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National Geospatial Program Office

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# Elements of a Global Model: An Example of Sea Level Rise and Human Populations at Risk

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# Outline

- Motivation
- Objectives
- Storm Surge and Effects
- Approach
  - Data Sources
  - Projection Methods and Problems
  - Model and Simulation
  - Animation Process
- Results and Animations
- Conclusions

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# Motivation

- Interest in global change and modeling
- Availability of high resolution global datasets
- Development of modeling/simulation/animation capabilities
- Effects of recent catastrophic events with high rises and surges of sea water
  - Hurricanes Katrina and Rita
  - Indian Ocean Tsunami

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# Objectives

- Examine effects of sea level rise and surges from global perspective
- Determine global population numbers in potential areas of inundation
- Determine population numbers in regional and local areas that could be inundated with large sea surges
- Model with simulation and animation of sea-level rise

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# Sea-Level Rise from Ice Melt

Minimal over time

Only now at 3 ½ mm per year

Not detectable in world wide GIS datasets

Anticipate maximum of 6-7 m rise

Slight rises can make high surges from storms more severe. Population numbers and land covers potentially affected by large sea surges can be modeled on local, regional, and global extents.

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# Hurricane Katrina Storm Surge

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# New Orleans MODIS Images

## Before and After Katrina

August 27, 2005

August 30, 2005

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# Hurricane Katrina Damage Assessments

U.S. Geological Survey Rocky Mountain Geographic Science Center

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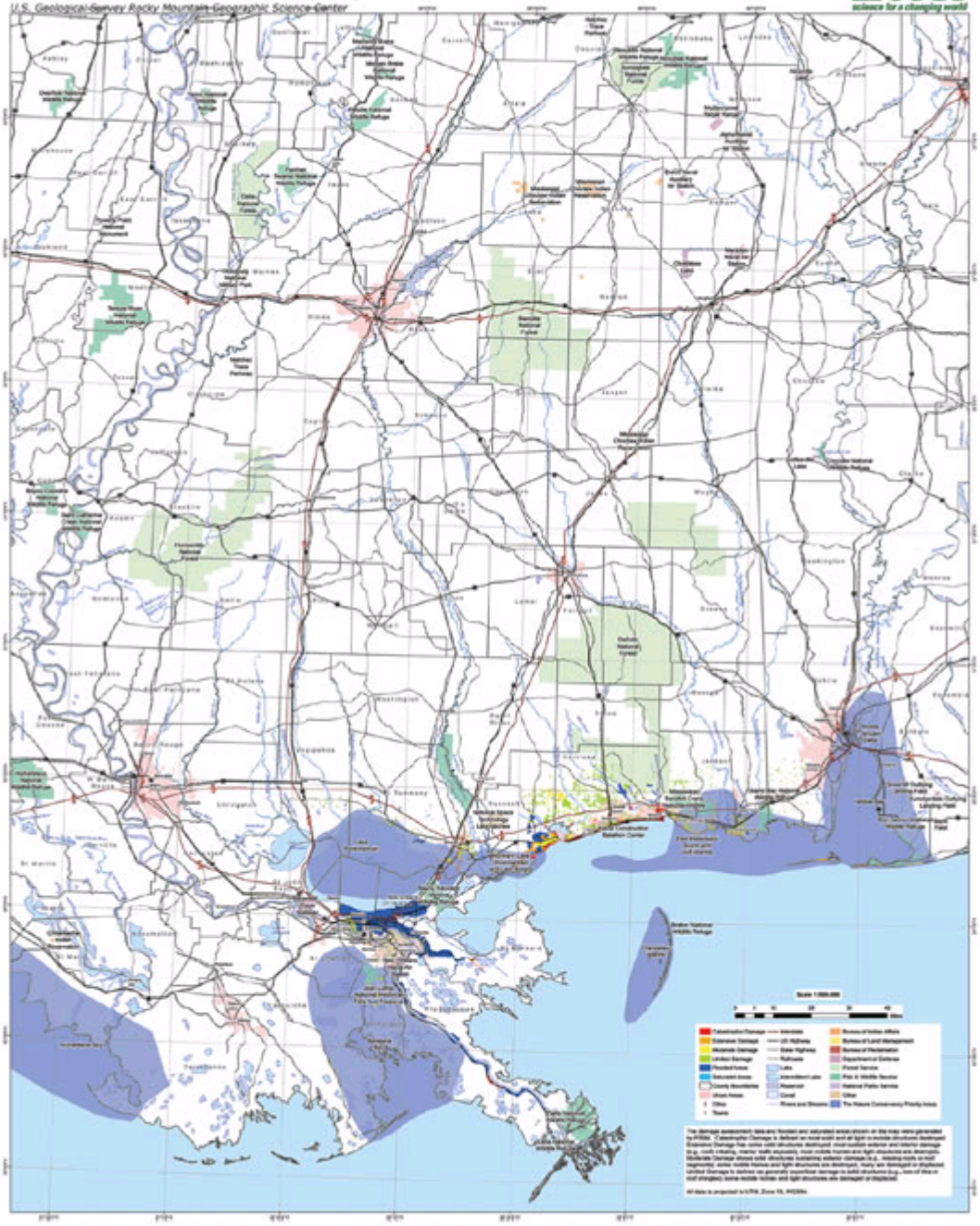

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Peveto Beach

Before and after Rita -- Note destruction of houses from storm surge

# The Indian Ocean Tsunami – 2004

Maximum run-up exceeding 30 m in Banda Aceh and 10 m in several locations in Sri Lanka

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# Indian Ocean Tsunami Effects – Banda Aceh, 2005

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Pankarang Cape – Jan 13, 2003

# Pankarang Cape – Dec 29, 2004

# Katchall Island, India

July 10, 2004 December 28, 2004

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# Modeling High Sea-Level Rise or Surge and Affected Population Numbers on Worldwide Basis

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# Approach

**Data Sources**

**Projection and Resampling Methods**

**Modeling and Simulation**

**Animation Process**

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# Data Sources -- Global

- Global land cover, 30 arc-sec, 1 Gb file, USGS source
- Global elevation, Gtopo-30, 30-arc-sec, 2 Gb file, USGS source
- Global population, Landscan 2005, 30 arc-sec, 1 Gb file, Oak Ridge National Laboratory source

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# Data Sources – Regional/Local

- SRTM Elevation Data, 90 m
- Global Land Cover, resampled to 90 m
- Global Population, resampled to 90 m
- For the United States
  - USGS National Elevation Dataset, 30 m
  - USGS National Land Cover Dataset, 30 m
  - Census block population resampled to 30 m

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# Projection of Global Data Sources

- All data originally in geographic coordinates (latitude and longitude)
- Projected to Mollweide for modeling and animation

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# Projection Problems

File size

Run times

Resampling

Raster projection

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# Projection Solutions

- **USGS developed *mapimg* projection software**
  - **Handles global raster data, large file sizes**
  - **Programmed new resampler for categorical data (land cover)**
    - **Modal category, statistical selection, or user choice for output pixel value**
  - **Programmed new resampler for population counts**
    - **Additive resampler**

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# Resampling

- Primary step in raster generalization, sometimes called down-sampling
- Geospatial data can suffer from great geometric distortions when being reprojected or transformed
- Errors associated with these distortions and scale changes affect resampling
  - For categorical data, such as land cover, pixel gain and loss result
  - For population counts, an additive resampler is required

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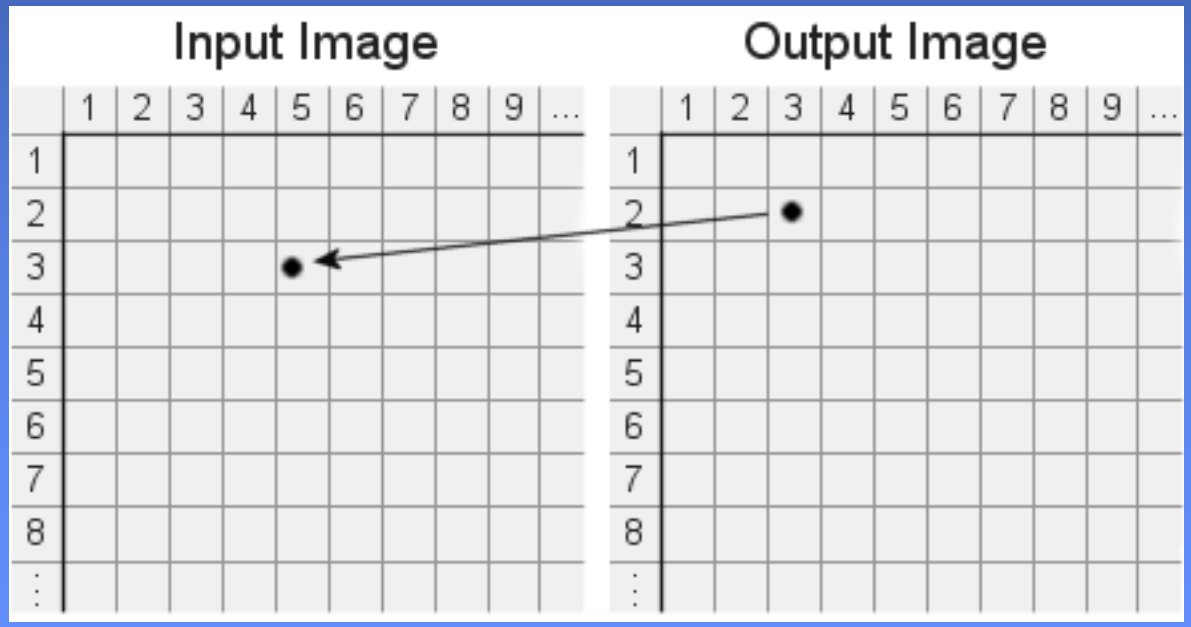
# Resampling – Nearest Neighbor Method without Generalization

One point in the output image space maps to a corresponding point in the input image space (via the inverse mapping algorithm)

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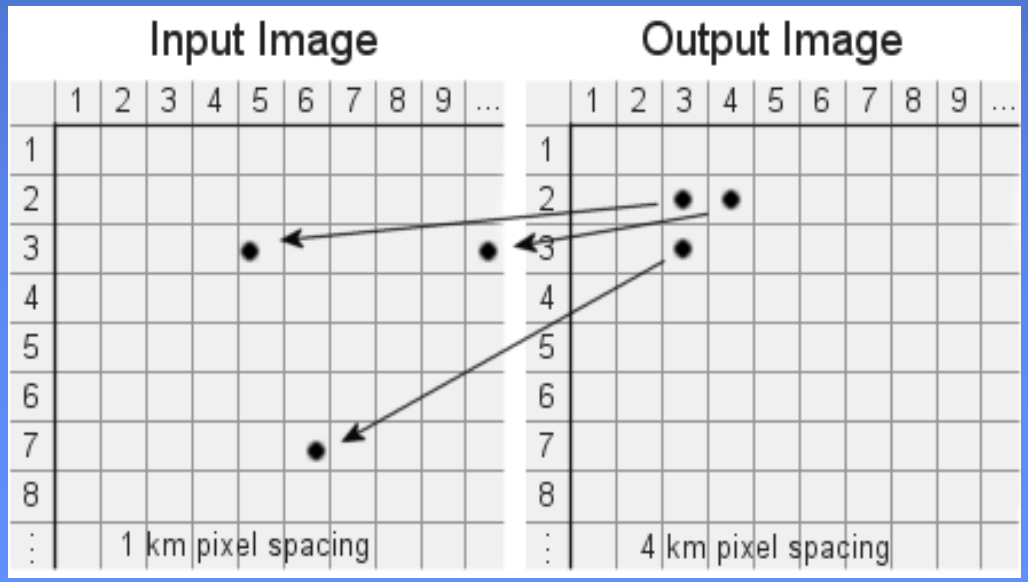
# Resampling – Nearest Neighbor Method with Generalization (Down-sampling)

If the resolution of the output image is reduced (generalized or down-sampled), adjacent pixels in the output may fall more than one pixel away in the input (via the inverse mapping algorithm)

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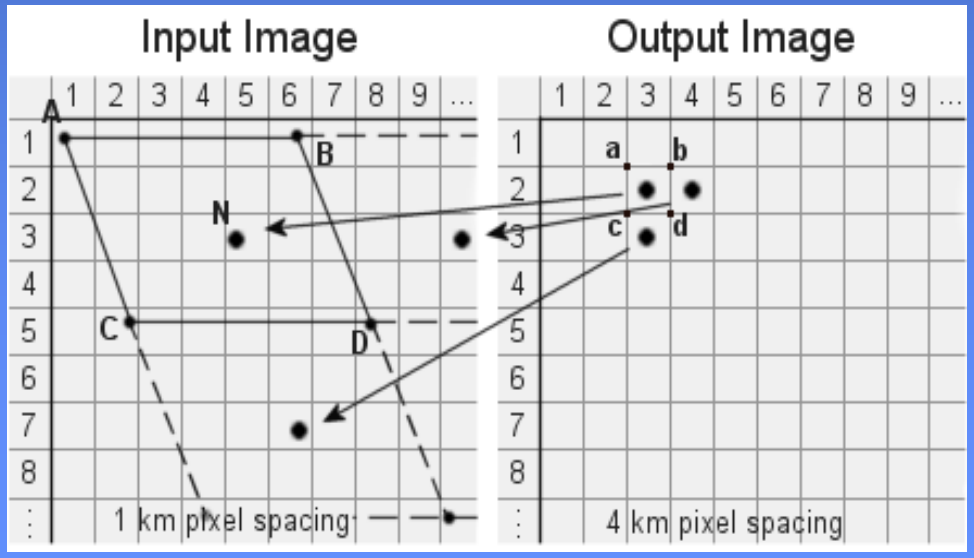
# Categorical Resampling

New resampling algorithm treats pixels as areas, not points (Steinwand, 2003)

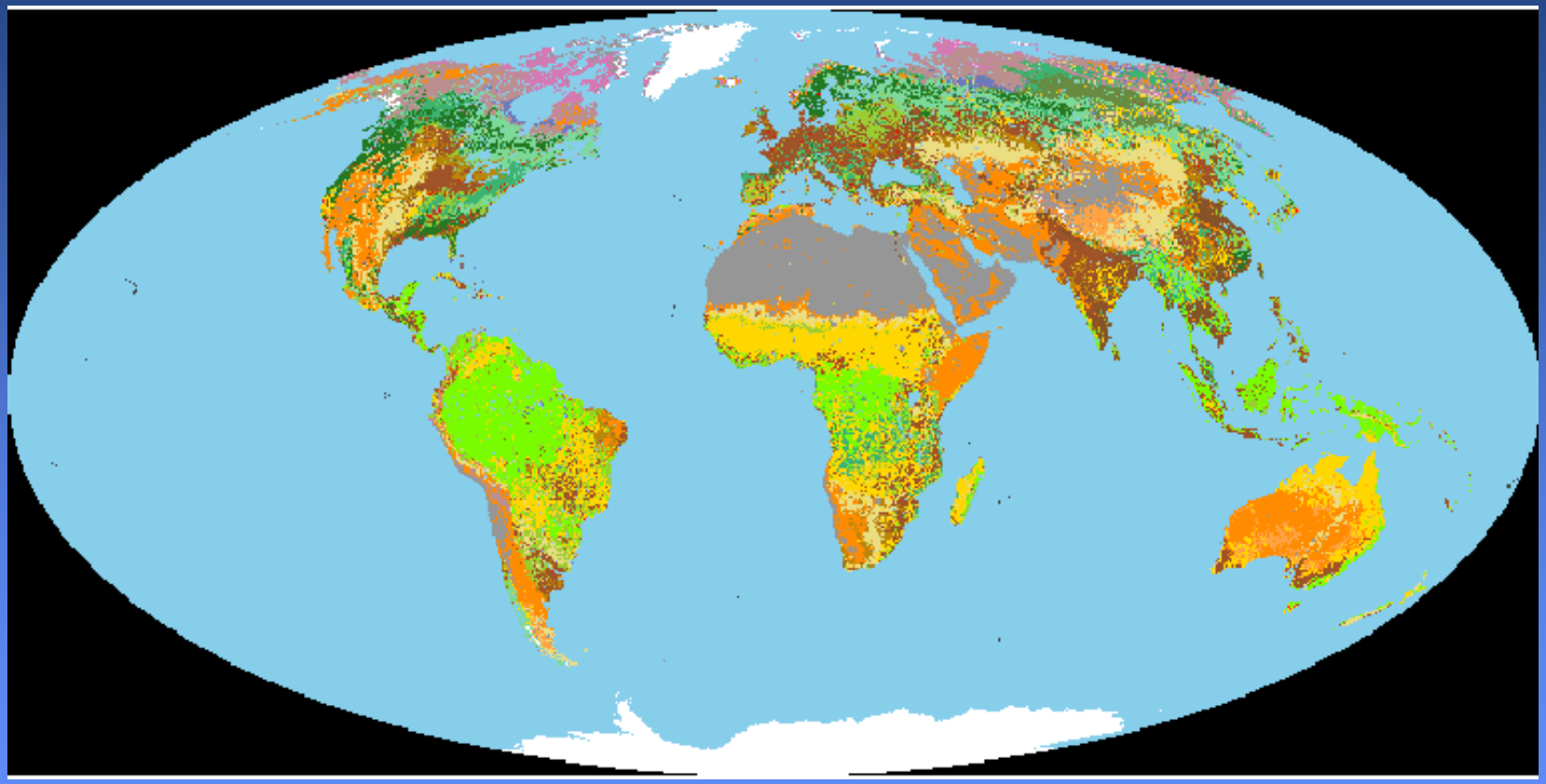
Four corners of each pixel are mapped into the input space

Many pixels involved

- Apply simple statistical methods or user specification to determine output image pixels based on the area the pixel covers in the input image

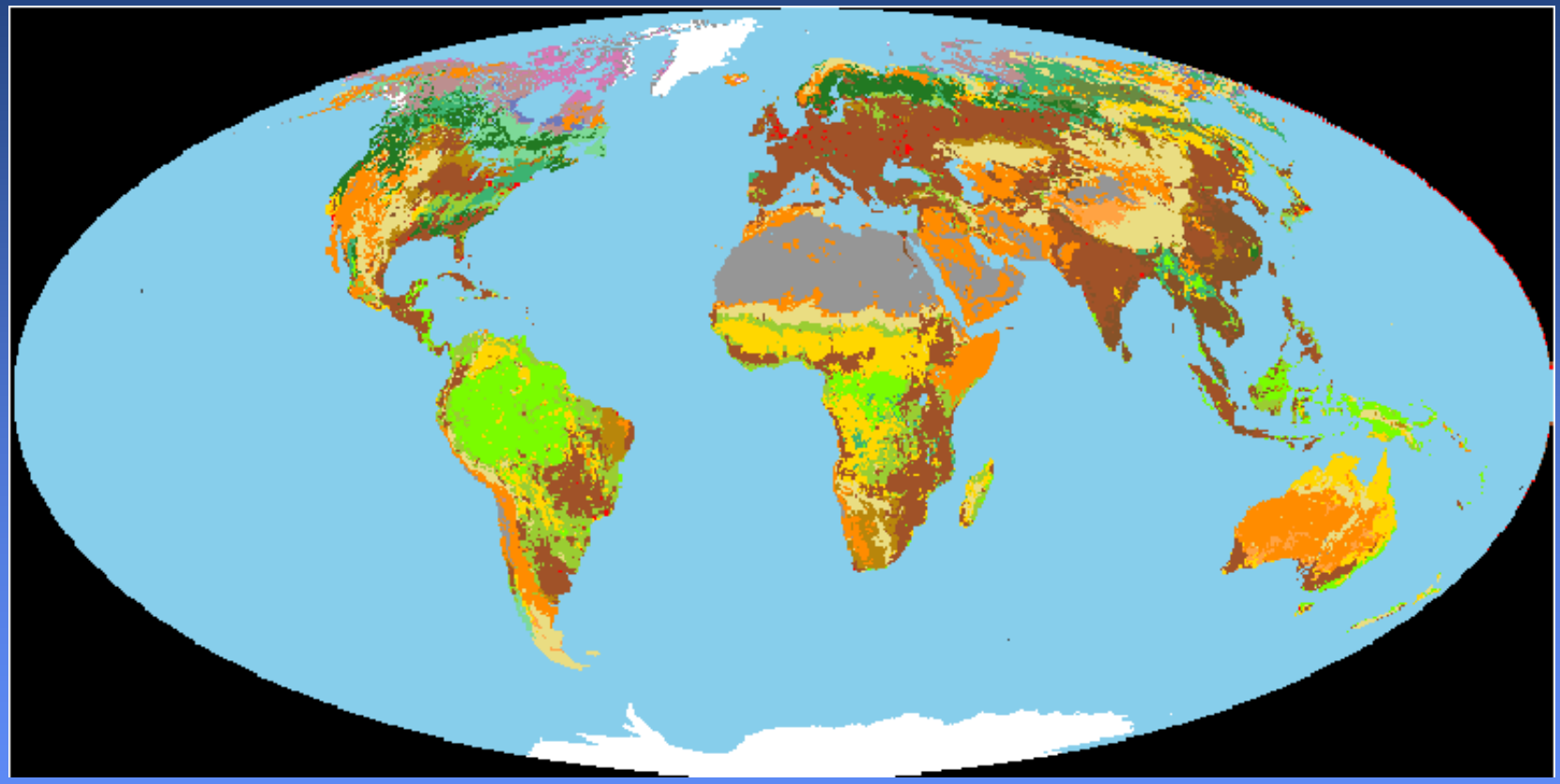


# Extreme Downsampling (64 pixels to 1) and Reprojection with the Nearest Neighbor



USGS Reduces data volume from 1 Gb to 16 Mb

# Extreme Downsampling (64 pixels to 1) and Reprojection with the New Algorithm



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# Generalizing Population Counts

Data are numbers of people per pixel

Generalize four pixels to one

Must add the four pixels together

Not available in commercial software

Developed in *mapimg*

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# The Application to Global and Regional Data for Sea-Level Rise and Surge Modeling

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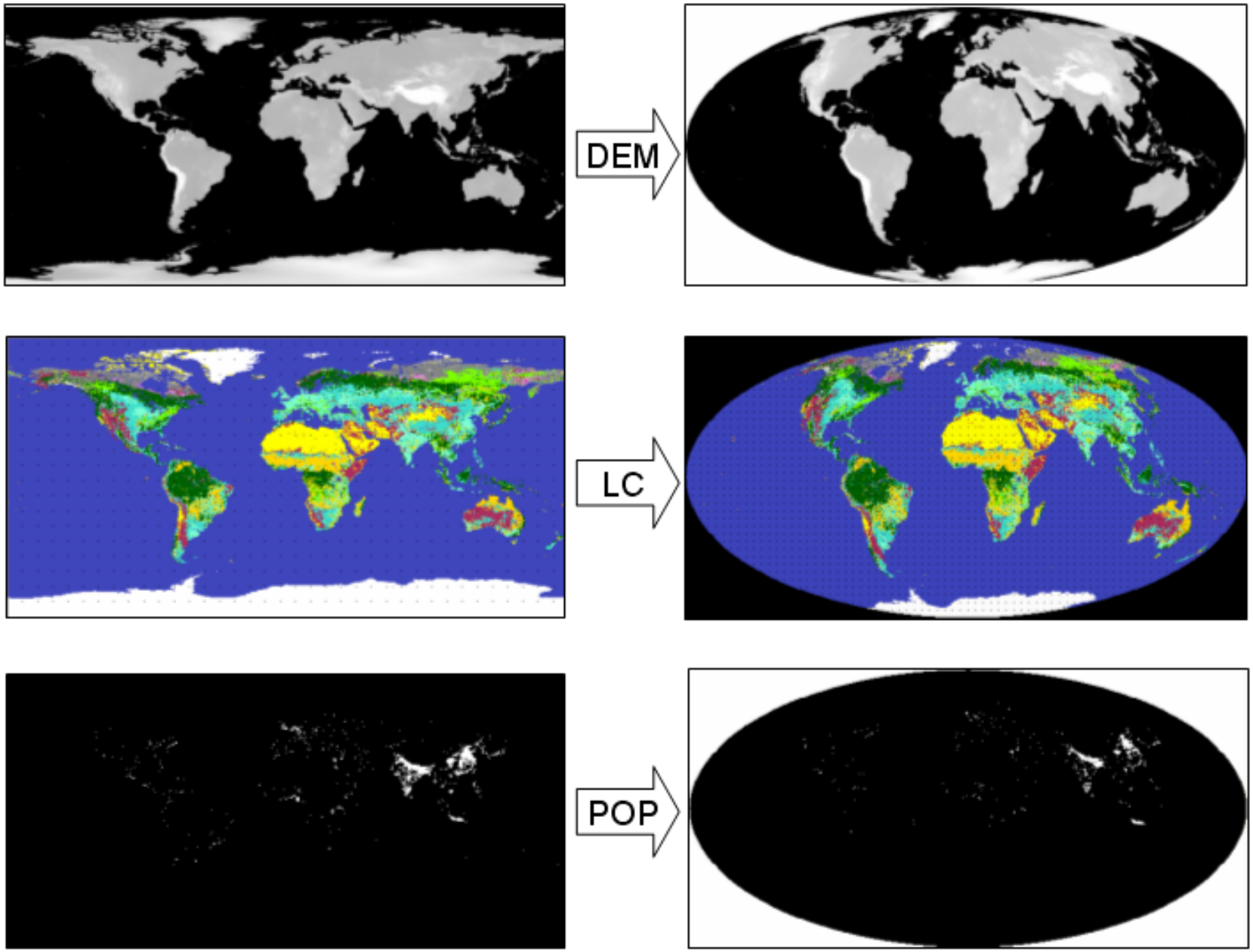
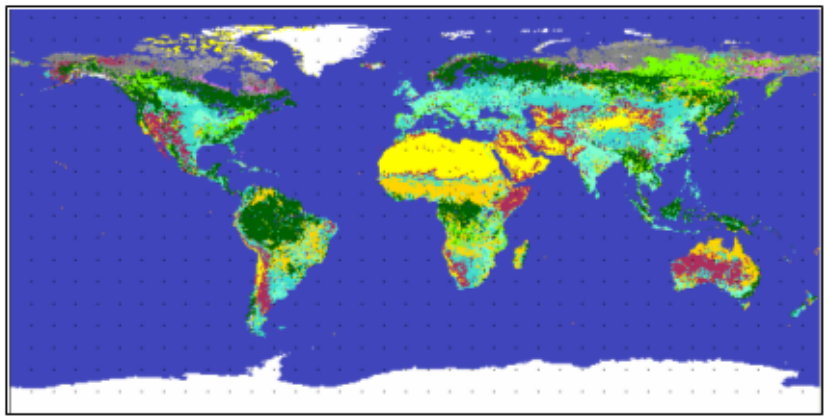
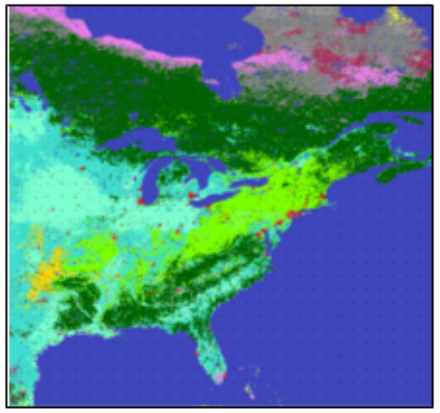
# Global Case, Reproject All Data

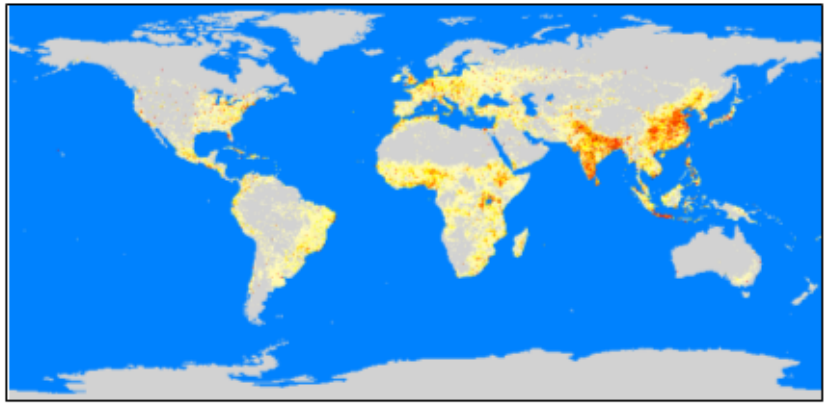


# Regional Case, Subset Data to Desired Area

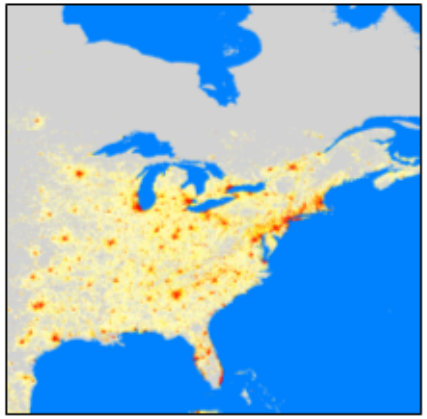


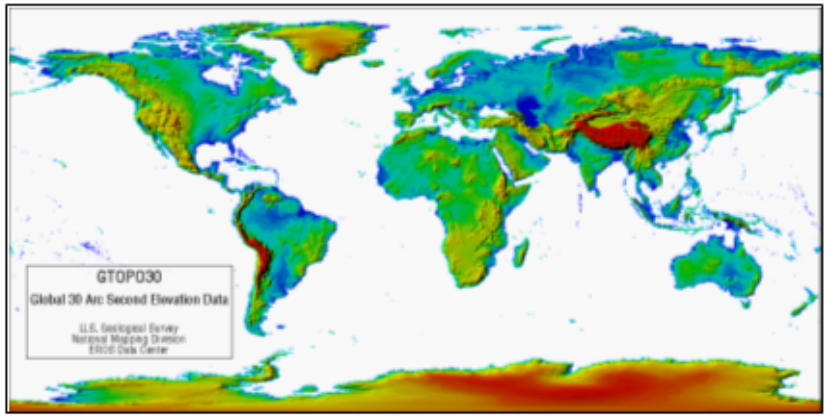
Land Cover



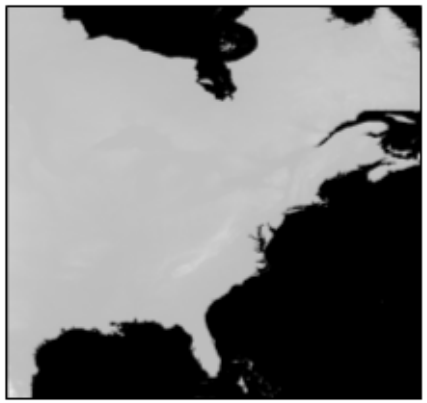


Population

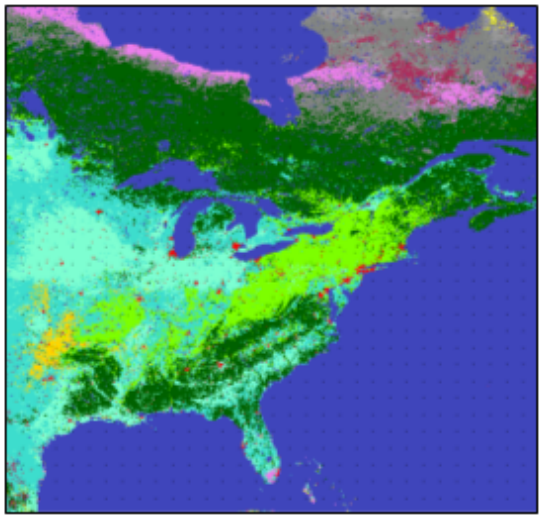


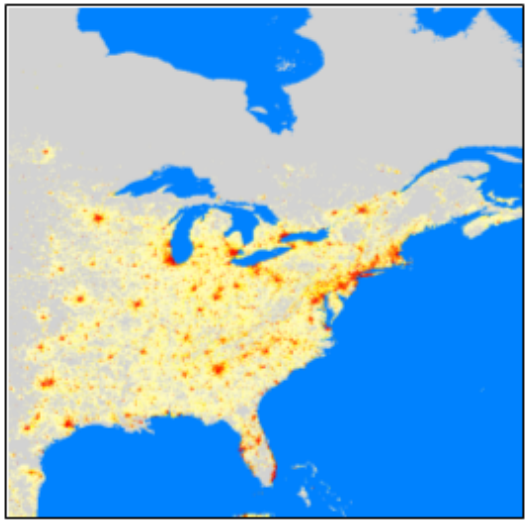


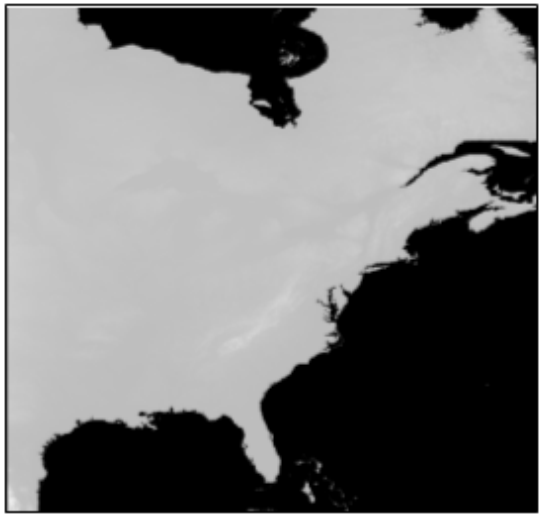

DEM



# Reproject Data Subset



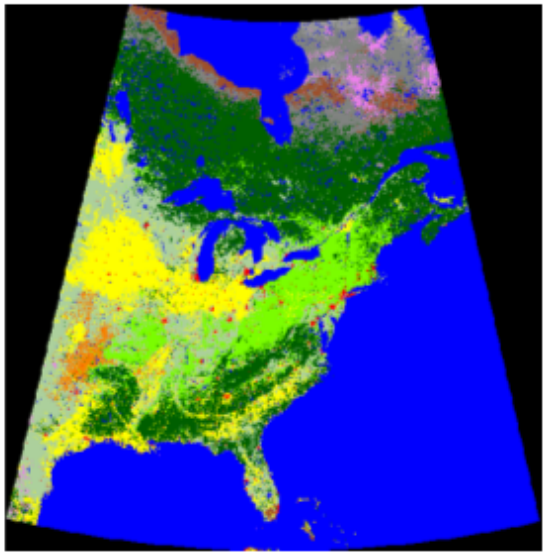


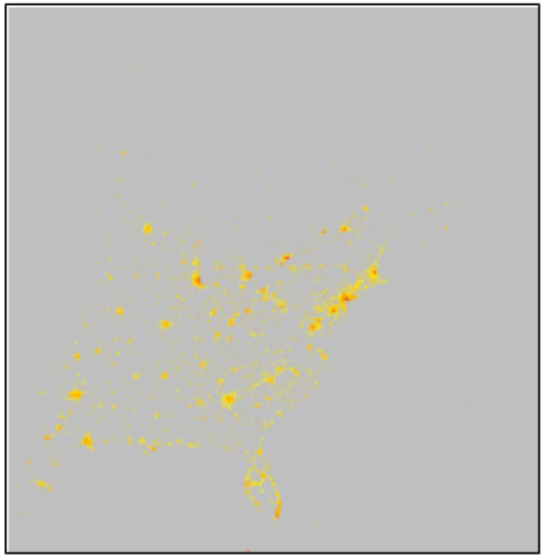


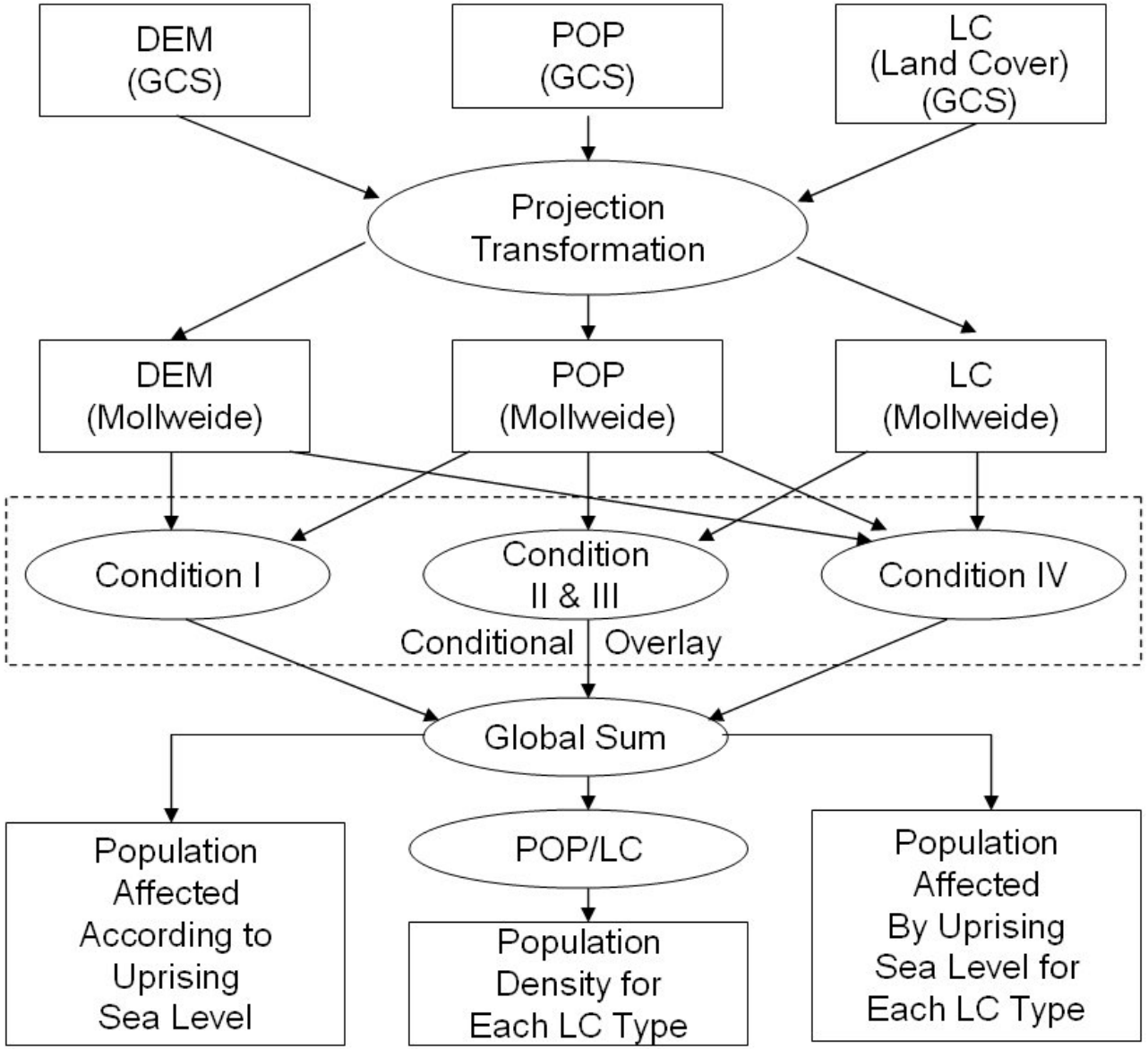
Land Cover

Population

DEM








Condition I: If DEM≤5(10,20,30), then POP else 0
Condition II: If Land Cover = 1(..24), then POP else 0
Condition III: if Land Cover = 1(..24), then 1 else 0
Condition IV: if DEM≤5(10,20,30) and Land Cover = 1(..24), then POP else 0

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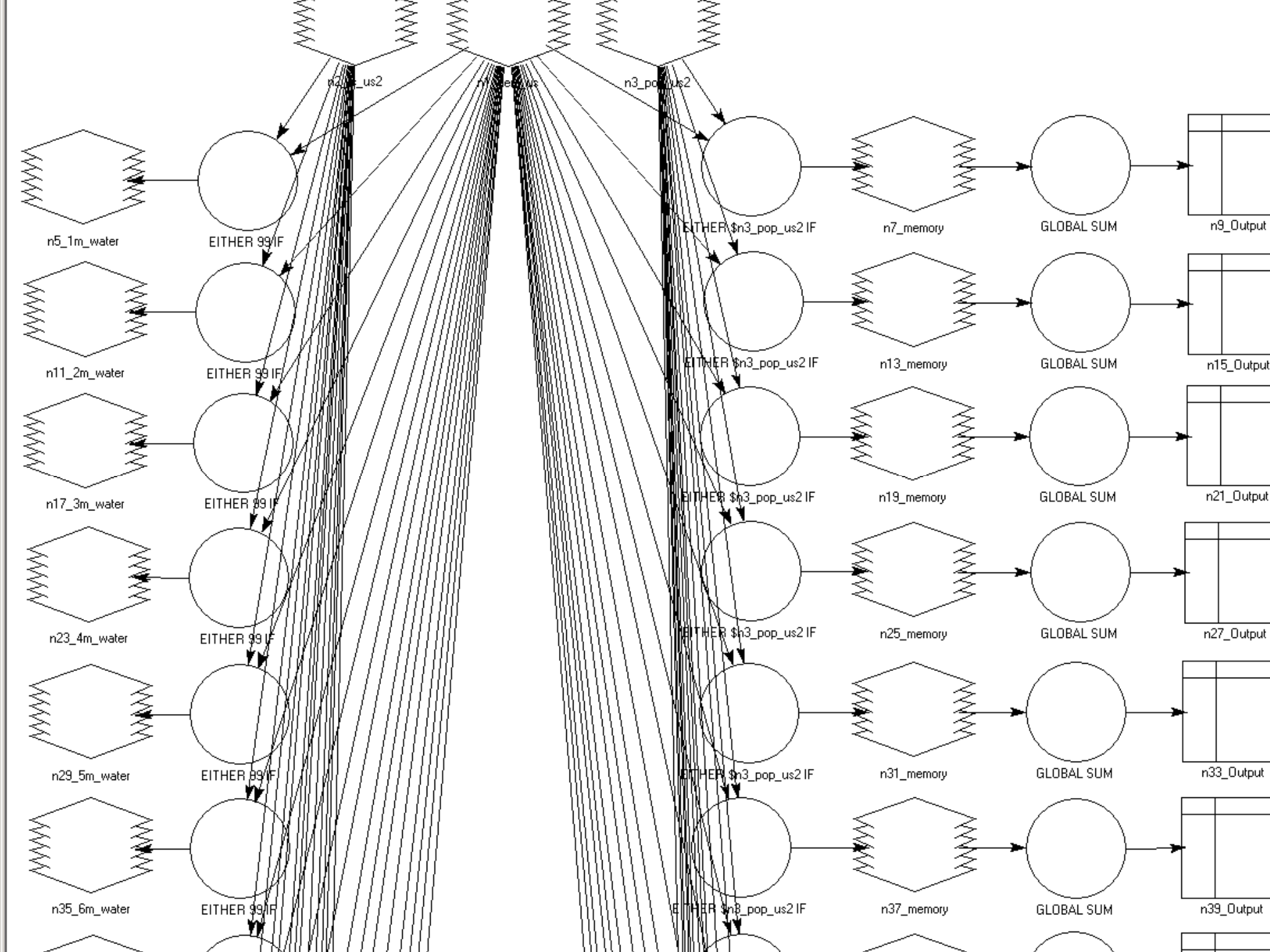
n5_1m_water
EITHER 99 IF
n11_2m_water
EITHER 99 IF
n17_3m_water
EITHER 99 IF
n23_4m_water
EITHER 99 IF
n29_5m_water
EITHER 99 IF
n35_6m_water
EITHER 99 IF
EITHER $n3_pop_us2 IF
n7_memory
GLOBAL SUM
n9_Output
EITHER $n3_pop_us2 IF
n13_memory
GLOBAL SUM
n15_Output
EITHER $n3_pop_us2 IF
n19_memory
GLOBAL SUM
n21_Output
EITHER $n3_pop_us2 IF
n25_memory
GLOBAL SUM
n27_Output
EITHER $n3_pop_us2 IF
n31_memory
GLOBAL SUM
n33_Output
EITHER $n3_pop_us2 IF
n37_memory
GLOBAL SUM
n39_Output

# Model Results

## Model yields multiple maps

- Each map is sea level rise at specified level, for example, 1 m, 2 m, 3 m, 5 m, 10 m
- Color mask shows inundation area
- Population counter tabulates number of people in inundated area
- Colors in the images are land cover categories from USGS Global Land Cover or NLCD for local and regional areas

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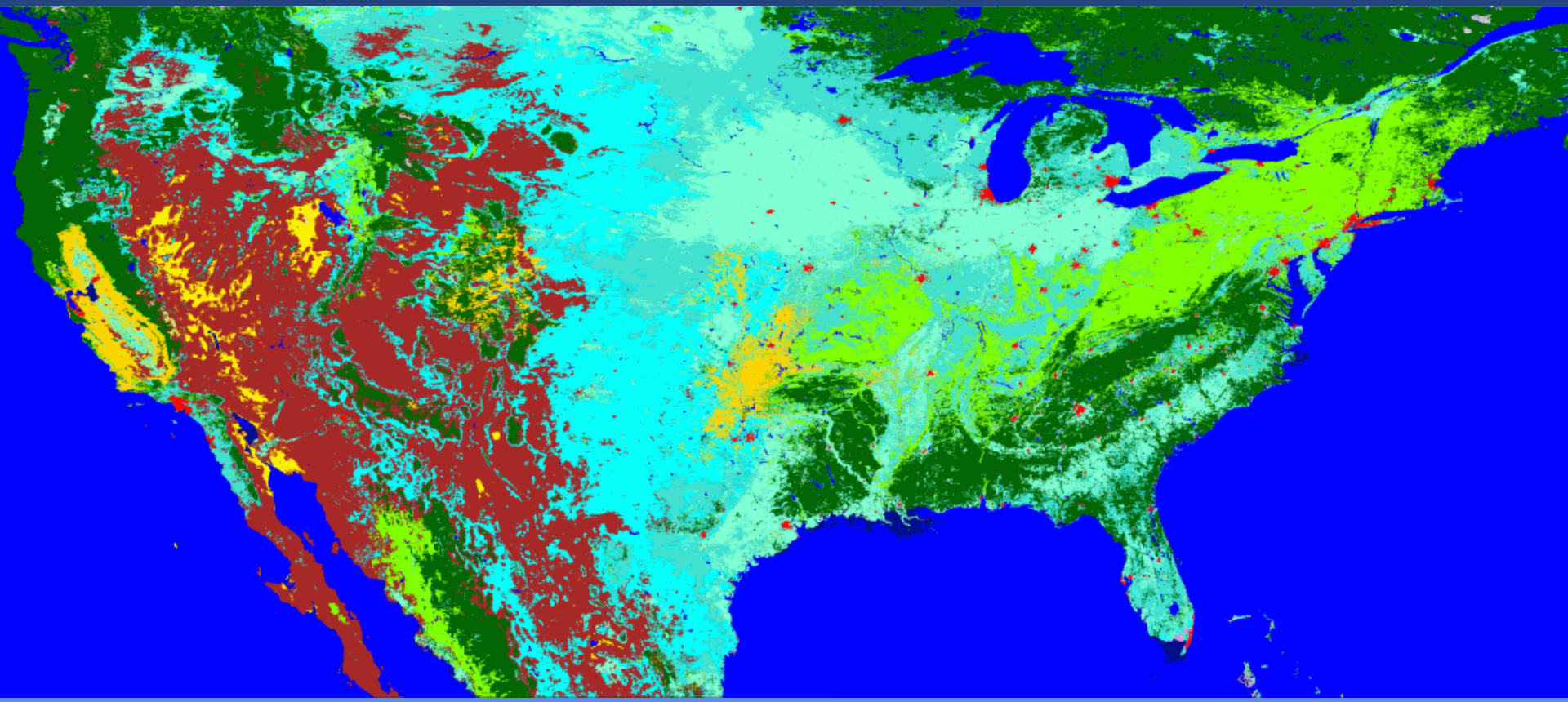
# 1 M Rise



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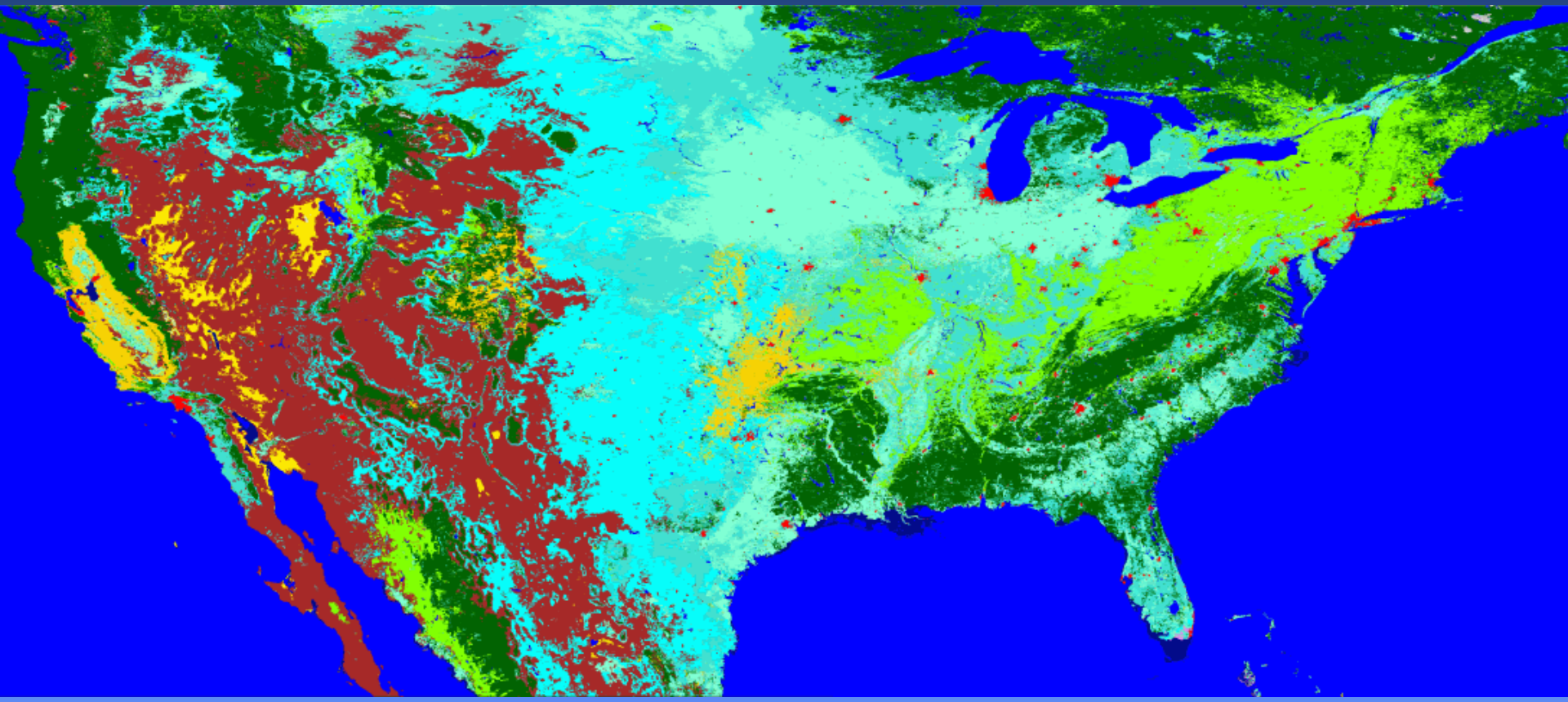
# 2 M Rise



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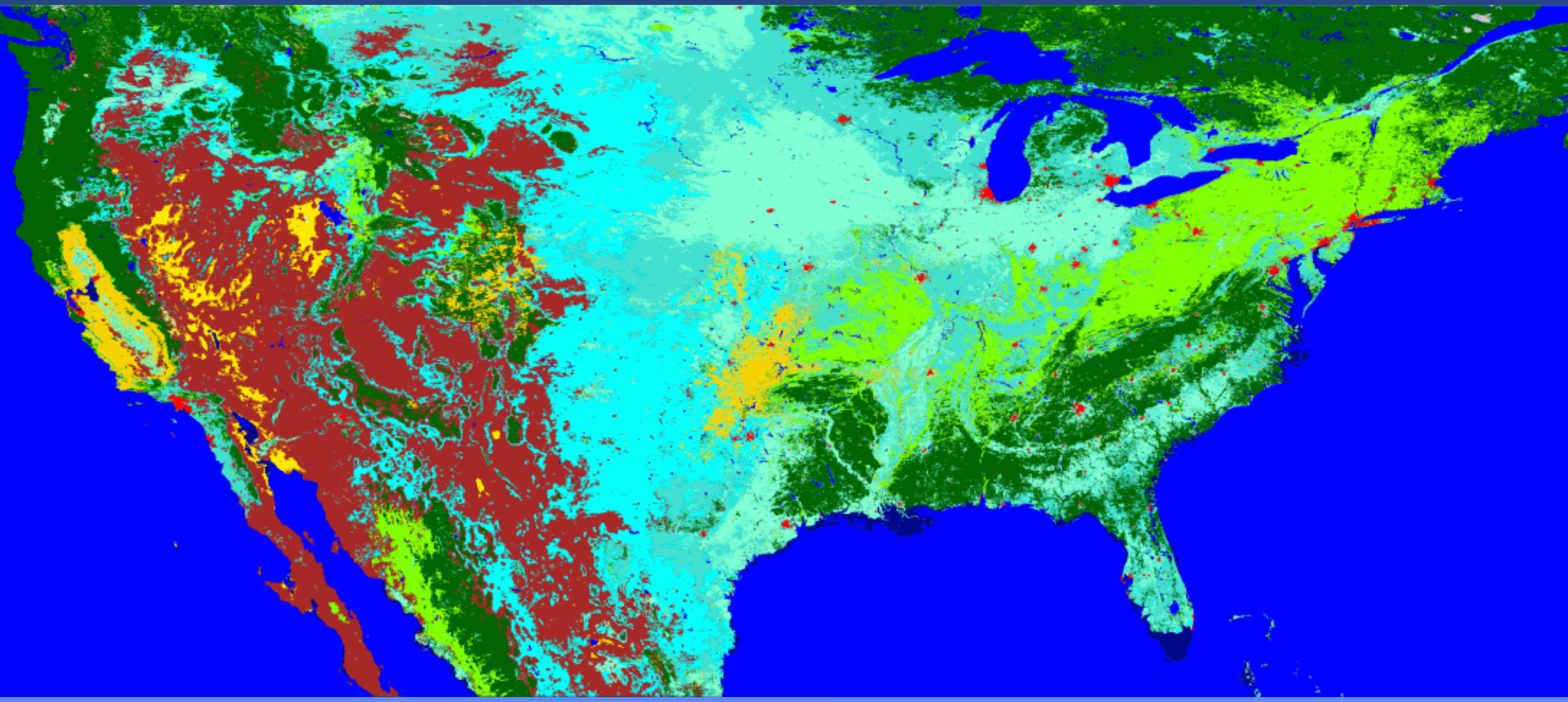
# 3 M Rise



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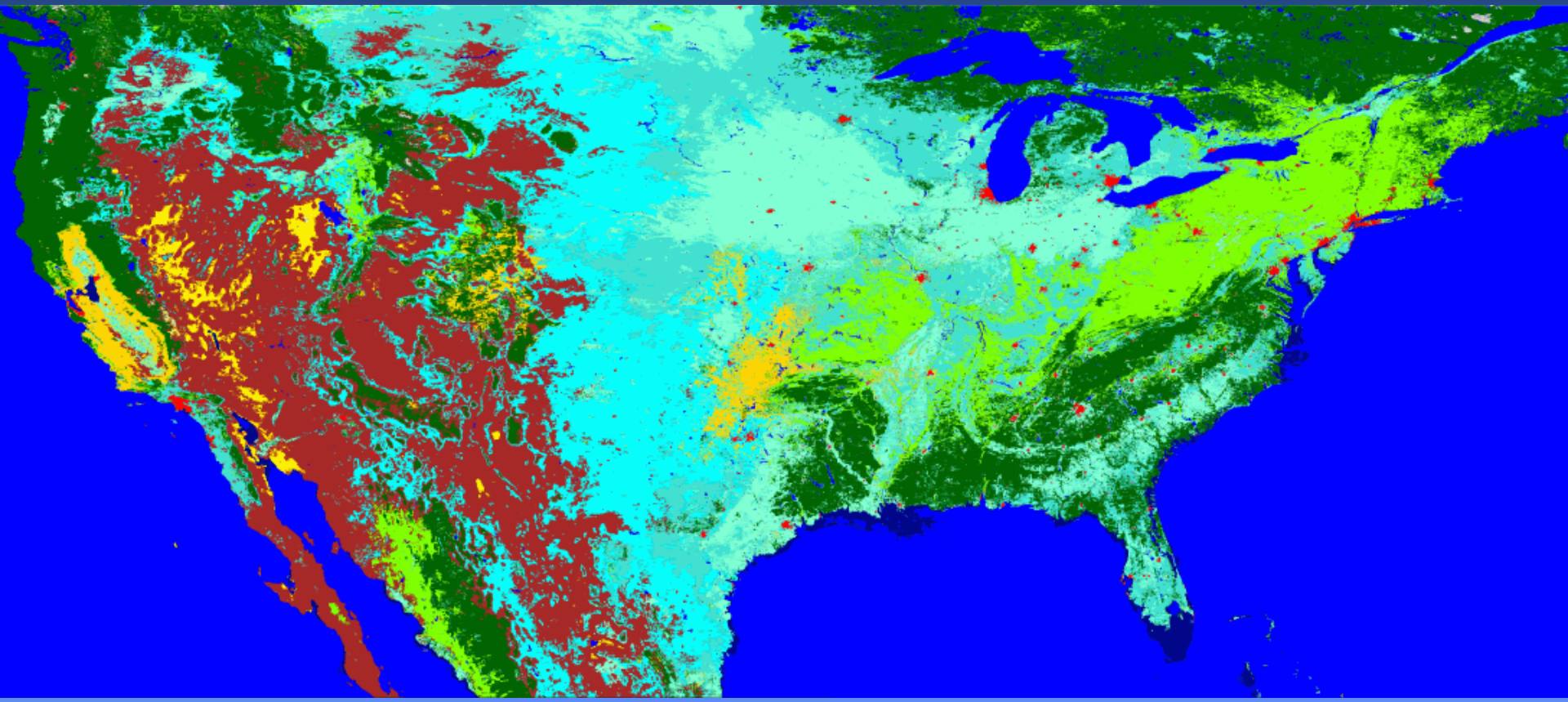
# 5 M Rise



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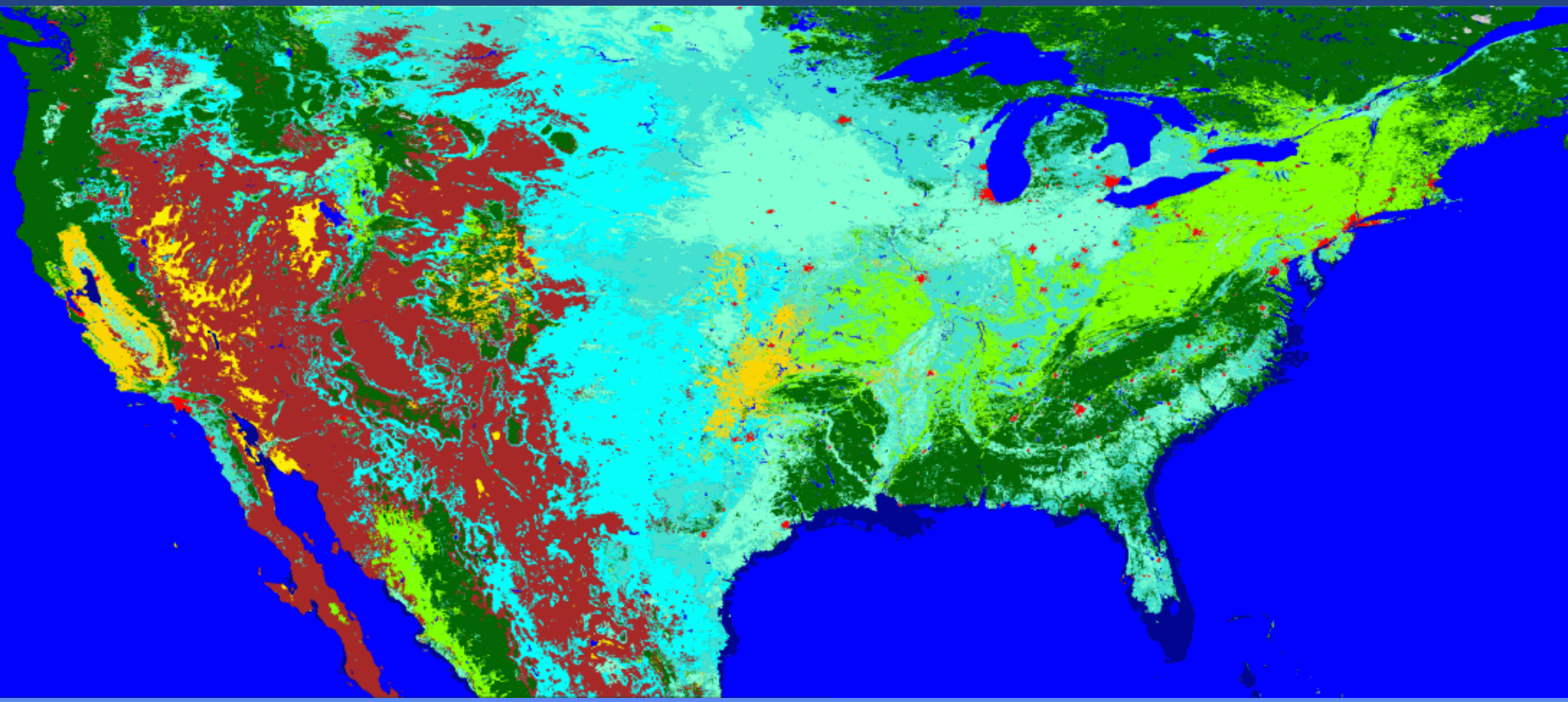
# 10 M Rise



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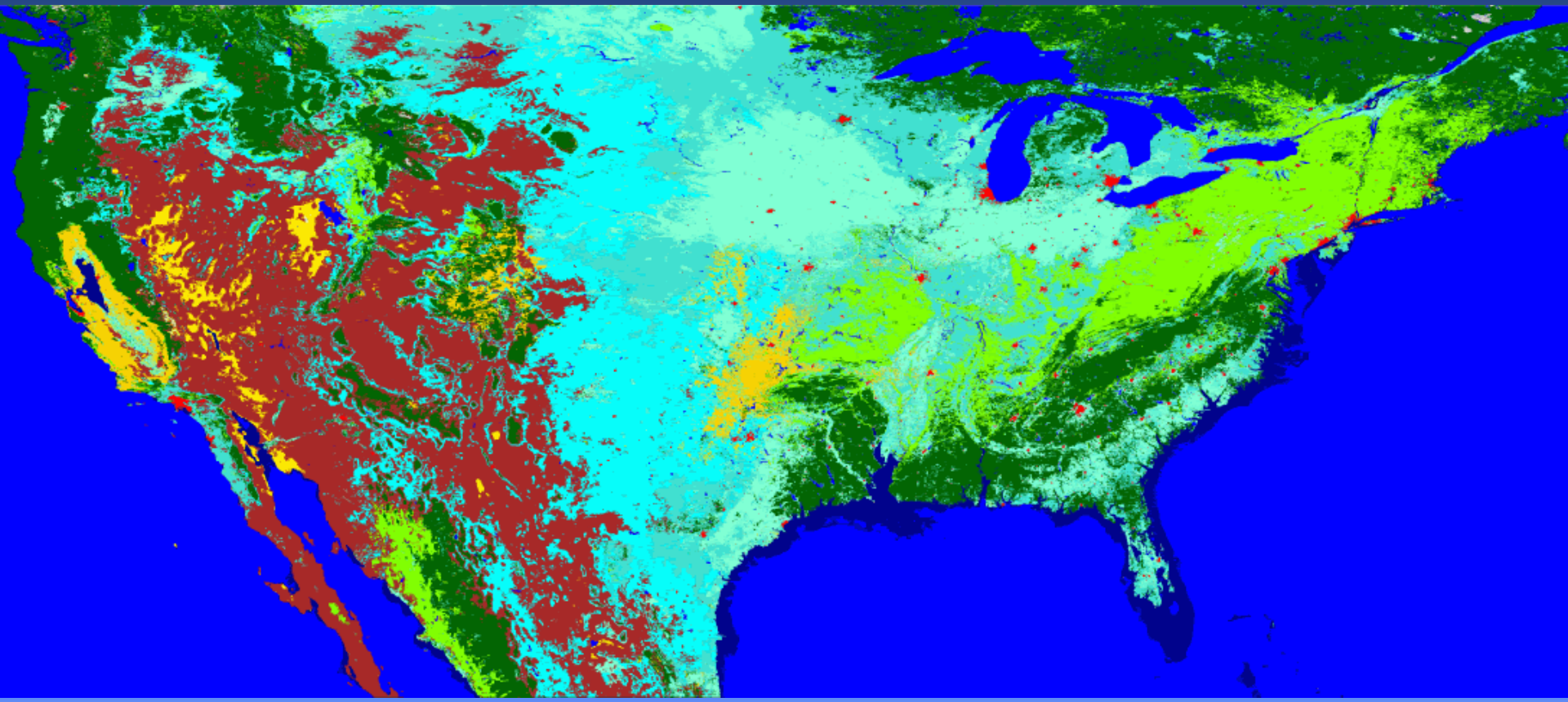
# 20 M Rise



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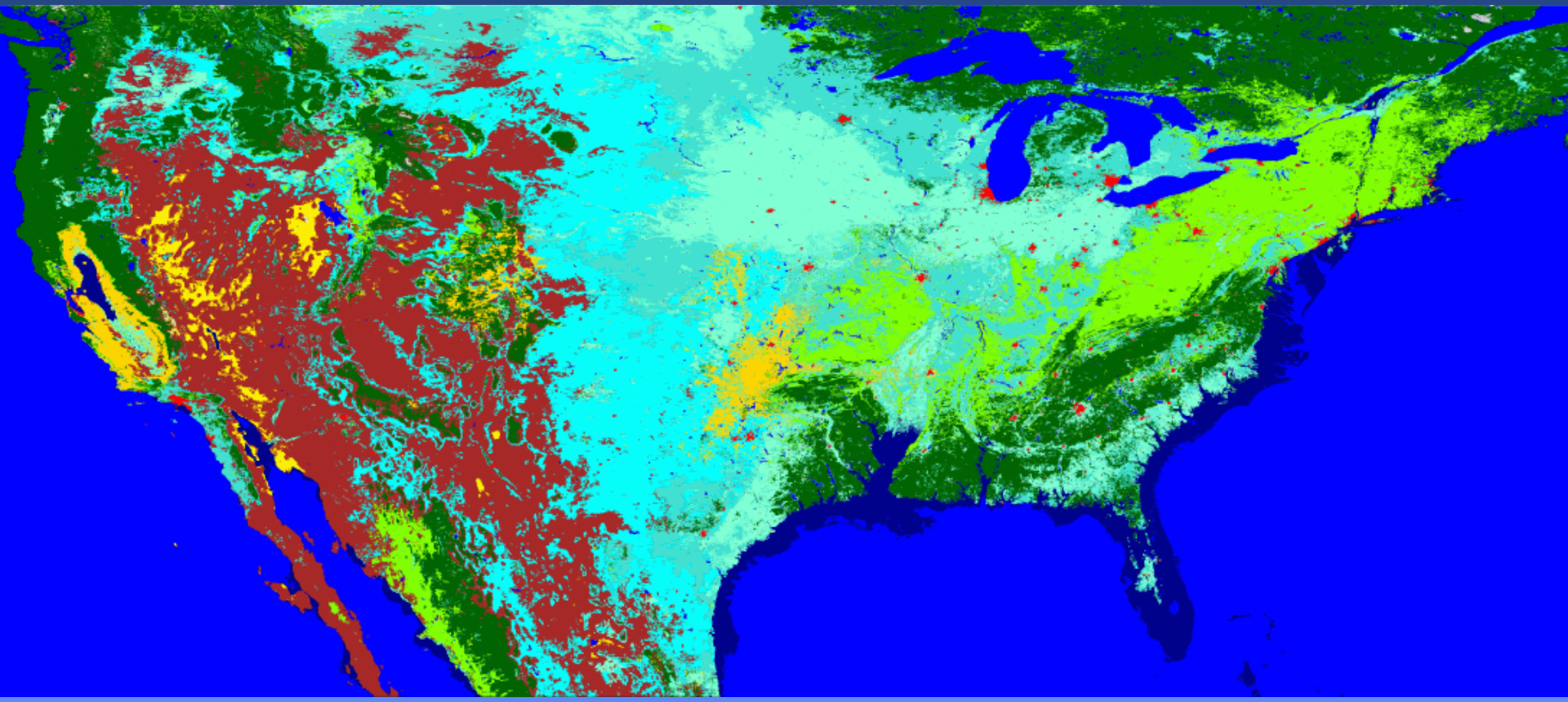
# 30 M Rise



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# Results -- World

| Water Level Increase (m) | Population Affected (Net) | Area of Land Loss ($km^2$) |
|---|---|---|
| 5 | 669,739,138 | 5,431,902 |
| 10 | 870,751,960 (201,012,822) | 6,308,676 |
| 20 | 1,176,709,476 (305,957,516) | 7,888,233 |
| 30 | 1,405,824,876 (229,115,400) | 9,459,562 (This is size of all of USA) |

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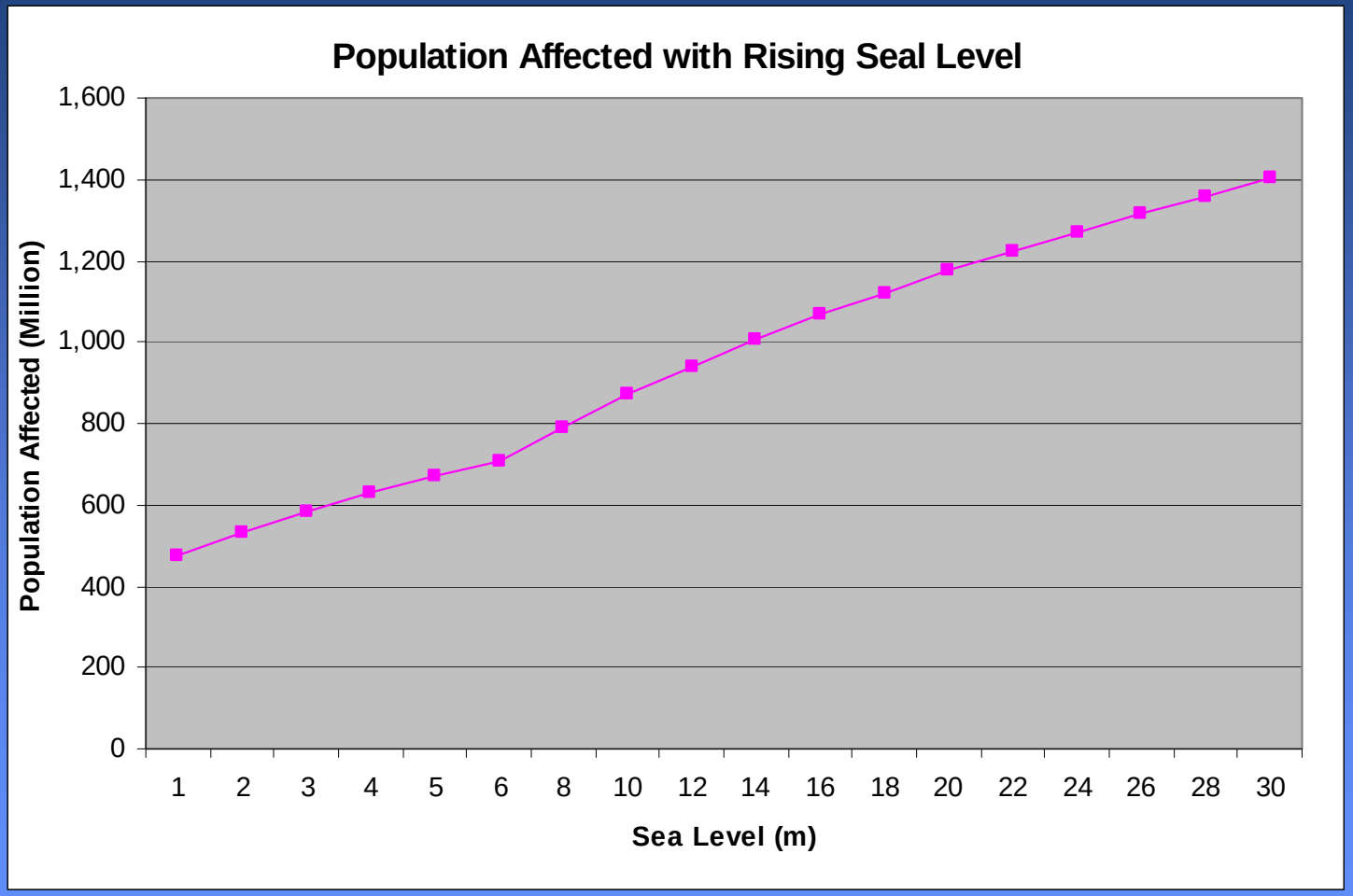
# Results – World Population Effects

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| Land Cover | POP Density (per km²) | Total # of Population (%) | Population affected with Rising Sea Level (Meter) | | | |
|---|---|---|---|---|---|---|
| | | | 5 (%) | 10 (%) | 20 (%) | 30 (%) |
| Urban and Built-Up Land | 3629.465 | 966,920,555 (15.5) | 125,426,492 (18.7) | 167,534,955 (19.2) | 225,034,603 (19.1) | 266,605,330 (19.0) |
| Irrigated Cropland and Pasture | 392.719 | 1,285,065,525 (20.6) | 146,650,929 (21.9) | 231,800,008 (26.6) | 353,447,741 (30.4) | 439,098,227 (31.2) |
| Dryland Cropland and Pasture | 121.907 | 1,480,209,129 (23.8) | 90,514,229 (13.5) | 117,463,463(13.5) | 169,232,478 (14.4) | 211,695,557 (15.1) |
| Cropland/Grassland Mosaic | 90.342 | 394,546,228 (6.3) | 18,977,528 (2.8) | 28,429,804 (3.3) | 46,827,725 (4.0) | 62,004,537 (4.4) |
| Cropland/Woodland Mosaic | 59.038 | 415,858,781 (6.7) | 29,235,588 (4.4) | 38,719,342 (4.4) | 52,366,472 (4.5) | 64,776,559 (4.6) |
| Savanna | 26.962 | 414,375,468 (6.7) | 11,853,796 (1.8) | 15,467,596 (1.8) | 21,710,314 (1.8) | 26,744,460 (1.9) |
| Grassland | 23.108 | 240,005,697 (3.9) | 15,189,230 (2.3) | 20,873,821 (2.4) | 28,653,270 (2.4) | 33,867,565 (2.4) |
| Wooded Wetland | 21.817 | 341,190,481 (5.5) | 22,577,955 (3.4) | 31,003,493 (3.6) | 42,853,389 (3.6) | 50,464,119 (3.6) |
| Shrubland | 19.383 | 18,005,767 (0.3) | 5,088,510 (0.8) | 5,871,408 (0.7) | 7,046,719 (0.6) | 7,603,461 (0.5) |
| Mixed Shrubland / Grassland | 18.735 | 41,128,137 (0.7) | 8,798,238 (1.3) | 9,259,268 (1.1) | 10,377,403 (0.9) | 11,435,638 (0.8) |
| Total | | 6,228,997,089 (100) | 669,739,138 (100) | 870,751,960 (100) | 1,176,709,476 (100) | 1,405,824,876 (100) |

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| Rise | China population | India population | Indonesia population |
|---|---|---|---|
| 2 | 26,099,831 | 31,570,268 | 70,018,448 |
| 4 | 49,674,881 | 77,628,763 | 87,039,631 |
| 6 | 79,947,770 | 106,267,732 | 99,785,077 |
| 8 | 113,783,077 | 131,675,091 | 109,634,830 |
| 10 | 139,764,861 | 160,884,256 | 119,778,508 |
| 12 | 162,303,430 | 192,194,566 | 130,218,653 |
| 14 | 181,333,693 | 219,755,727 | 138,902,415 |
| 16 | 198,707,264 | 240,782,631 | 147,648,541 |
| 18 | 214,870,946 | 258,577,458 | 154,865,835 |
| 20 | 230,946,568 | 273,551,521 | 163,062,060 |
| 22 | 244,844,853 | 287,786,046 | 170,021,796 |
| 24 | 257,965,940 | 299,736,207 | 177,410,945 |
| 26 | 272,153,421 | 310,352,779 | 183,919,866 |
| 28 | 286,410,739 | 319,870,658 | 189,645,051 |
| 30 | 299,961,032 | 328,417,614 | 196,351,041 |
| 40 | 357,433,094 | 378,128,793 | 218,466,879 |
| 50 | 397,126,742 | 421,916,410 | 240,375,635 |
| 60 | 426,318,214 | 467,519,741 | 257,775,204 |
| 70 | 450,838,668 | 518,300,053 | 271,459,269 |
| 80 | 471,351,294 | 554,828,474 | 284,432,733 |

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| Rise | Japan population | Netherlands population | Italy population |
|---|---|---|---|
| 2 | 6,837,446 | 11,096,402 | 1,460,116 |
| 4 | 10,450,632 | 13,694,359 | 2,132,919 |
| 6 | 15,166,804 | 15,653,995 | 3,391,984 |
| 8 | 18,887,482 | 16,953,580 | 3,970,818 |
| 10 | 24,301,014 | 18,660,406 | 5,183,872 |
| 12 | 27,086,369 | 19,572,457 | 6,089,009 |
| 14 | 29,866,950 | 20,395,629 | 6,625,007 |
| 16 | 32,898,067 | 21,499,610 | 7,358,672 |
| 18 | 35,476,653 | 22,508,709 | 7,677,540 |
| 20 | 42,551,216 | 23,828,461 | 8,081,173 |
| 22 | 44,717,735 | 24,558,687 | 8,608,146 |
| 24 | 46,532,021 | 25,332,679 | 9,128,093 |
| 26 | 48,281,312 | 26,305,777 | 9,916,391 |
| 28 | 49,730,754 | 26,972,235 | 10,244,657 |
| 30 | 51,787,617 | 27,946,231 | 10,795,495 |
| 40 | 60,888,876 | 31,745,294 | 12,893,252 |
| 50 | 68,973,117 | 35,713,003 | 14,590,445 |
| 60 | 74,193,607 | 38,867,364 | 15,756,447 |
| 70 | 78,465,454 | 41,523,604 | 17,035,915 |
| 80 | 82,850,542 | 43,632,590 | 18,352,586 |

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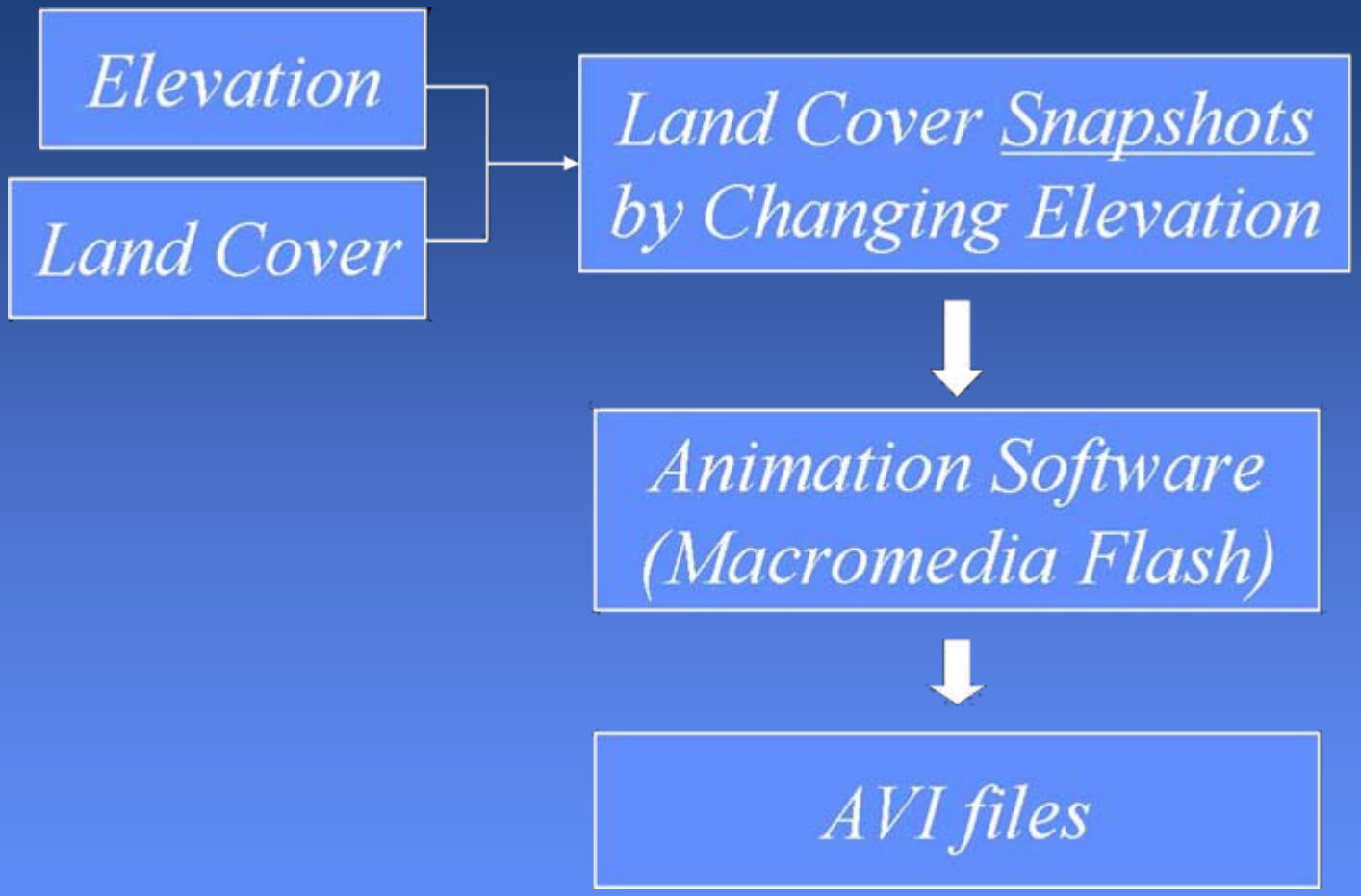
# Animation Process

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# Conclusions

- Global sea level rise and storm surges potentially affect large numbers of people and various types of land cover
- Sea-level rise can be modeled on a global scale with data at 30 arc-sec resolution
- Modeling requires specially designed projection and resampling software
  - Better categorical resampler for global land cover
  - Additive resampler for population counts
- Animation effectively portrays results and effects of potential sea-level rise and storm surge

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# Caveats – Resolution and Accuracy

**Resolution**

- **Global data – 30 arc-sec resolution affects results; small areas, for example, river valleys smaller than twice resolution (60 arc-sec, 2 km at Equator) cannot be modeled effectively**
- **Regional/local data – areas smaller than twice resolution (180 m for SRTM, 60 m for NED) cannot be modeled effectively**

**Accuracy**

- **Errors in data reflect as errors in model (for example, in the gTopo30 data, the Fly River, New Guinea, is 30 km wide, but doesn't show in model because of data errors)**

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# **Animations -** *separate movie files*

*Table below gives resolution for three layers*

**1 – World – 1 km, all 3 layers**

**2 – Regional – 1 km, all 3 layers**

**3 – US Coasts – 1 km, all 3 layers**

**4 – Malaysia – 90 m DEM, 1 km resampled to 90 m for land cover and population**

**5 – Delaware – 30 m all 3 layers**

**6 – New York – 30 m all 3 layers**

**7 – Alabama Coast – 30 m DEM, population, 1 km land cover resampled to 30 m**

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# Elements of a Global Model: An Example of Sea Level Rise and Human Populations at Risk

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