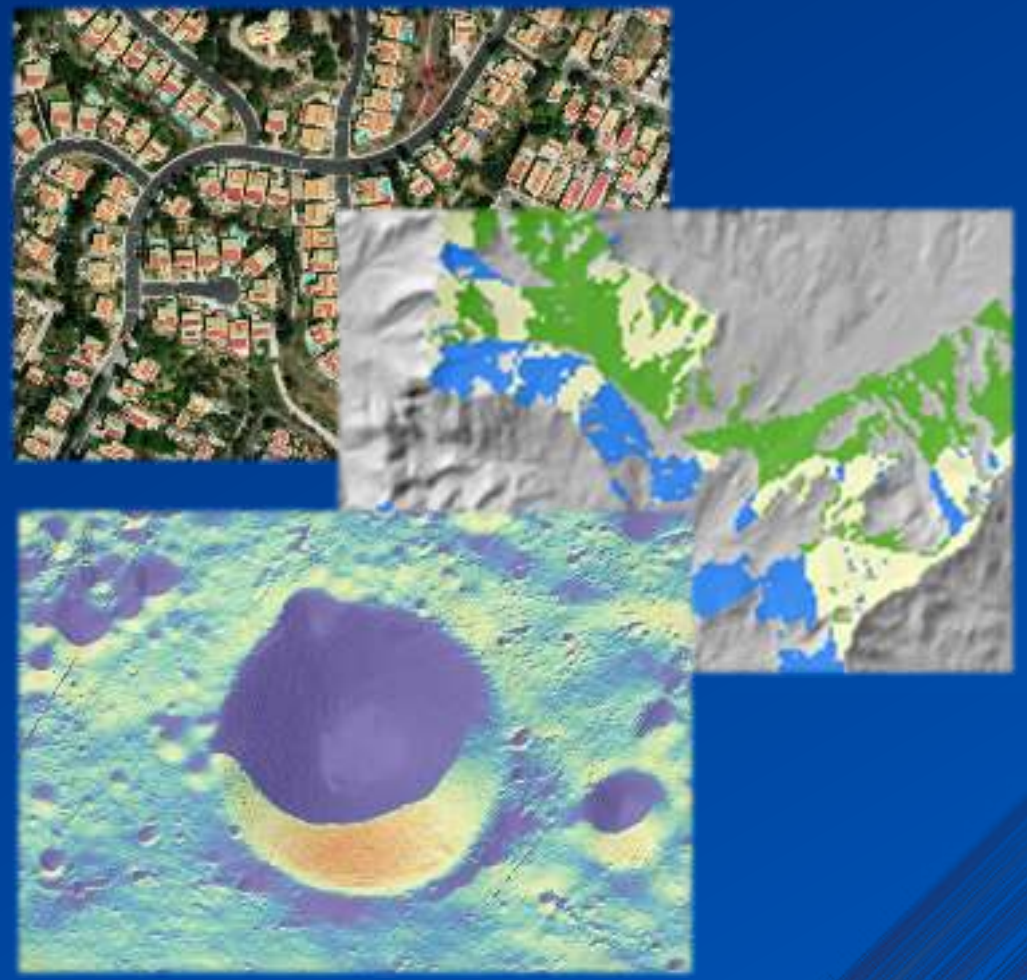
Easy to modify terrain to add levees, diversions then re-run the simulation to evaluate protection



Solar Radiation and Viewshed Modeling

- New and improved tools
  - Raster Solar Radiation
  - Feature Solar Radiation
  - Geodesic viewshed
- Significant algorithm, performance, and workflow improvements
- Supports CPU and GPU computations

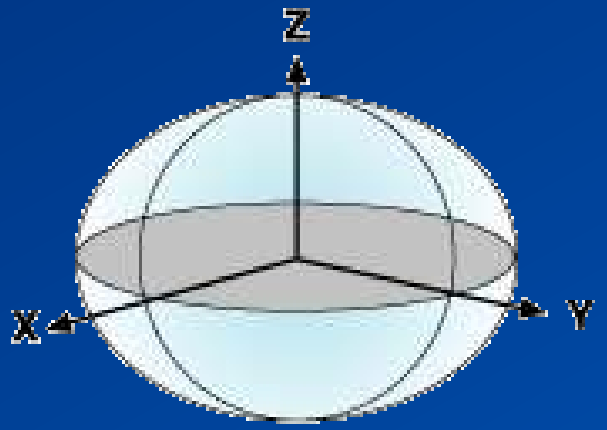
- Solar radiation tools support the Earth and the Moon



Geodesic Algorithms

No Map Projection Distortion

- Geodesic calculations in most ArcGIS geomorphometry tools
- Coordinate system of input data does not matter (spherical or planar).
- Eliminates map projection distortion of distances and angles.

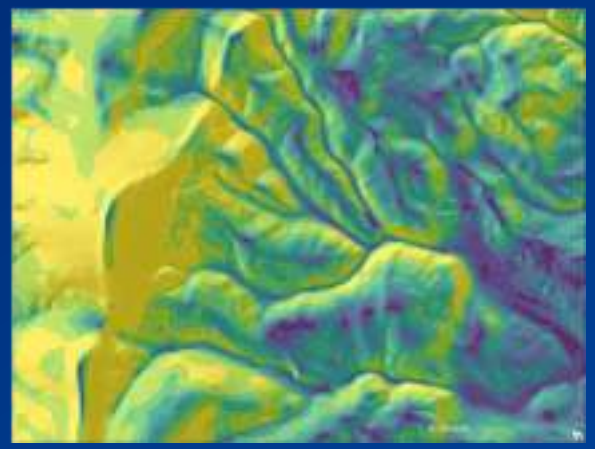



```
# Find geodesic distance and geodesic angle of all cell centers from window center
for i in range(len(x_values)):
    x_any = x_values[i]
    y_any = y_values[i]
    pnt_window_any = arcpy.PointGeometry(arcpy.Point(x_any,y_any), sr)
    geodesic_angle, geodesic_distance = pnt_window_center.angleAndDistanceTo(pnt_window_any, "GEODESIC")

    # Convert angles from North (0 degrees starts from) to East, counterclockwise
    if (geodesic_angle < 0): #2nd and 3rd quadrant
        geodesic_angle_from_east = 90 + math.fabs(geodesic_angle)
    elif (geodesic_angle >= 0) and (geodesic_angle < 90): #1st quadrant
        geodesic_angle_from_east = 90 - geodesic_angle
    elif (geodesic_angle >= 90) and (geodesic_angle <= 180): #4th quadrant
```

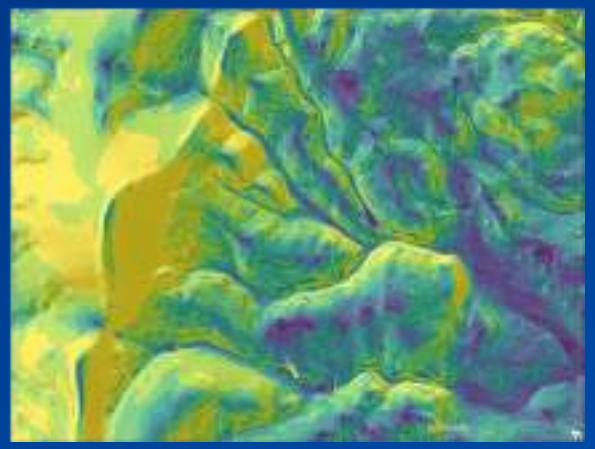
Surface and Terrain Analysis: Multiscale Analysis

Fixed Window



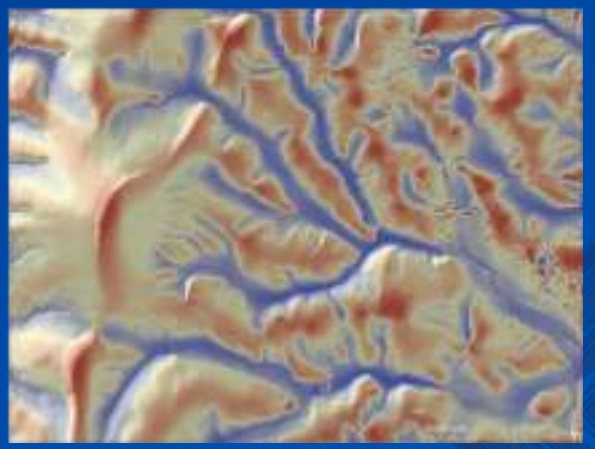
Slope using fixed window

Adaptive Window



Slope using adaptive window

Multiscale Analysis



Elevation percentile using multiscale analysis

Documentation and Blogs

Tool Reference

Multiscale Surface Percentile (Spatial Analyst)

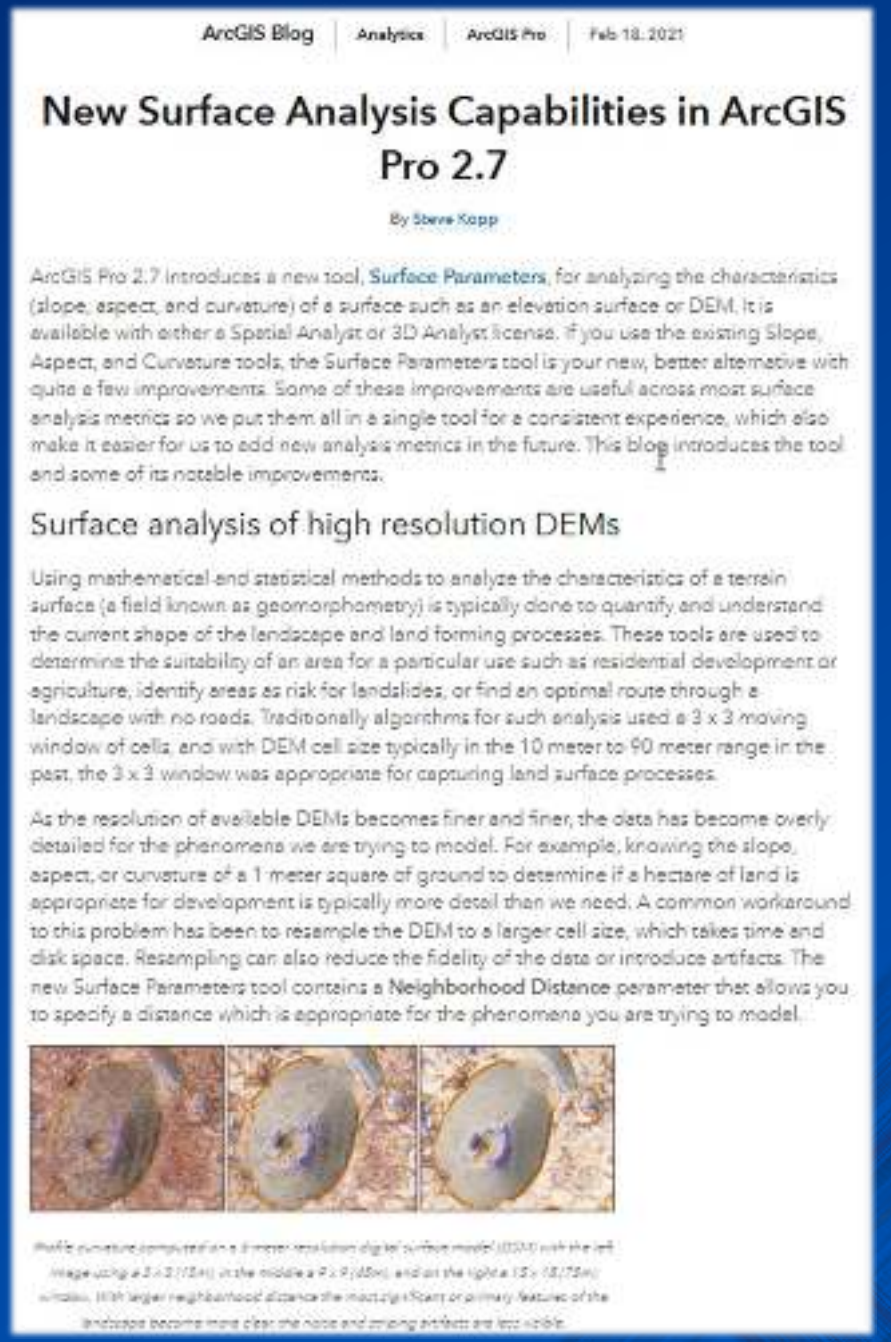
Summary

Usage

Concepts

How Multiscale Surface Percentile works

Blogs



ArcGIS Blog | Analytics | ArcGIS Pro | Feb 18, 2021

New Surface Analysis Capabilities in ArcGIS Pro 2.7

By Steve Kopp

ArcGIS Pro 2.7 introduces a new tool, Surface Parameters, for analyzing the characteristics (slope, aspect, and curvature) of a surface such as an elevation surface or DEM. It is available with either a Spatial Analyst or 3D Analyst license. If you use the existing Slope, Aspect, and Curvature tools, the Surface Parameters tool is your new, better alternative with quite a few improvements. Some of these improvements are useful across most surface analysis metrics so we put them all in a single tool for a consistent experience, which also make it easier for us to add new analysis metrics in the future. This blog introduces the tool and some of its notable improvements.

Surface analysis of high resolution DEMs

Using mathematical and statistical methods to analyze the characteristics of a terrain surface (a field known as geomorphometry) is typically done to quantify and understand the current shape of the landscape and land forming processes. These tools are used to determine the suitability of an area for a particular use such as residential development or agriculture, identify areas as risk for landslides, or find an optimal route through a landscape with no roads. Traditionally algorithms for such analysis used a 3 x 3 moving window of cells, and with DEM cell size typically in the 10 meter to 90 meter range in the past, the 3 x 3 window was appropriate for capturing land surface processes.

As the resolution of available DEMs becomes finer and finer, the data has become overly detailed for the phenomena we are trying to model. For example, knowing the slope, aspect, or curvature of a 1 meter square of ground to determine if a hectare of land is appropriate for development is typically more detail than we need. A common workaround to this problem has been to resample the DEM to a larger cell size, which takes time and disk space. Resampling can also reduce the fidelity of the data or introduce artifacts. The new Surface Parameters tool contains a Neighborhood Distance parameter that allows you to specify a distance which is appropriate for the phenomena you are trying to model.

GeoAI in ArcGIS

Detection, Classification, Extraction from many data types

- Automate Data Extraction
  - Computer vision on imagery, 3D, and video data
  - NLP on unstructured text data
- Uncover Insights
  - Machine learning and deep learning on vector, tabular, and time series, raster and imagery data
  - NLP on unstructured text data

GeoAI Models

Pre-Trained & Ready-to-Use

- Cars
- License plate blurring
- Parking lots
- **Land cover**
- Parking spots
- Humans
- Crowd counting
- Face blurring
- Buildings
- **Roads**
- Parcels

- **Ag fields**
- Swimming pools
- Well pads
- Oil spills
- Palm trees
- Power lines
- Transmission towers
- Insulator defects
- Wind turbines
- Solar arrays

- Solar panels
- Ships
- Shipwrecks
- **Segment Anything Model (SAM)**
- Text Sam
- **Trees**
- Common object detection
- Text parsing from photo
- **Object tracking**

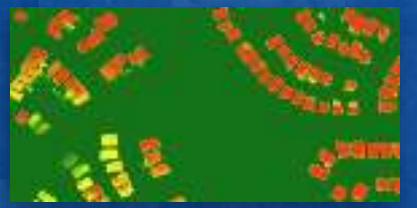
new

- **Canopy height estimation**
- **Hugging Face Hub integration**
- Depth anything
- **Prompt-based segmentation**
- Pedestrian infrastructure classification
- Wildfire and smoke classification
- **Wildfire delineation**
- **Damage classification**

- CLIP Zero-Shot classifier
- GroundingDINO
- Damage assessment (Drones)
- Map simplification
- Edge detection
- **Vision-language context-based classification**
- Building point classification
- Building change detection
- **Image Interrogation**

. . . Automating workflows

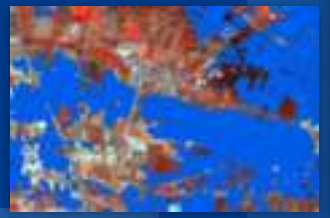
. . . Creating new data layers



Change detection buildings

Cars (**SAM**)

Flood segmentation



Clouds

Building footprints

Land cover

Map simplification

Crop classification (**Prithvi**)

Python APIs for Raster Processing in ArcGIS

- ArcGIS API for Python
  - ArcGIS Enterprise / ArcGIS Online
  - Remote processing

- ArcPy
  - Desktop App (ArcGIS Pro)
  - Local processing

ArcPy: Over 1300+ Comprehensive GIS Functions

Data Management

- Convert between formats, 2D <-> 3D, build topology, data reviewer, linear referencing,
- data comparison, manage spatial databases, distributed editing, servers & services
- **Specialized datasets** – parcels, utility networks, address locators, network datasets

Location analytics

- **business intelligence** – market penetration, Huff model, suitability analysis, territory design,
- **Network** – routing, OD cost matrix, service area, location allocation
- **Geocoding** – batch, reverse, composite

Raster Analysis

- Extraction, overlay, proximity, distance, hydrology, multivariate, map algebra, neighborhood, fuzzy overlays

Cartography

- annotations, generalization, map series, masks
- **100+** projections and transformations
- **editing tools** – conflation, densify, cartographic refinement
- Layouts, printing, map series

3D

- LAS classification, extraction, terrain, TIN, DEM, DSM, volume analysis
- **Surface analysis** – aspect, contour, cut fill, hillshade, slope, line of sight, sun shadow, viewshed, hydrology

Imagery analysis

- **management** – mosaic datasets, raster algebra,
- **ortho mapping** – point cloud, stereo model, photogrammetry, surface creation, ortho rectification
- **information extraction** – classification, object detection, segmentation, spectral analysis, statistics
- Full motion imagery, multidimensional rasters, solar radiation
- Hundreds of math and stat tools

Spatial Machine Learning

- **Interpolations**, spatial sampling, simulations,
- **Stats** – enrich, density, hot spot, clustering, autocorrelations, balanced zones, outliers, similarity search, local bivariate relationships
- **Prediction** – random forests, GLR, OLS, GWR, validation
- **Pattern mining** – emerging hot spot, time series clustering,
- **Big Data** – GeoAnalytics desktop tools
- **Deep Learning** – classify objects, classify pixels, detect objects, export training data, train model

R-ArcGIS Bridge

Two R packages available

{arcgisbinding}

*Brings R to GIS analysts **in ArcGIS Pro***

- Connects ArcGIS Pro and R
- Data I/O between Pro and R
- R-driven GP tools

{arcgis}

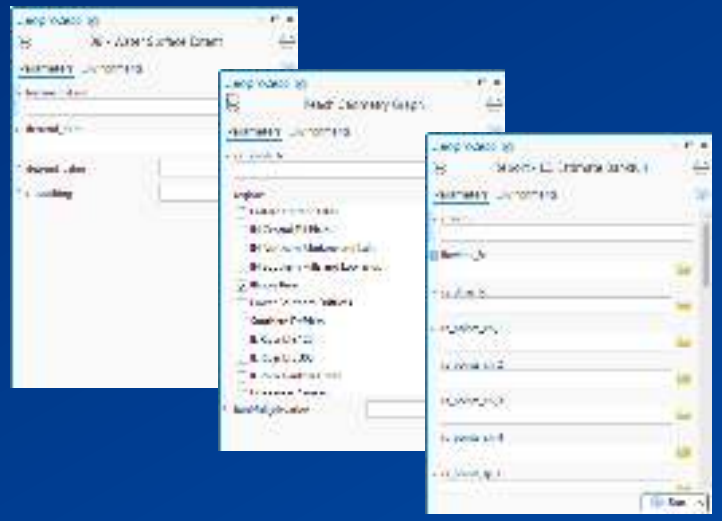
Brings ArcGIS to R data scientists where they work

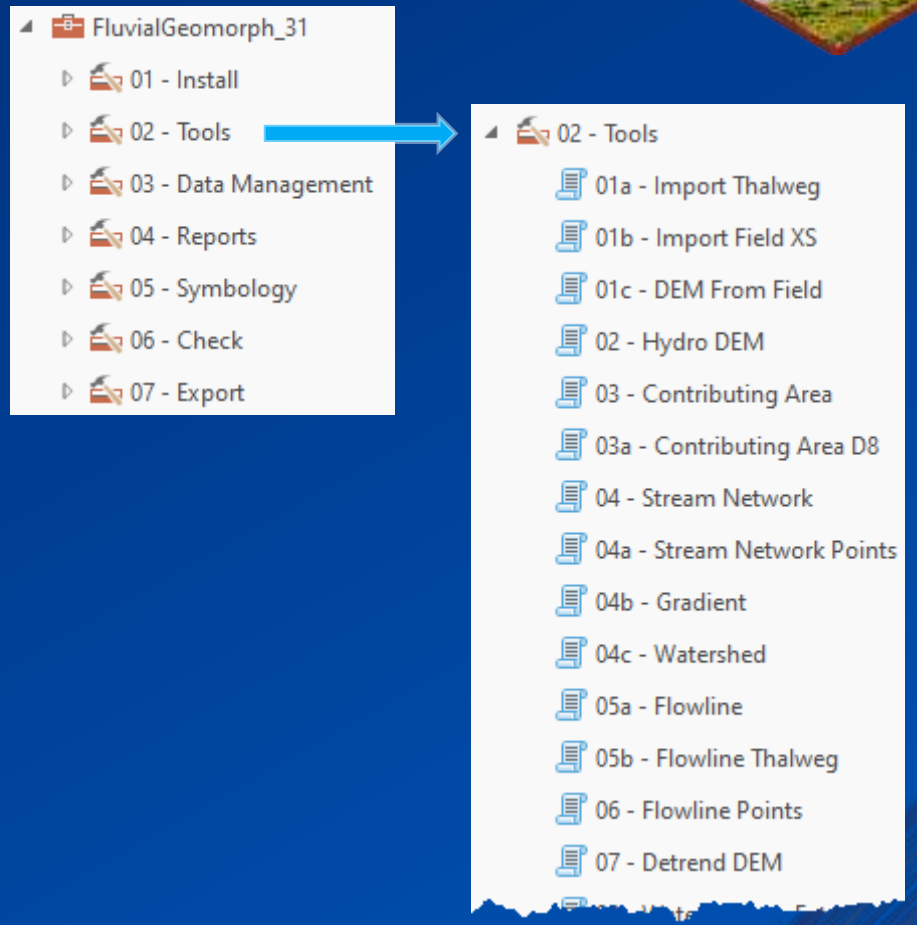
- Access to ArcGIS Location Services in R
  (Hosted data I/O, Geocoding, Routing, Enrichment, etc.)
- R data scientists with ArcGIS Online, Enterprise, or Platform accounts (e.g. existing subscriptions)
- Open-source, available on CRAN

R-ArcGIS Bridge Example

Fluvial Geomorph

- 70+ R and Python tools in Geoprocessing Toolbox
- Calculate stream channel dimensions
- Calculate stream planform dimensions
- Produce graphs and reports of stream channel and planform dimensions





https://github.com/FluvialGeomorph

Summary

- ArcGIS is a geospatial analytics system for all types of users.
- Living Atlas provides 10,000+ quality items and supports billions of requests daily.
- ArcGIS Online provides web-based analysis on the cloud.
- Developed many new surface, hydrology, solar, etc. tools.
- Improved scalability and performance.
- Developed many AI tools and pretrained models.
- Extend capability using Python APIs and R-ArcGIS bridge

… we are continuously improving with your support

Questions