Integrating deep-learning models to forecast land use

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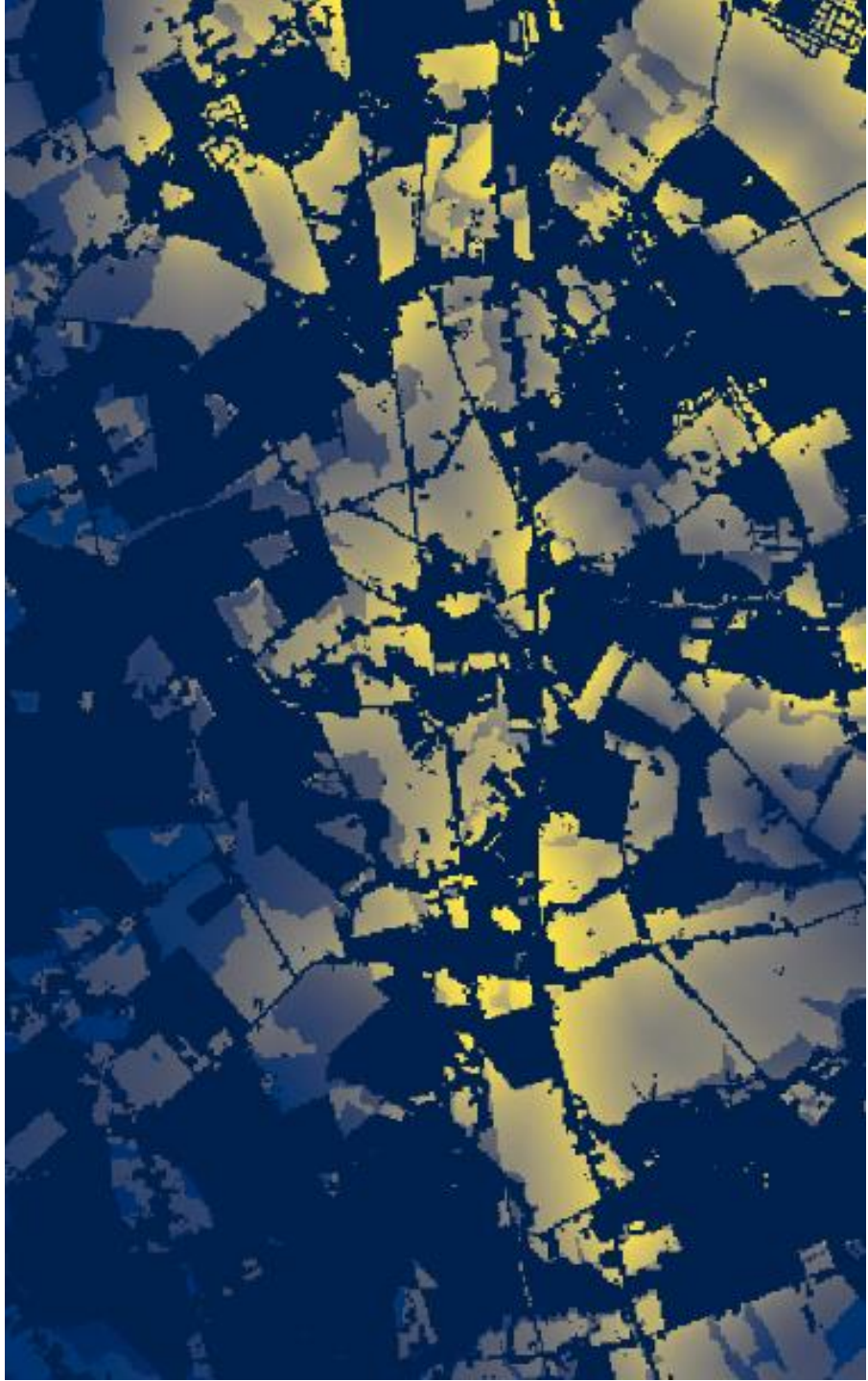
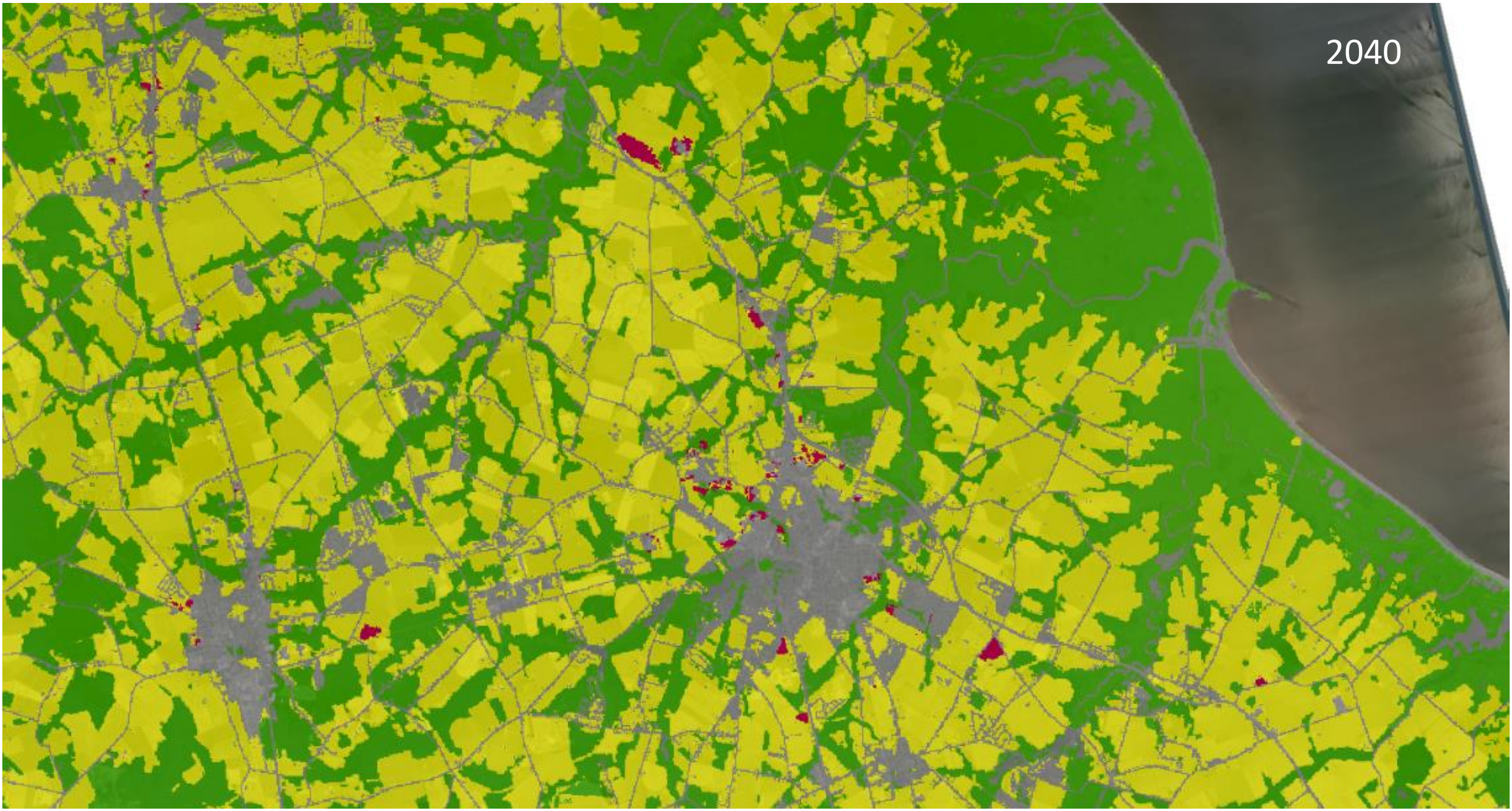
Goal

Make spatially and temporally accurate allocations of population and employment projections

Objectives

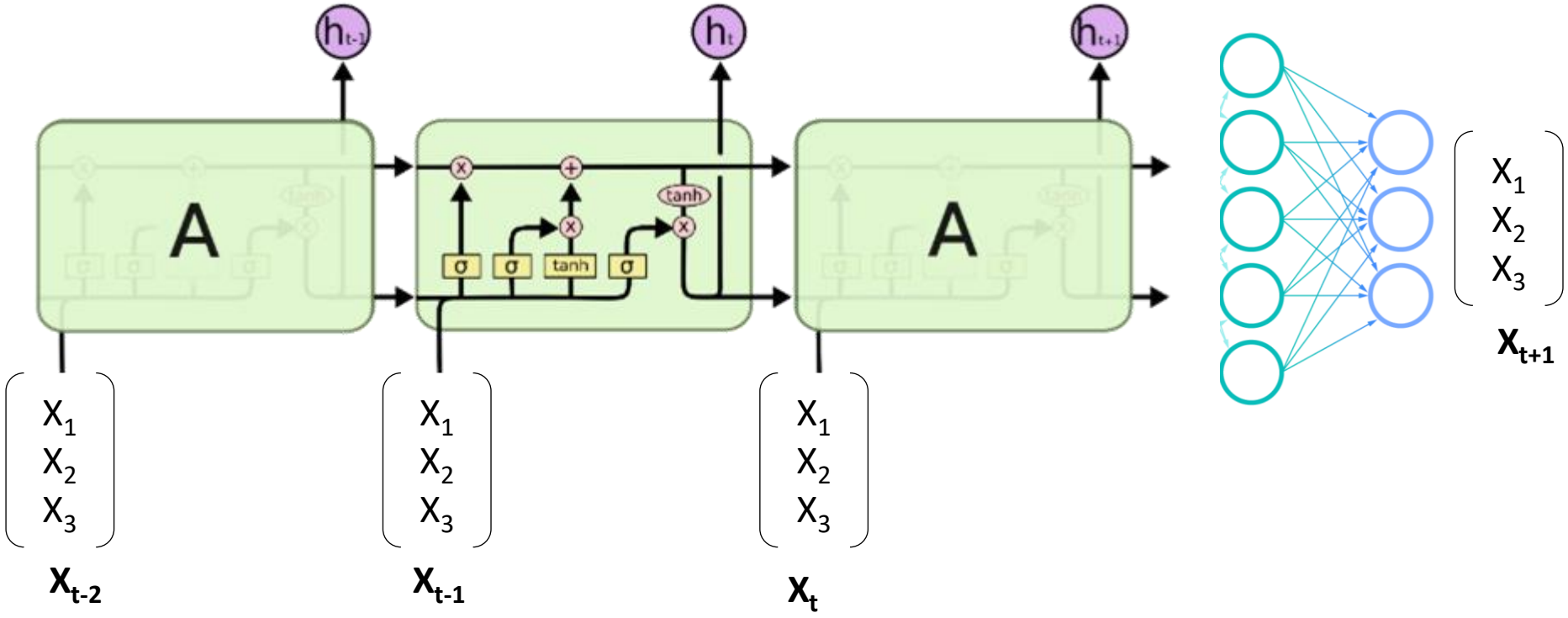
1. Account for Variation in Types of Places
2. Accommodate Dynamic Growth Trajectories
3. Improve the Surface of Transition Probabilities




2040

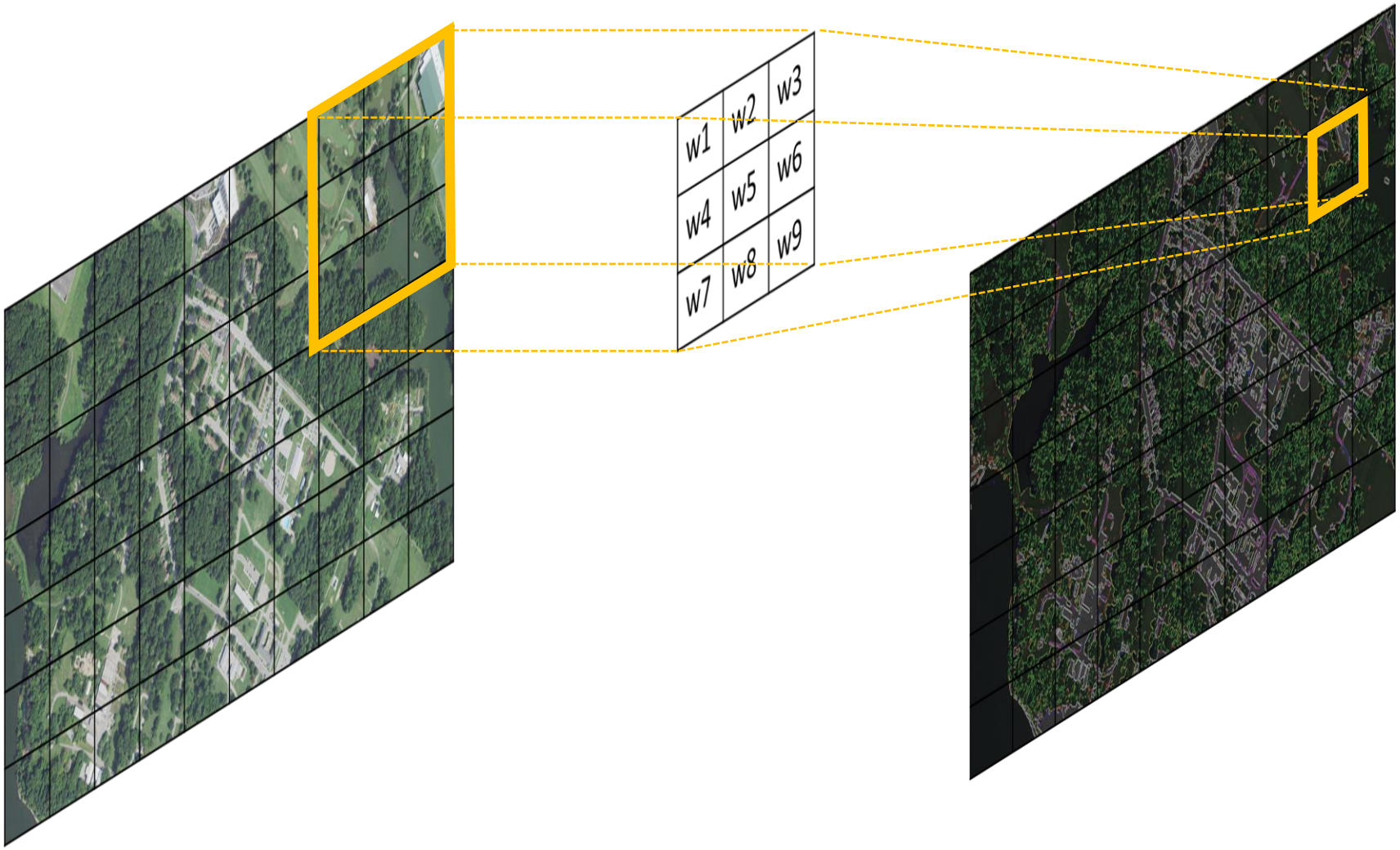
Deep Learning: Long Short-Term Memory

Capturing temporal information



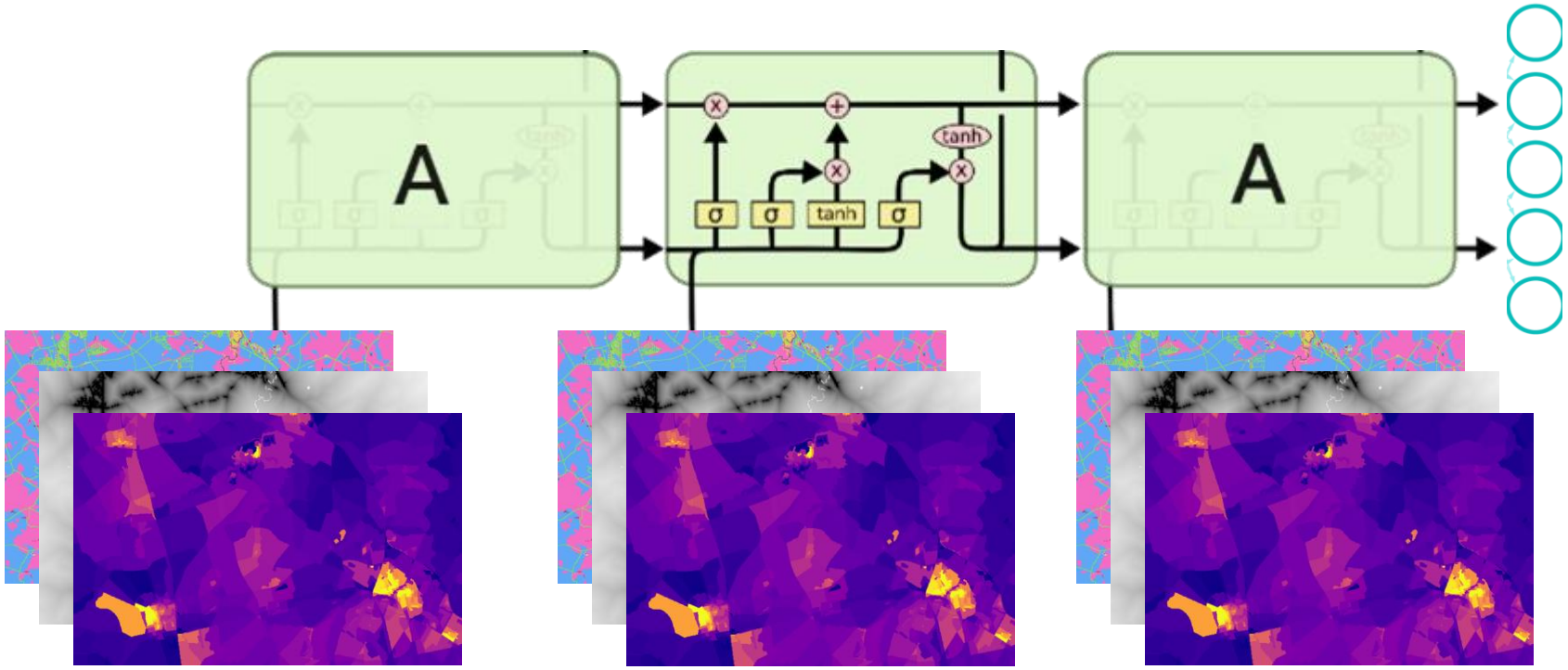
Deep Learning: Convolution

Capturing spatial information



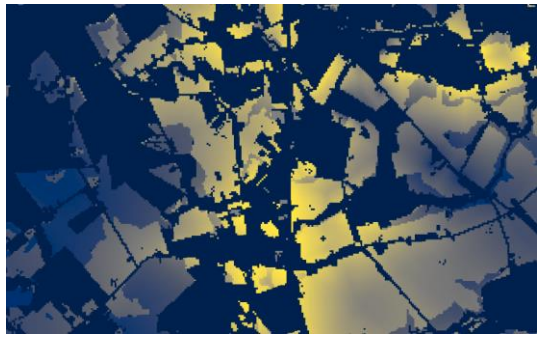
Convolutional Long Short-Term Memory

1. *Model Dynamic Growth*
2. *Improve the Surface of Transition Probabilities*



T_{-2} T_{-1} T

Transition Probability



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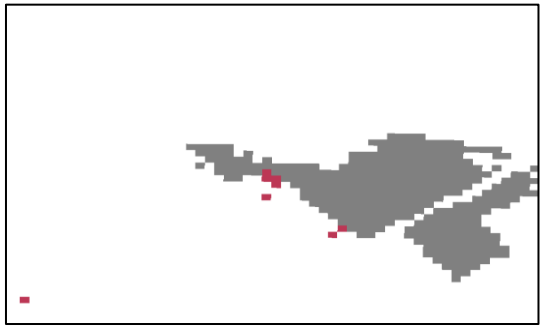
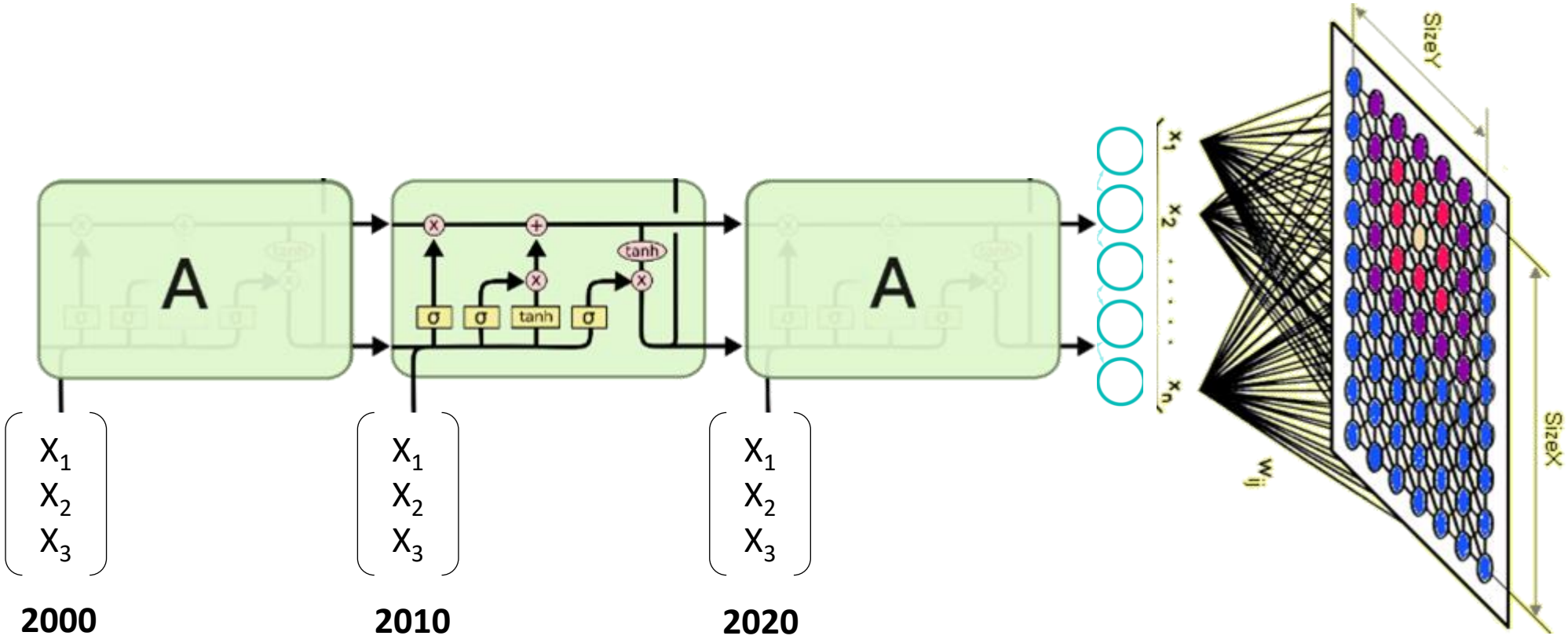


Self Organizing Map

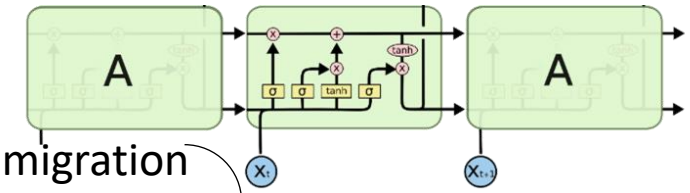
Account for Variation in Types of Places



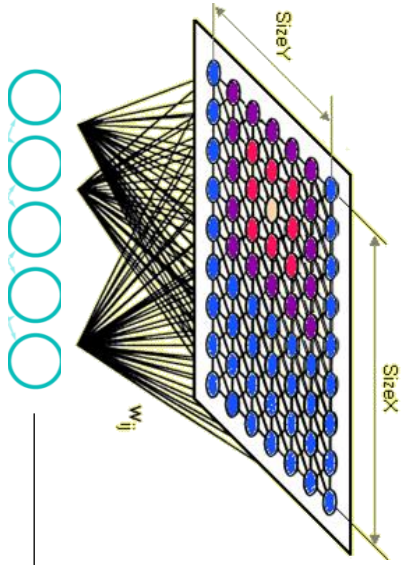
Socio-Economic Data

Hierarchical Self Organizing Map

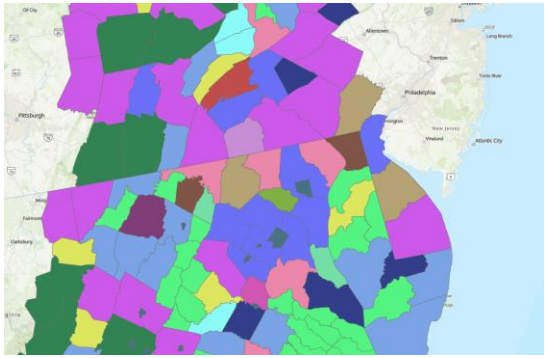
Counties



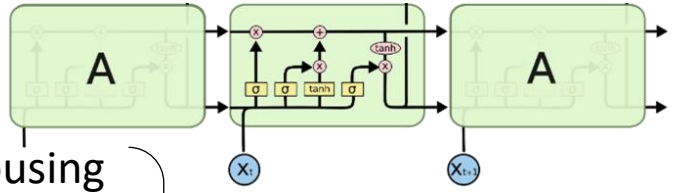
Immigration
Emigration
Housing
Population
Income
Employment



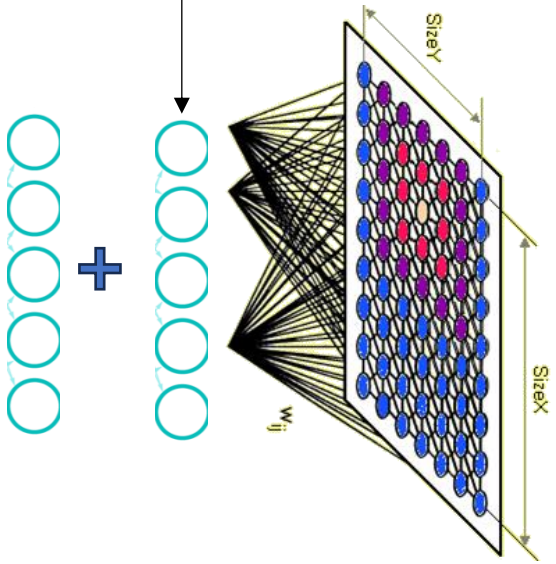
County ‘Types’



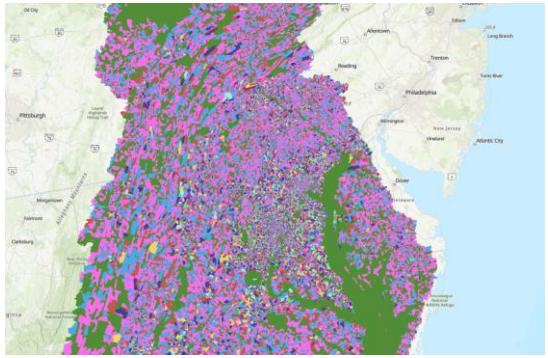
Census Blocks



Housing
Population
Workers
Jobs

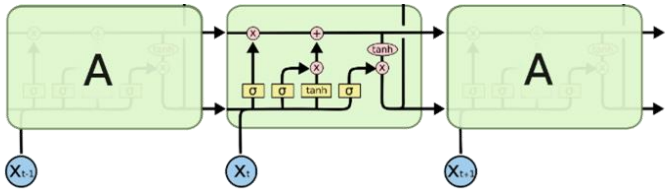


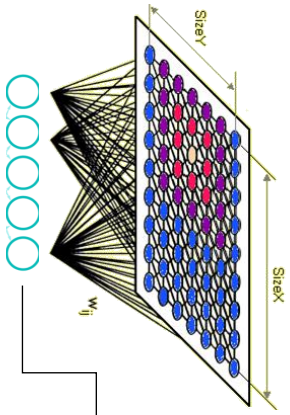
Census Block ‘Types’



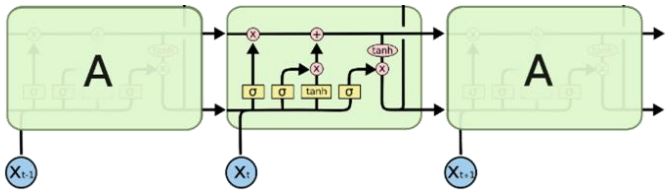
Integrated Model

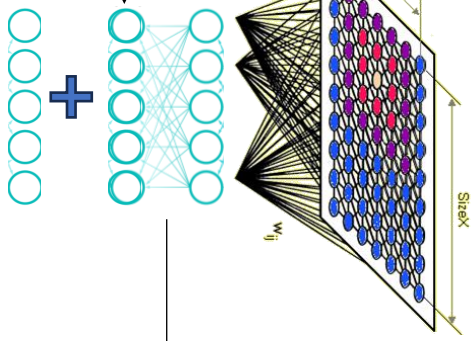
County SE Timeseries





Block SE Timeseries





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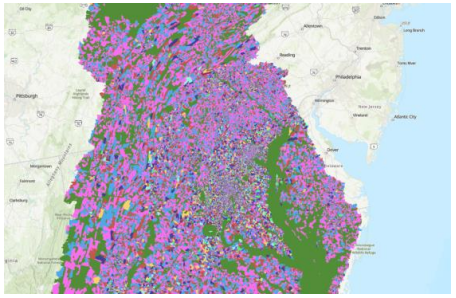
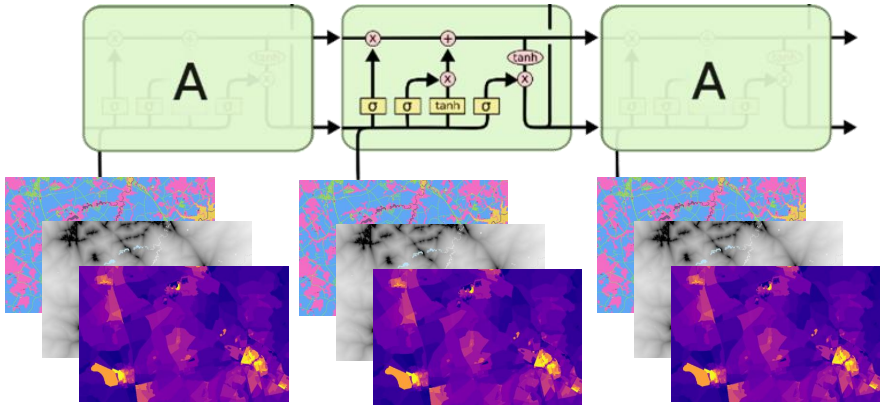
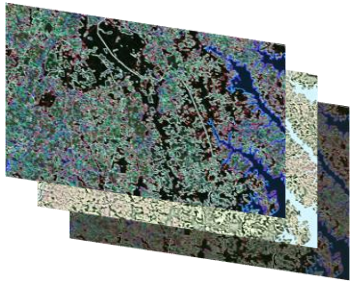
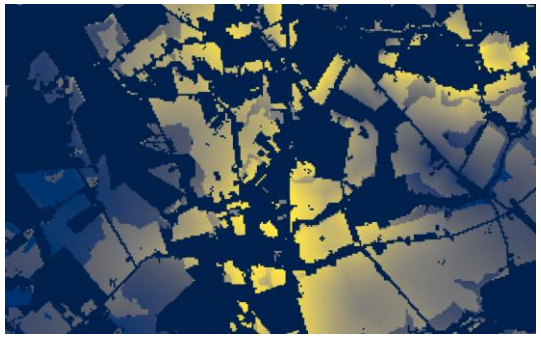


Geographic Timeseries







Transition Probability

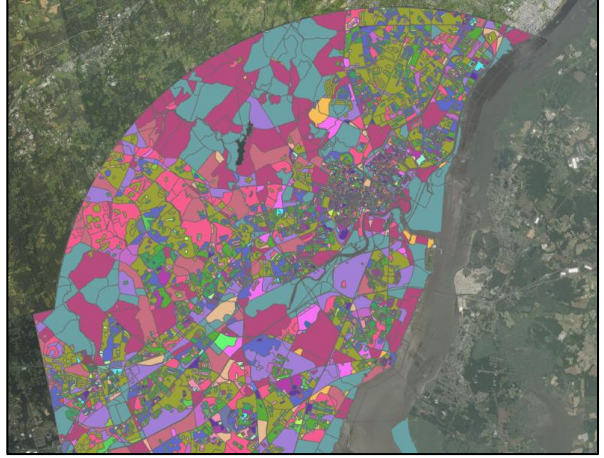
Block Types

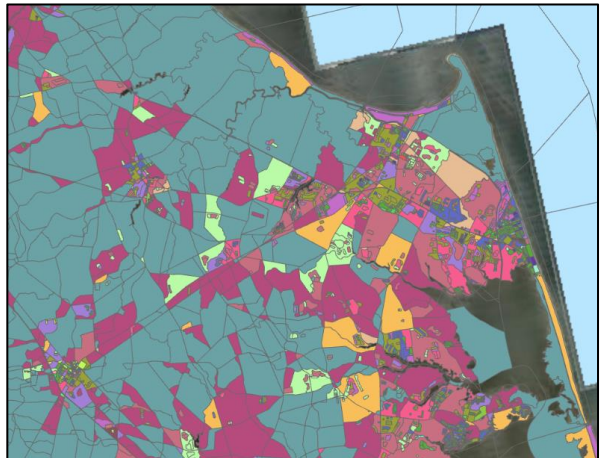
1. 66 ‘Types’ of Census Blocks
2. Differences in growth rates

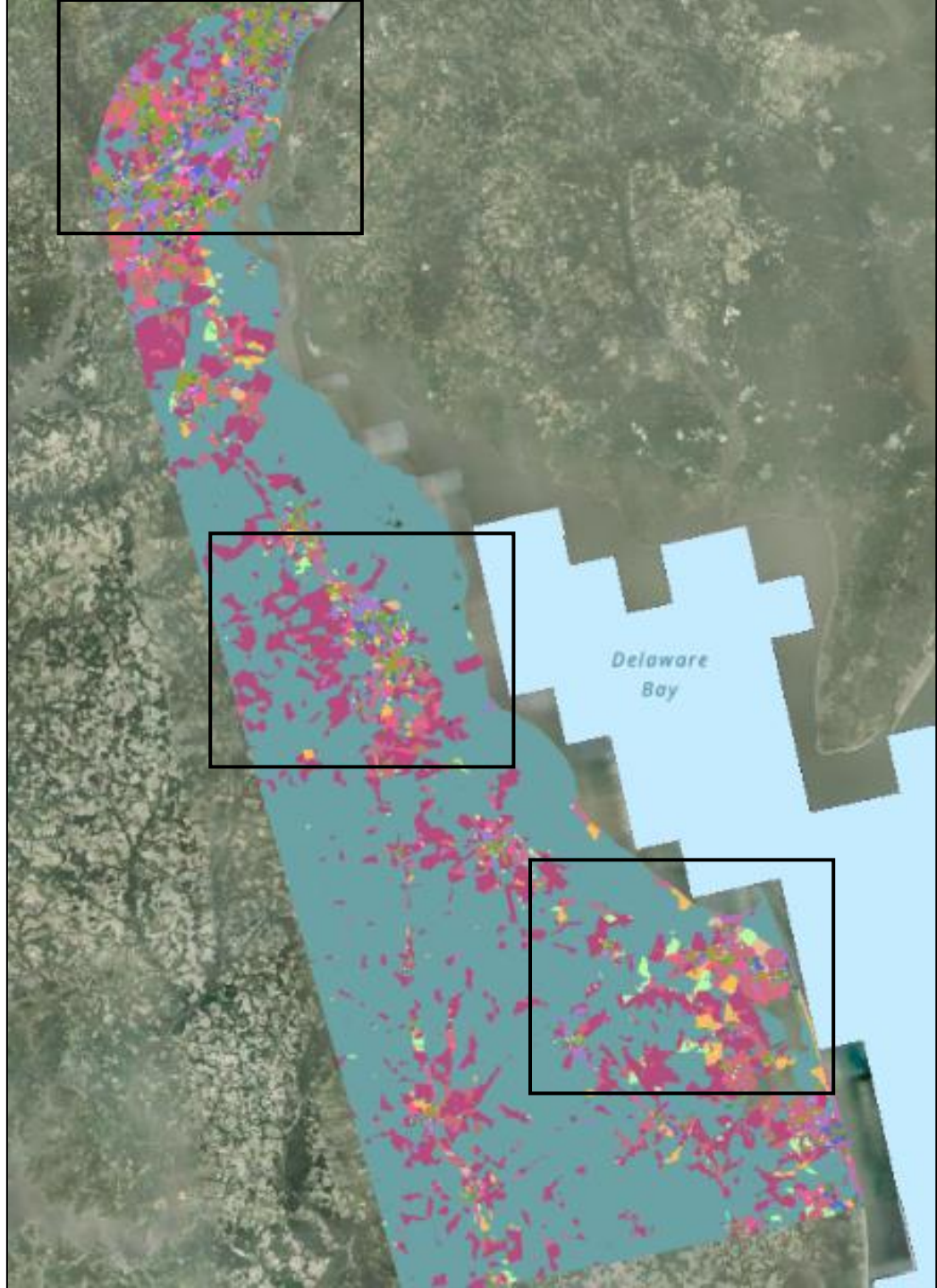
Quantization Error = 0.000005

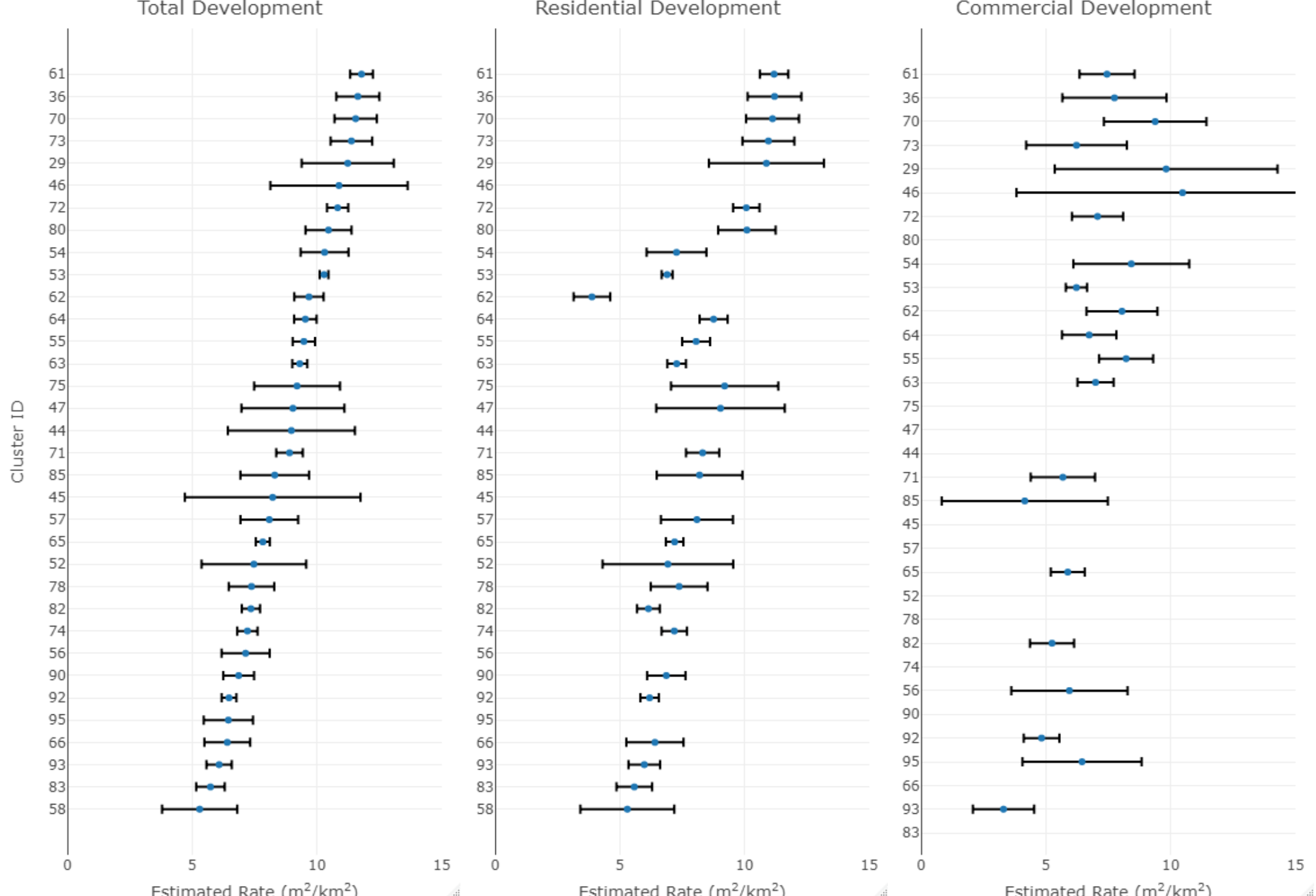
Topographic Error = 0.3

Combined Error = 0.002



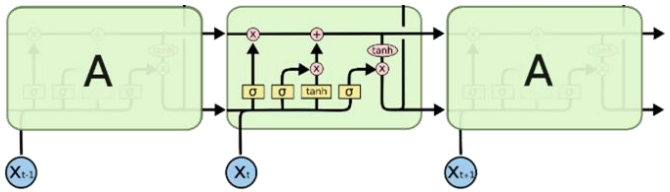


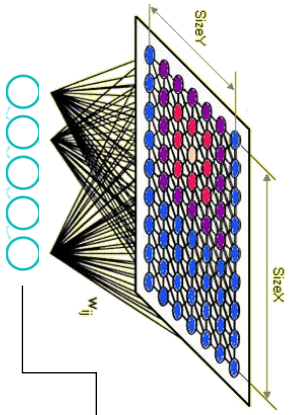



Total Development
Residential Development
Commercial Development
Cluster ID
61
36
70
73
29
46
72
80
54
53
62
64
55
63
75
47
44
71
85
45
57
65
52
78
82
74
56
90
92
95
66
93
83
58
0
5
10
15
Estimated Rate (m²/km²)

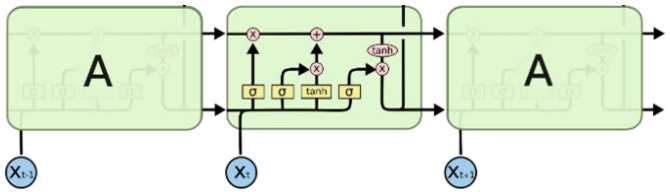
Combined Model

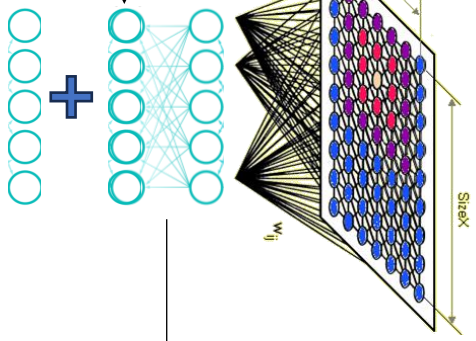
County SE Timeseries



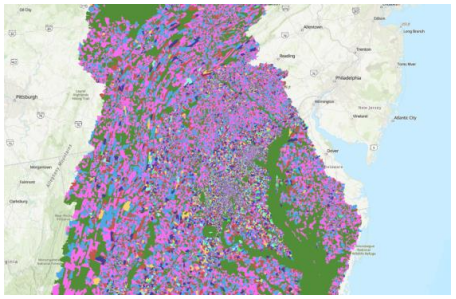


Block SE Timeseries

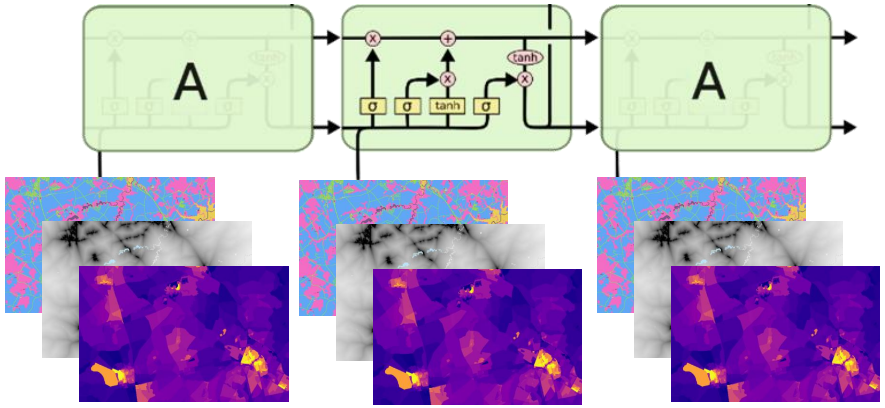


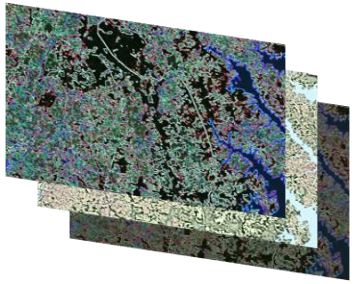


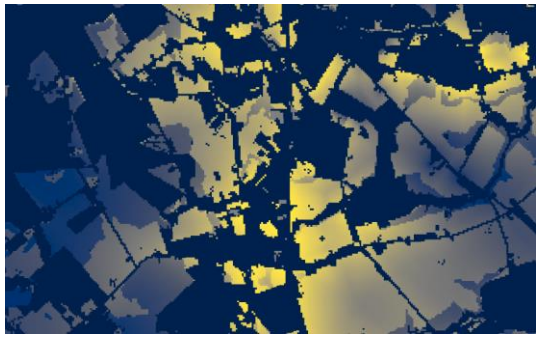
Block 'Types'



Geographic Timeseries







Transition Probability

LSTM Training

Static variables

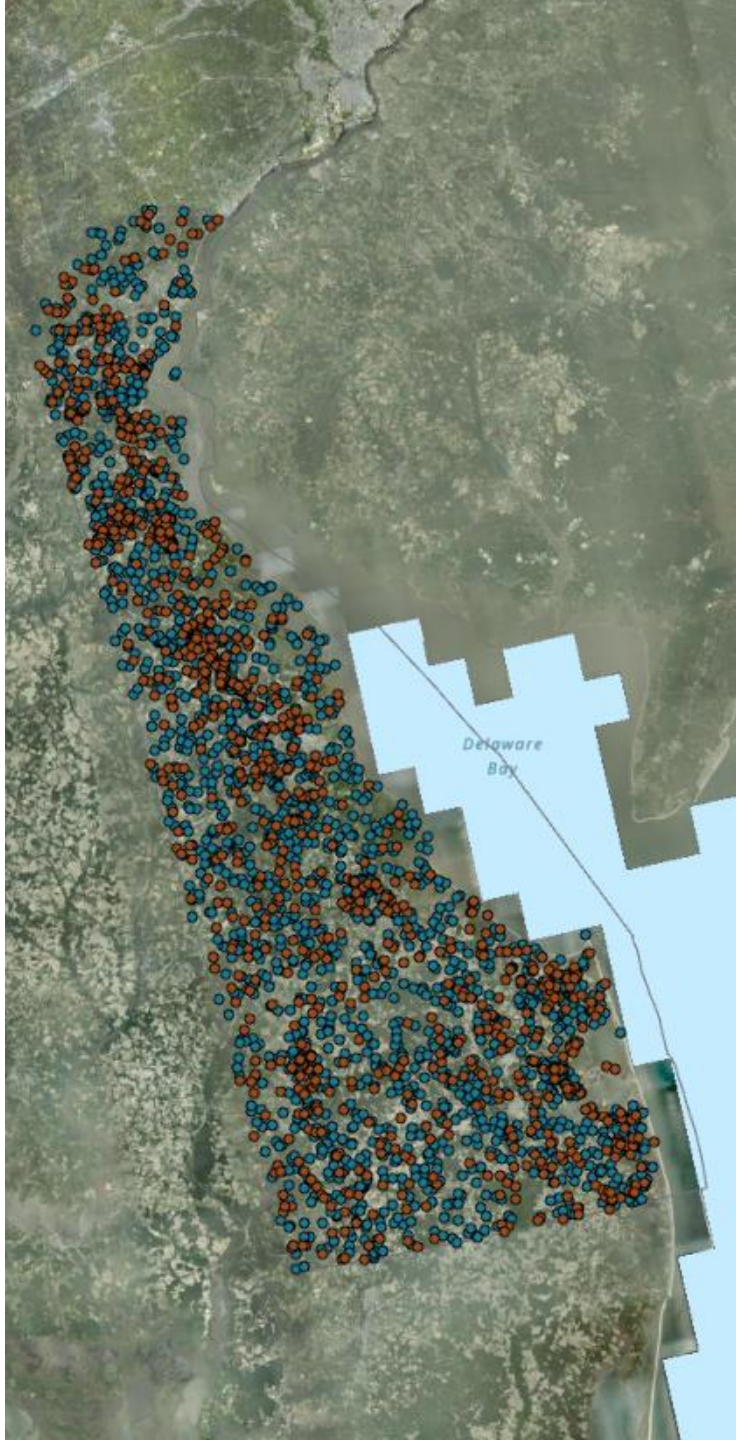
1. Distance to water
2. Distance to sewer
3. Regional employment

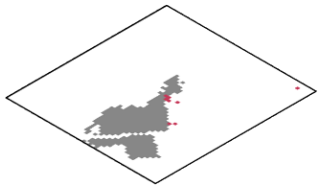
Temporal variables (2000, 2010)

1. Distance to commercial hotspots
2. Distance to residential hotspots
3. Distance to urban clusters
4. Travel time
5. Landcover
6. Developed vs. Natural vs. Agricultural

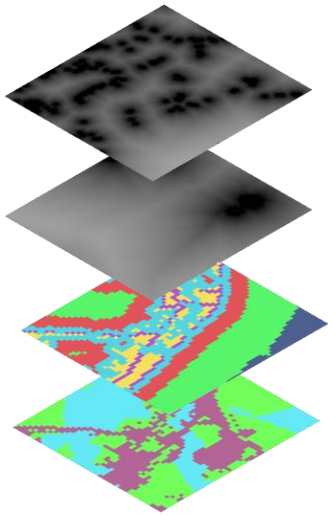
Response Variable

Residential vs. Commercial vs. No Change in 2020

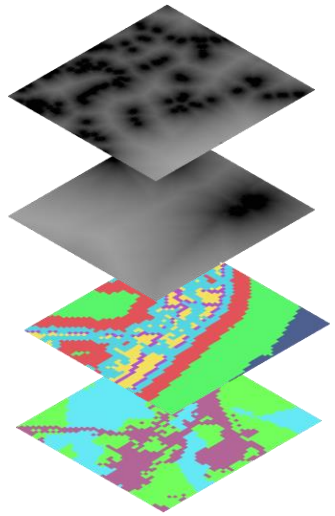




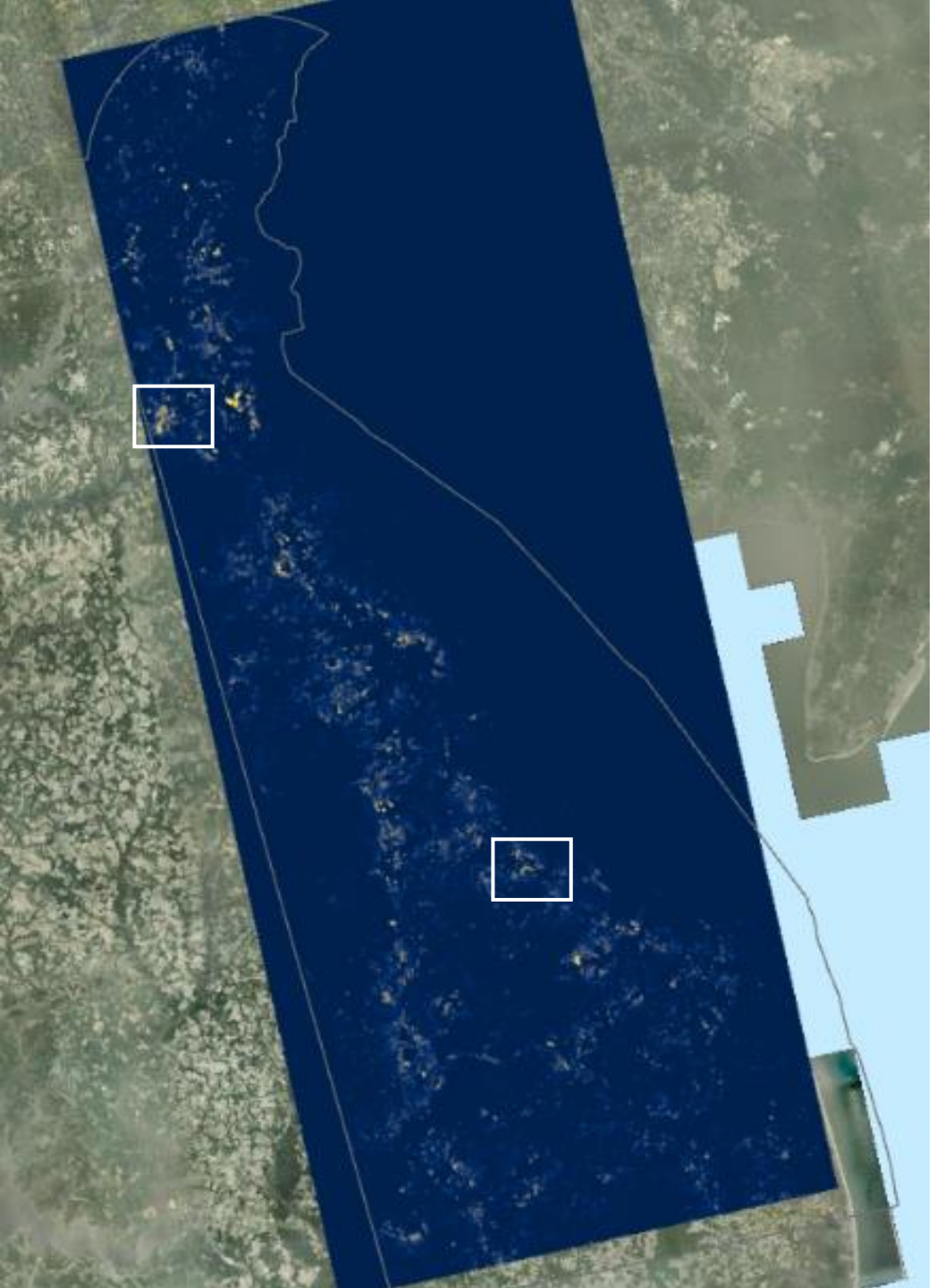
2020

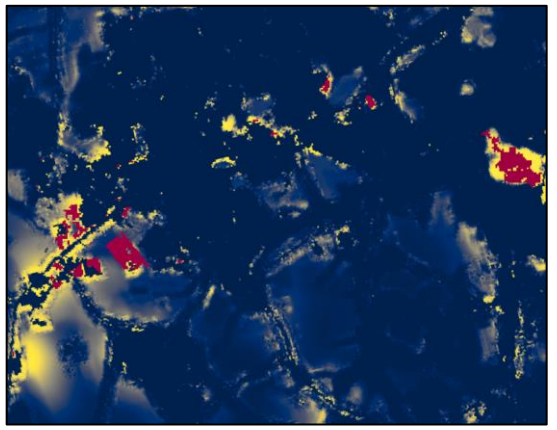


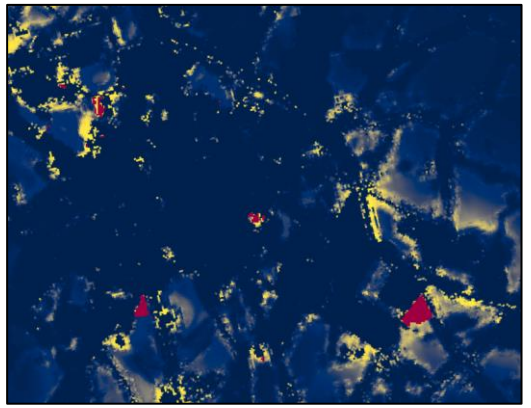
2000



2010



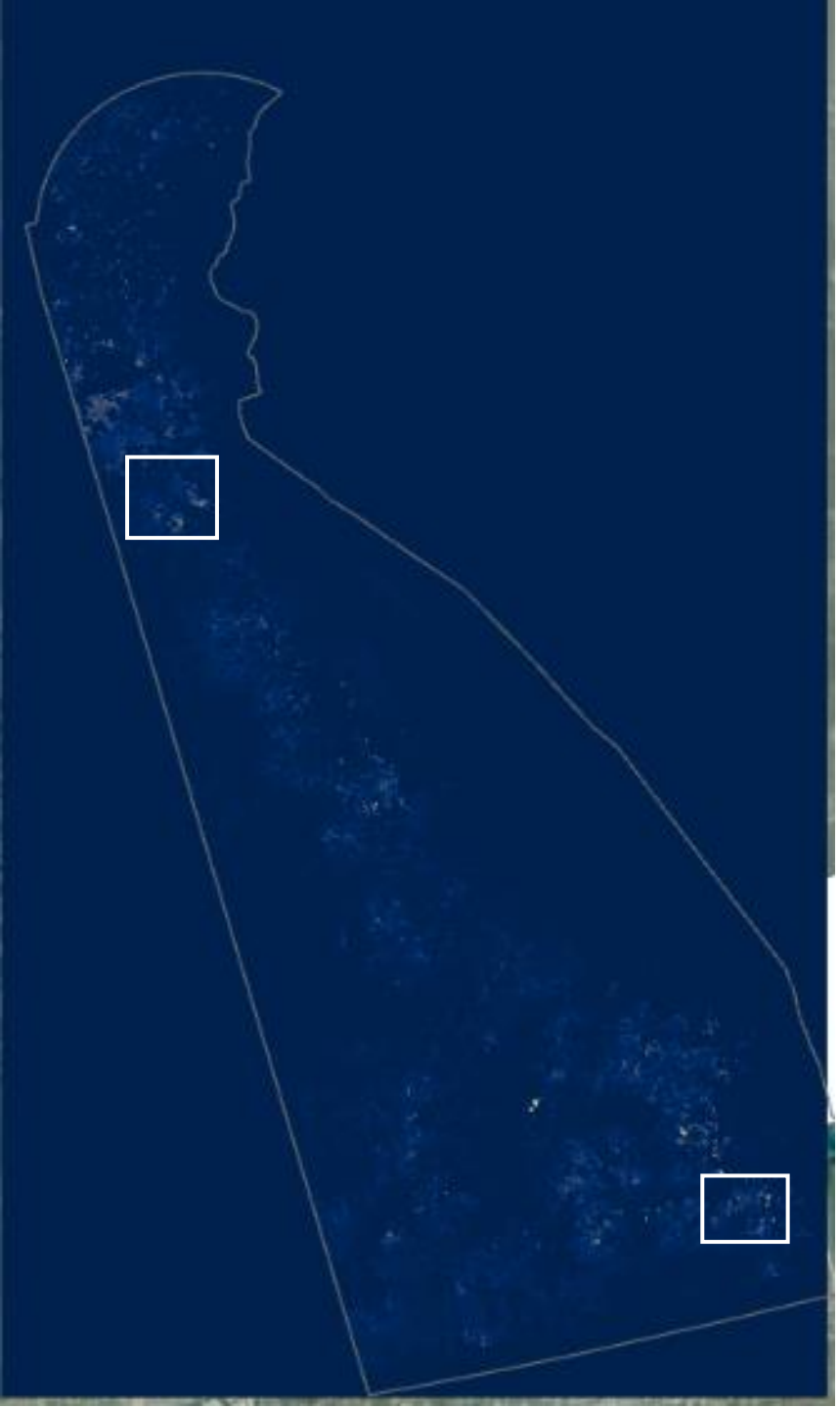


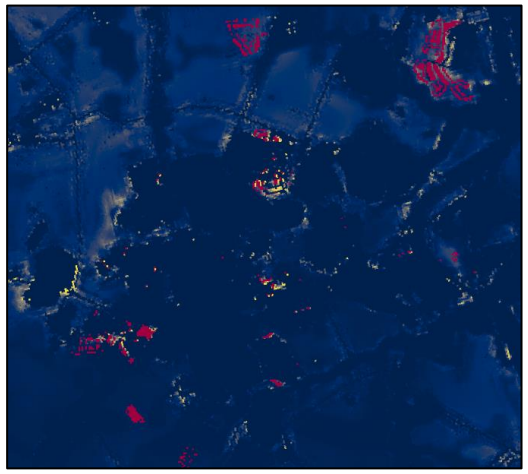


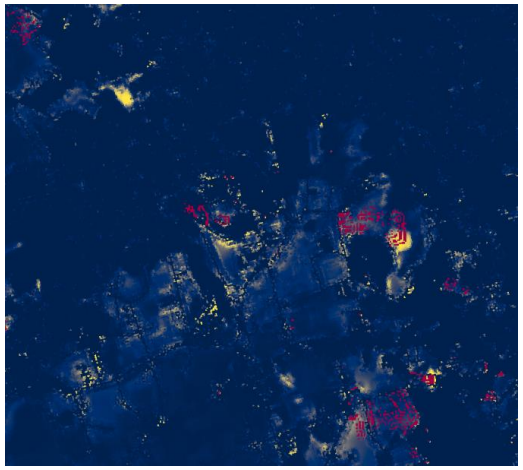
Predicted 2020 Commercial Development Probability

0.0 1.0

2020 Commercial Development







Predicted 2020 Residential Development Probability

0.0 1.0

2020 Residential Development

Questions?

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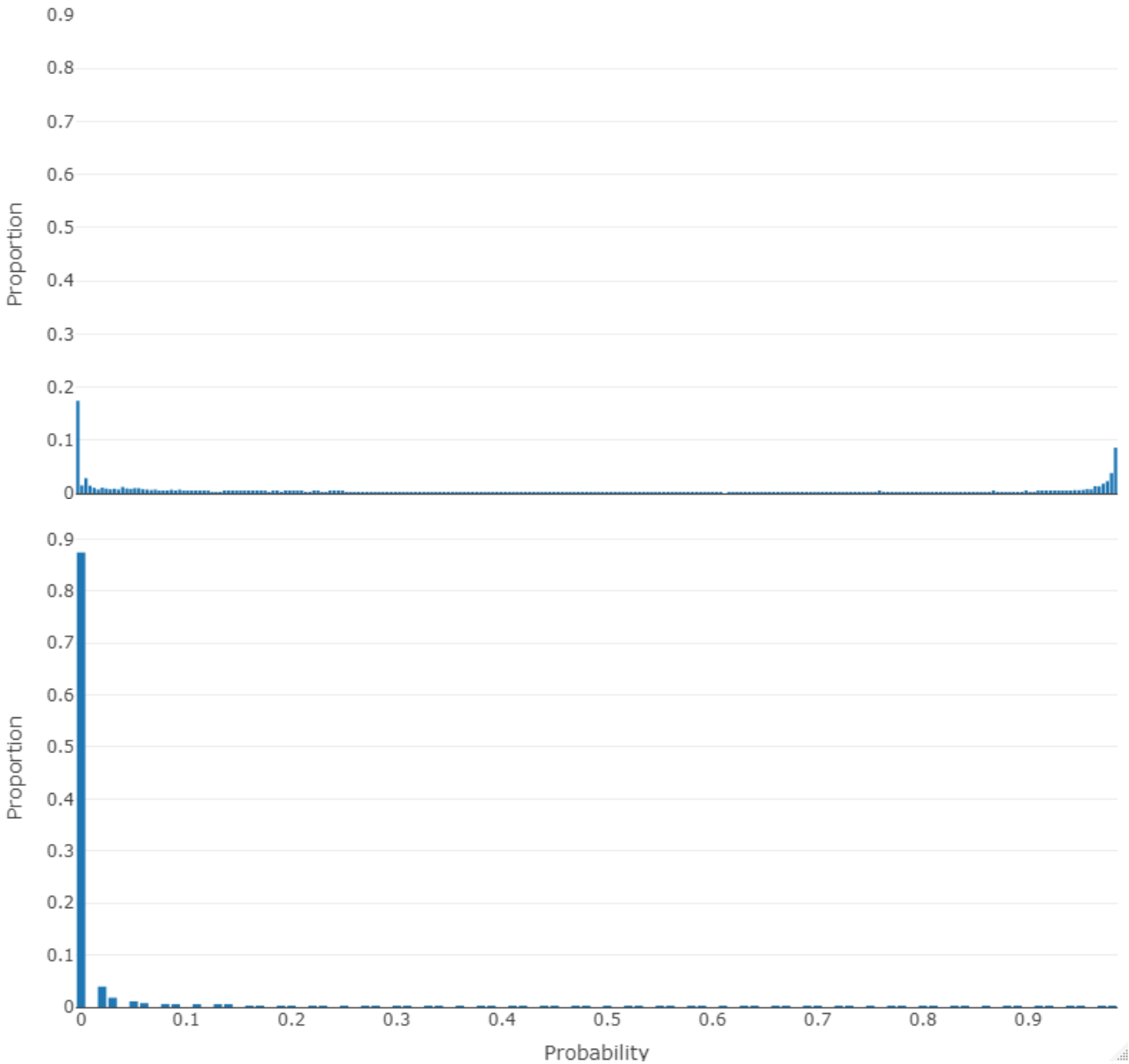
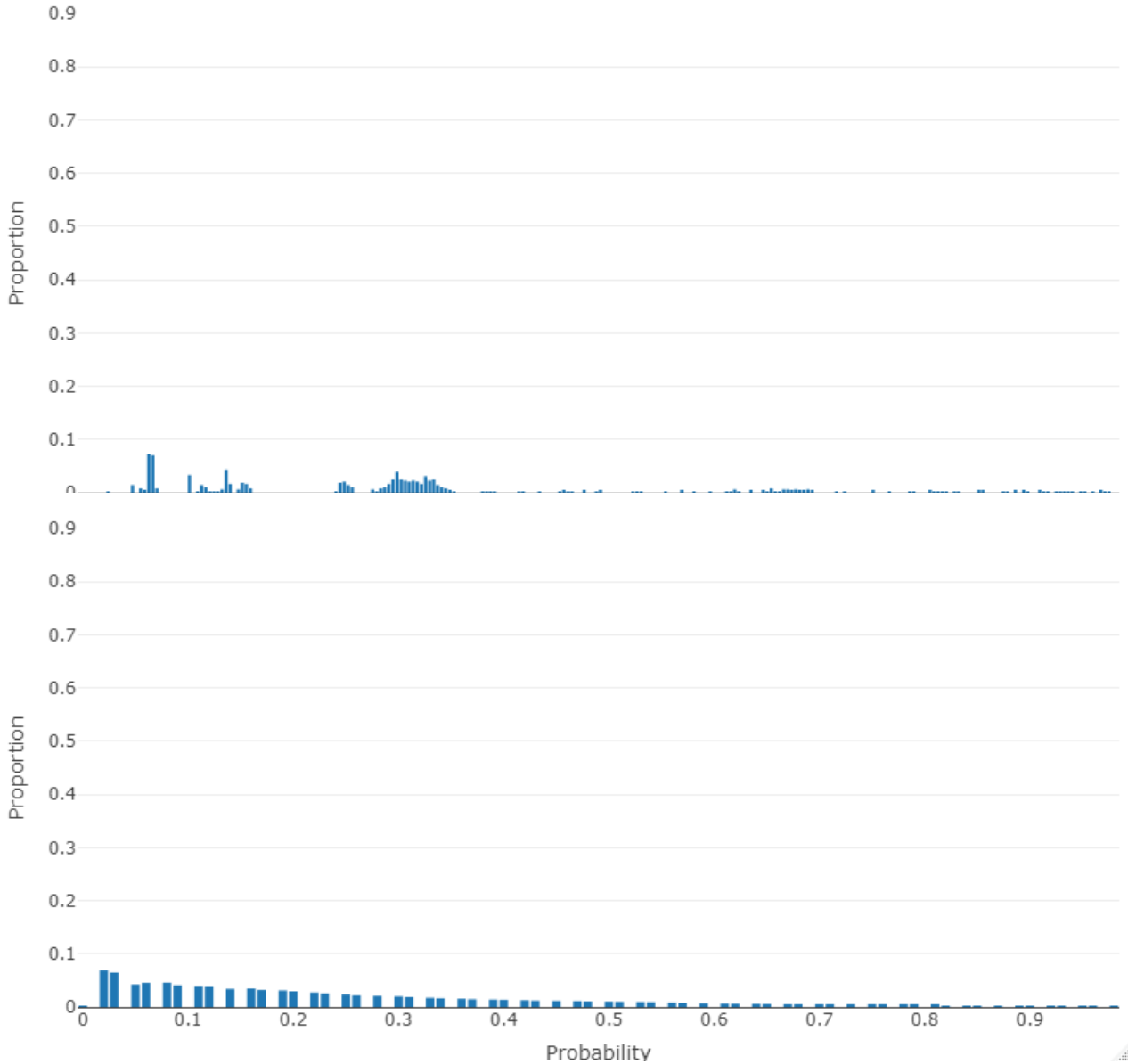
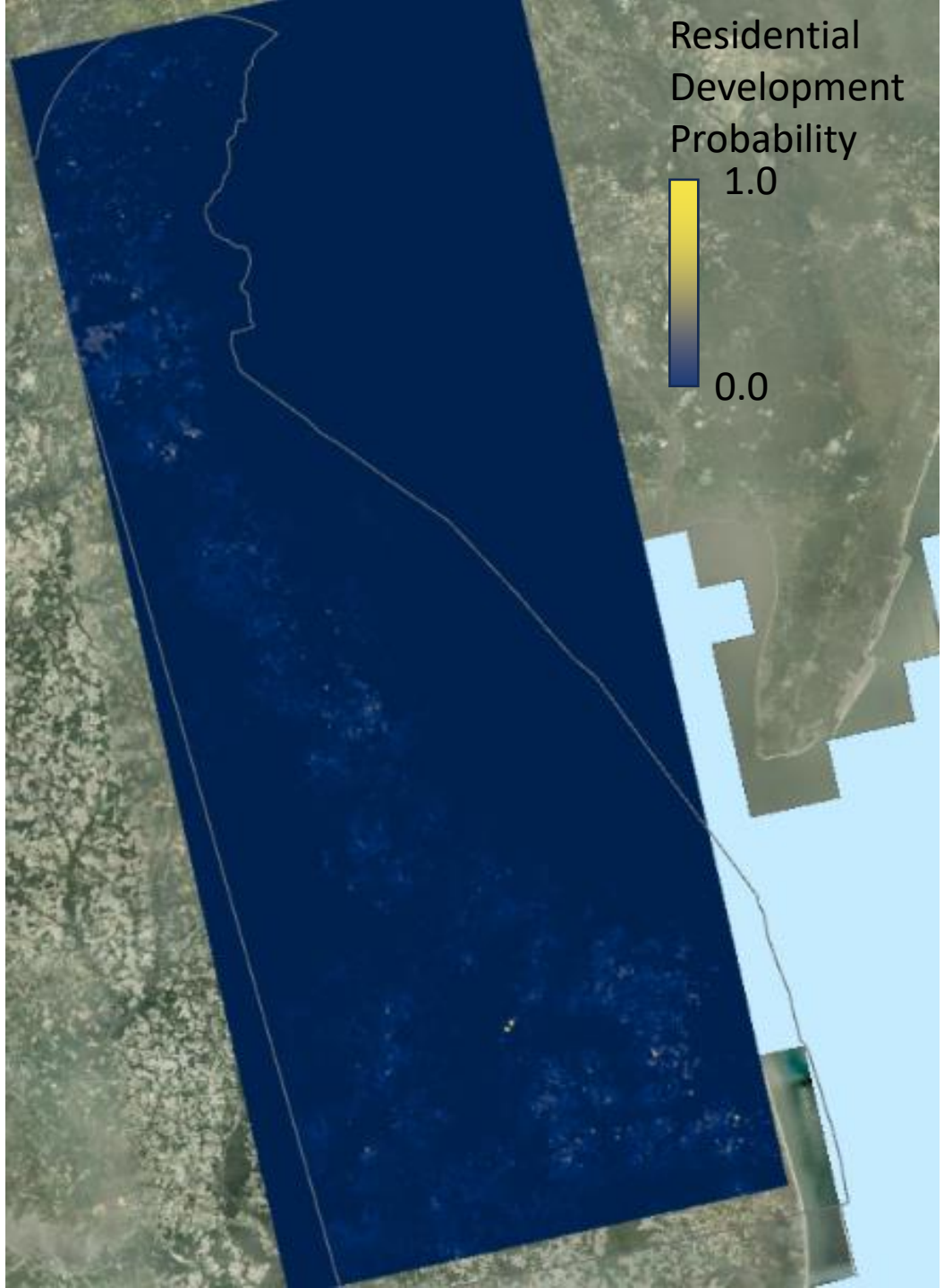

0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Proportion


0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Proportion

0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Proportion
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
Probability

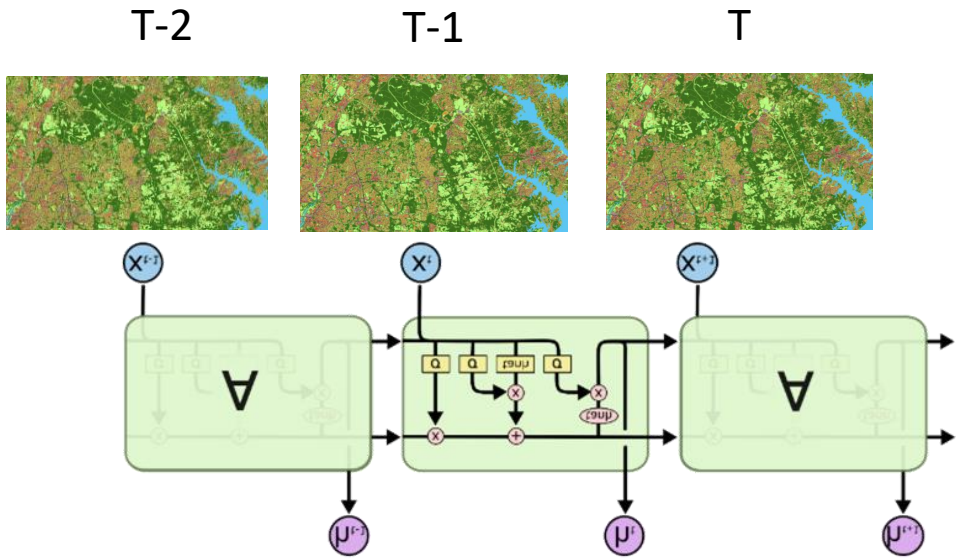
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Proportion
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
Probability

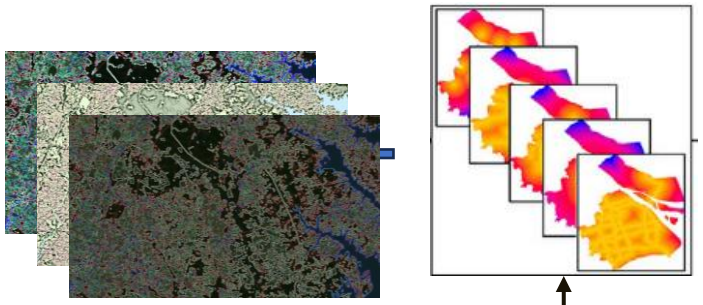

Residential
Development
Probability
1.0
0.0

256 x 256 x C x T

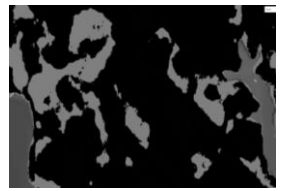
256 x 256 x 1

T-2 T-1 T

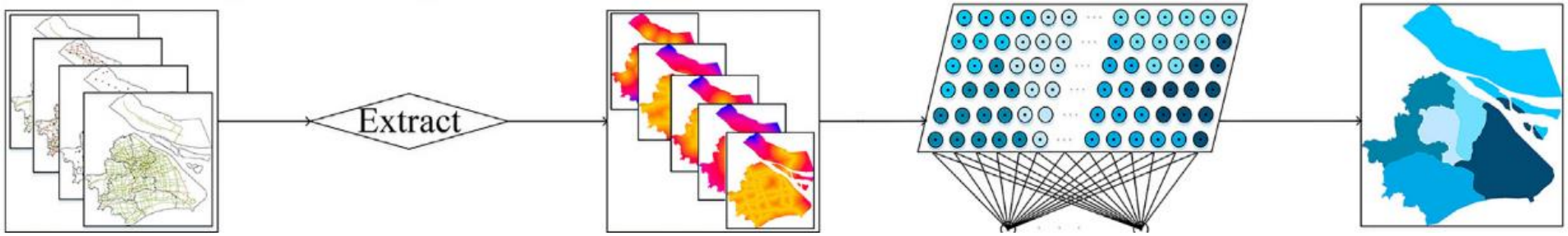




Transition Probability

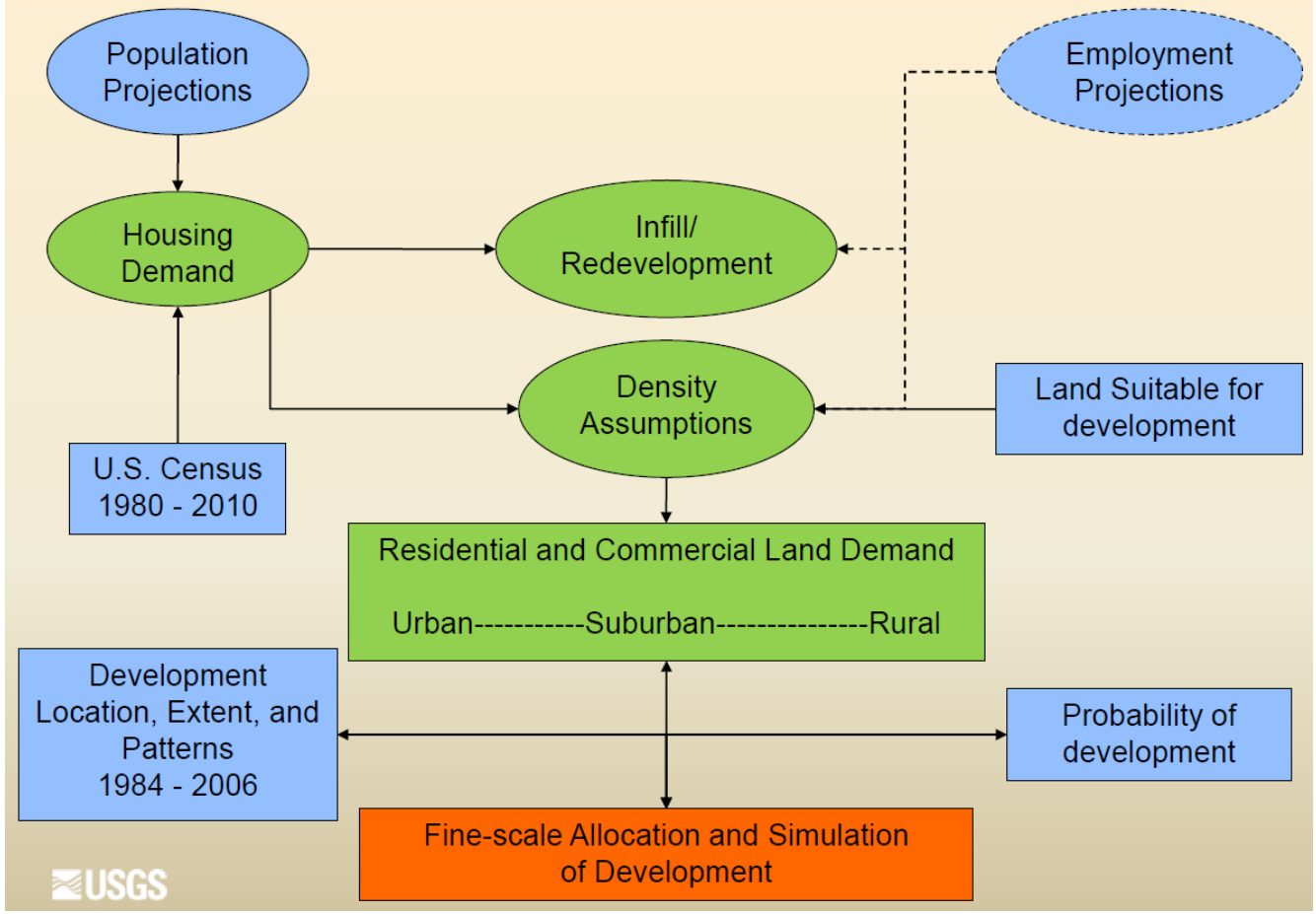


T +1



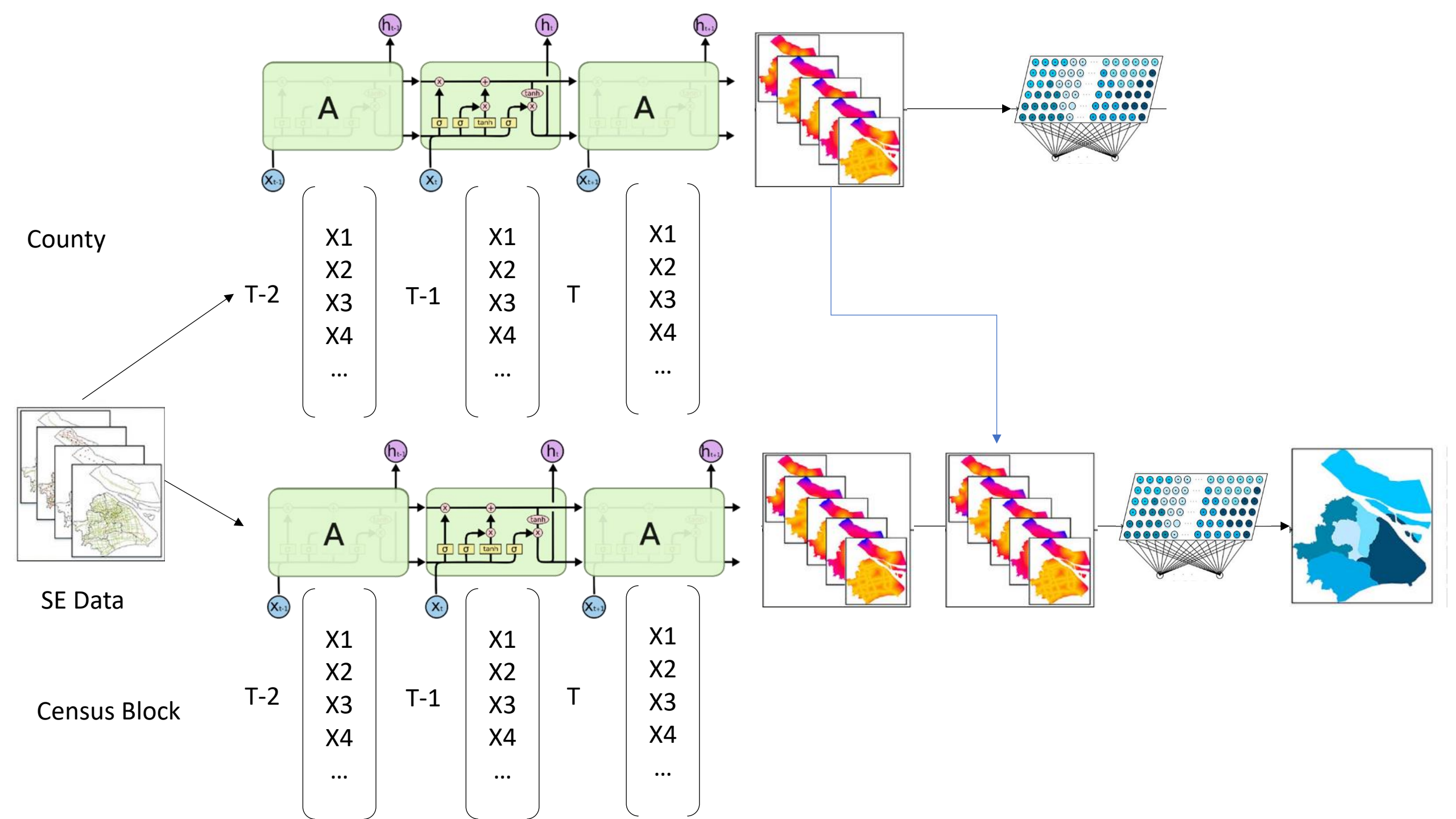
Socioeconomic Data Extracted Features Clusters ‘Zones’ Map

Chesapeake Bay Land Change Model (CBLCM)



Application

1. Estimate extent of future development
2. Estimate future population and households on sewer and septic
3. Estimate future conversion of forest and farmland

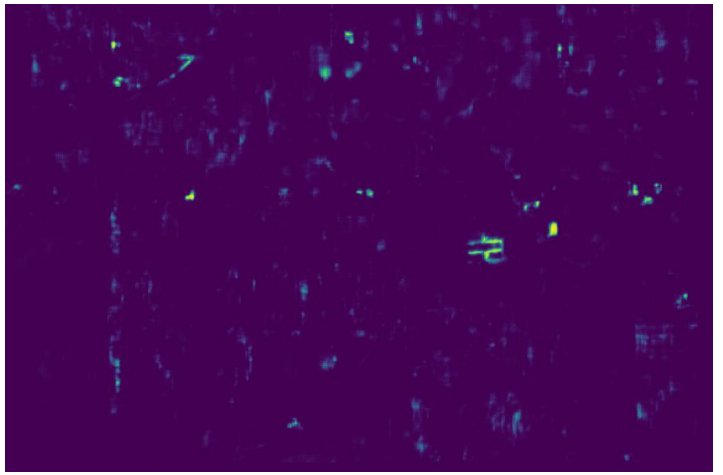

County
T-2
X1
X2
X3
X4
...
T-1
X1
X2
X3
X4
...
T
X1
X2
X3
X4
...
A
A
tanh
σ
σ
tanh
σ
SE Data
Census Block
T-2
X1
X2
X3
X4
...
T-1
X1
X2
X3
X4
...
T
X1
X2
X3
X4
...
A
A
tanh
σ
σ
tanh
σ

May, 2018 Sentinel-2 image

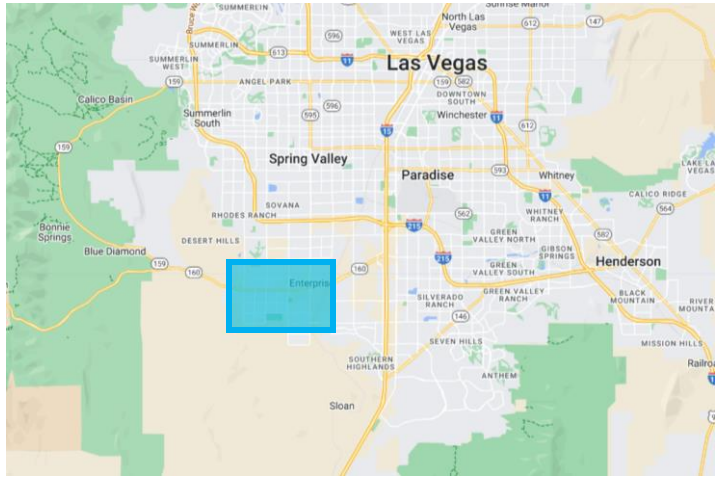
2 km

Aug, 2018 Sentinel-2 image

Siamese U-Net Difference



0.0 1.0



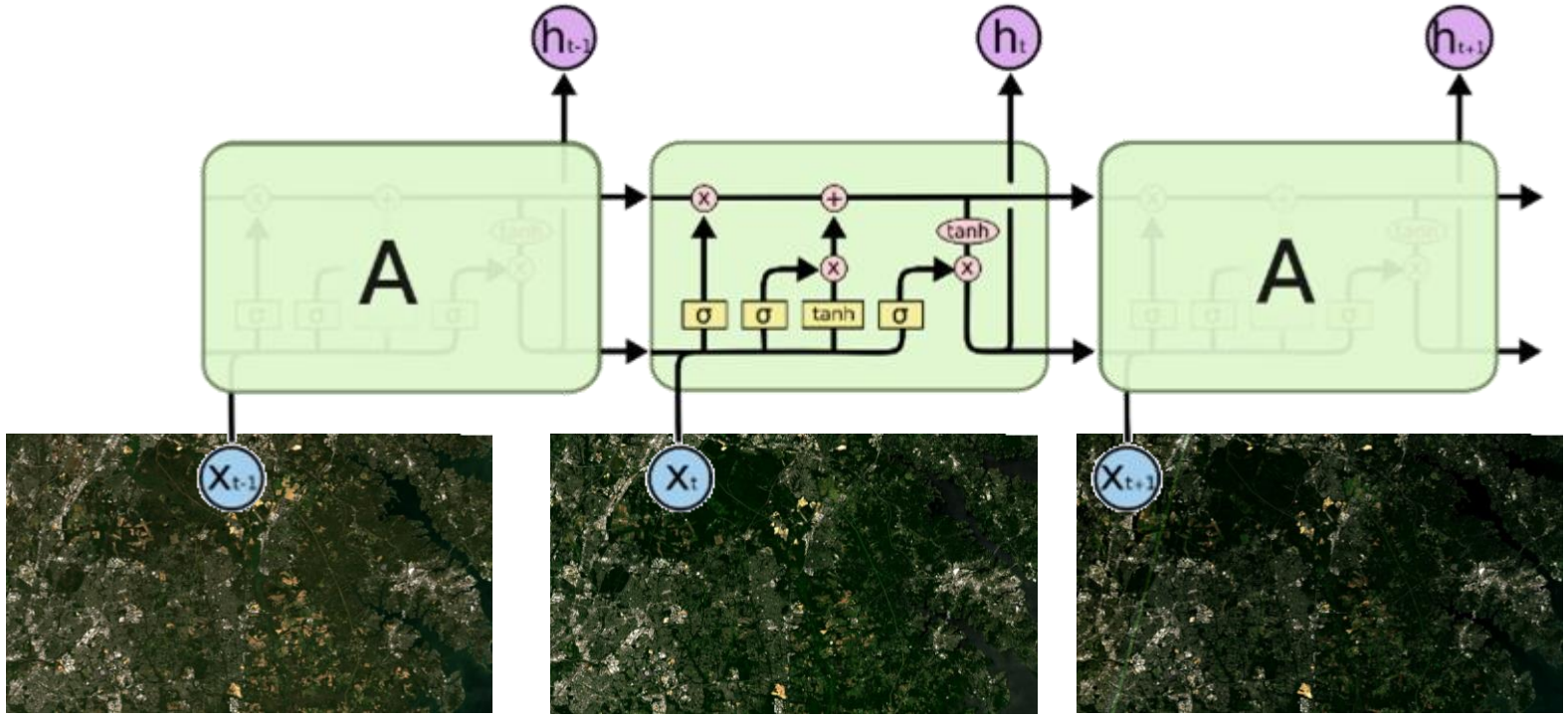
LSTM Aug, 2018 prediction

Normalized Diff (LSTM Aug, real Aug)

-1.0 1.0

Long Short-Term Memory

Capturing temporal information



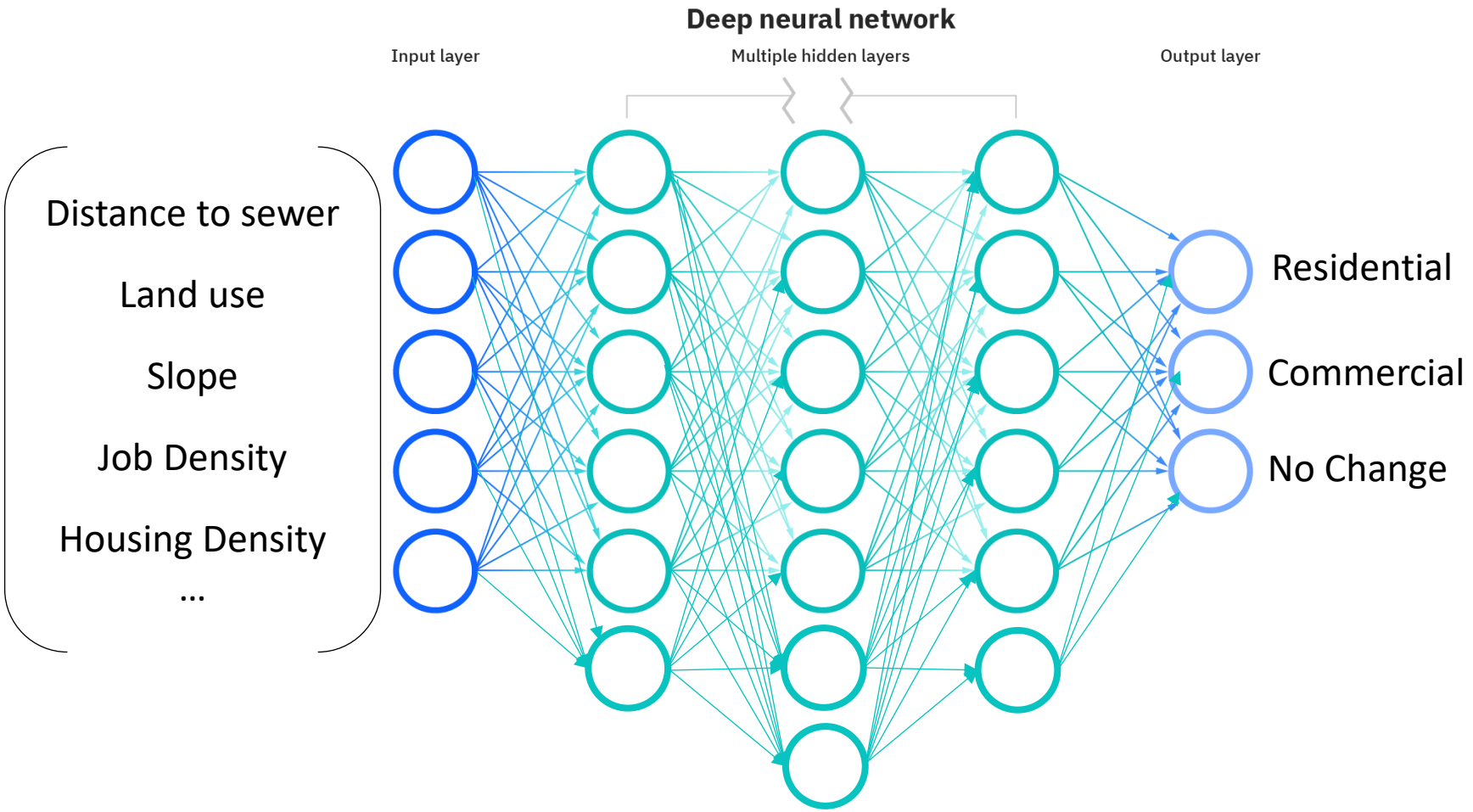
April/May

June/July

Aug/Sep

Classification

Deep Learning (AI)



Good at learning non-linearities, conditionality, and interactions