

Augmenting Urban Resilience through Land Use Planning

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Outline

- ❖ Motivation
- ❖ Process of land use planning: change monitoring, modeling and generation of plans (with consideration of resilience)
- ❖ Summary



Definition

“**Urban resilience** refers to the ability of an urban system and all its constituent socio-ecological and socio-technical networks across temporal and spatial scales to maintain or rapidly **return to desired functions in the face of a disturbance**, to adapt to change, and to quickly transform systems that limit current or future adaptive capacity”.

Source: Meerow, S., Newell, J. P., Stults, M., 2016, Defining urban resilience: A review, *Landscape and Urban Planning* **147**:38-49.

- **Conceptualization of “urban”**
- **The notion of equilibrium**
- **Resilience as a positive concept**
- **Pathway to resilience**
- **Adaptation**
- **Timescale of action**



Process of Land Use Planning

1

Image fusion for generating dense time-series high-resolution land surface imagery

2

Land use change modeling and analysis

3

Multiojective change optimization for land use planning

Resilience related objectives



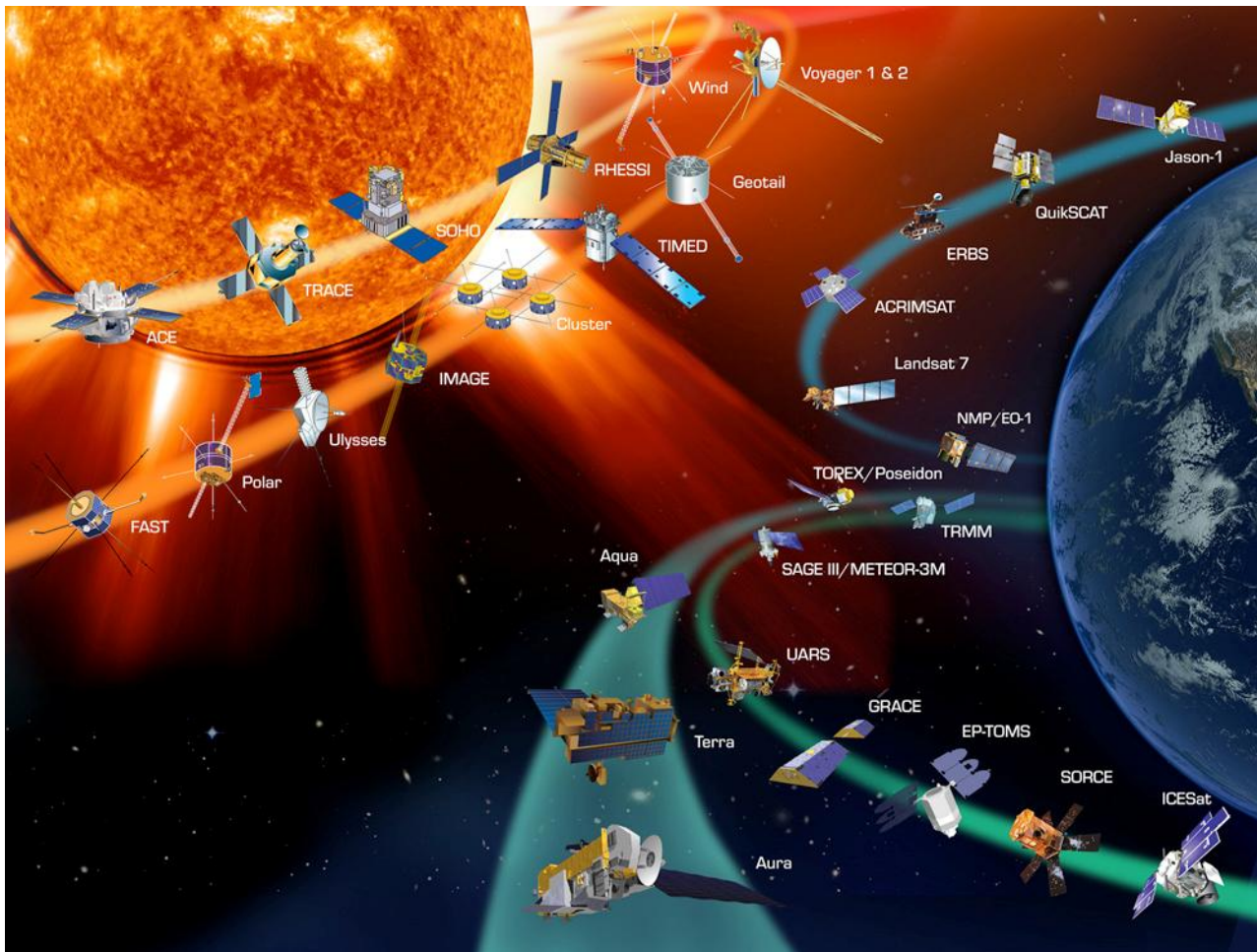
Spatio-temporal image fusion for generating dense time-series high-spatial- resolution imagery

Funded by:

863-Hightech Program of China
Hong Kong Research Grants Council
National Science Foundation of China



Numerous RS satellites have been launched.....



Problems of Current Satellite Remote Sensing

- ❖ Remote sensing instruments still need to **trade off between spatial and temporal resolution**
 - **High spatial** resolution → **Low temporal** resolution
 - **High temporal** resolution → **Low spatial** resolution
- ❖ Limited the applicability of remote sensing technology



Motivation for Spatiotemporal Fusion

MODIS:

- ♀ Low spatial resolution-250~1000 m
- ♀ High temporal resolution - 1 day

Landsat:

- ♀ High spatial resolution - 30 m
- ♀ Low temporal resolution - 16 days

❖ Possible solution: **blending two types of images**



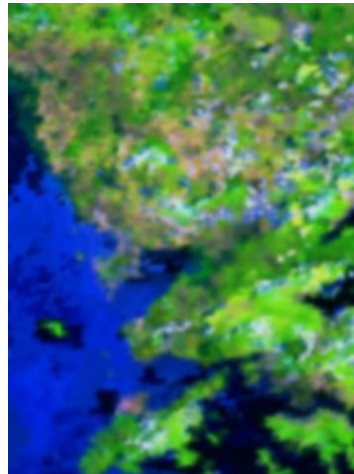
Spatio-Temporal Image Fusion

Seasonal change

LANDSAT
(EVERY 16 DAYS)

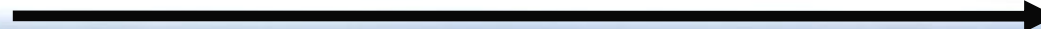


MODIS
(EVERY DAY)



2001-07-28

2001-12-03



Different acquisition dates

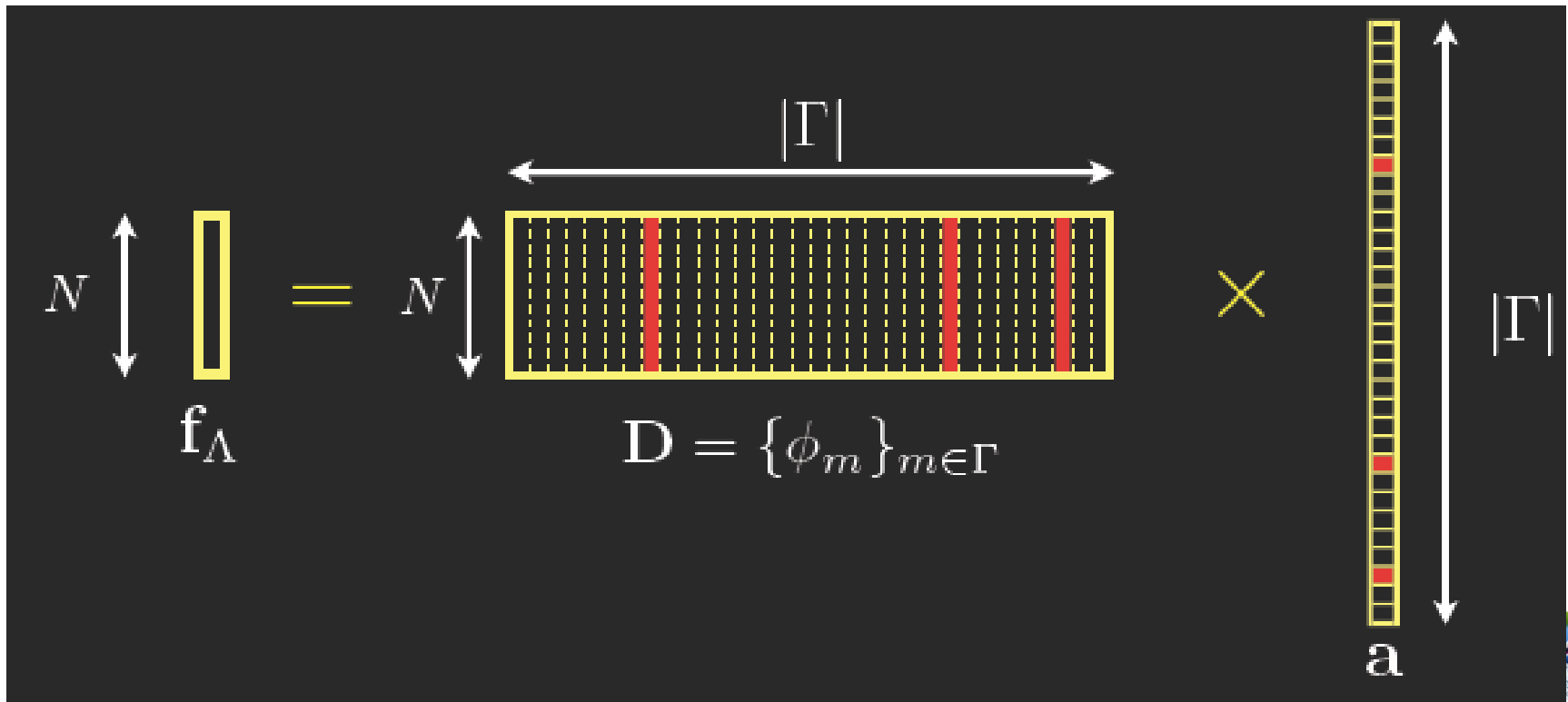


Implementation Methodology

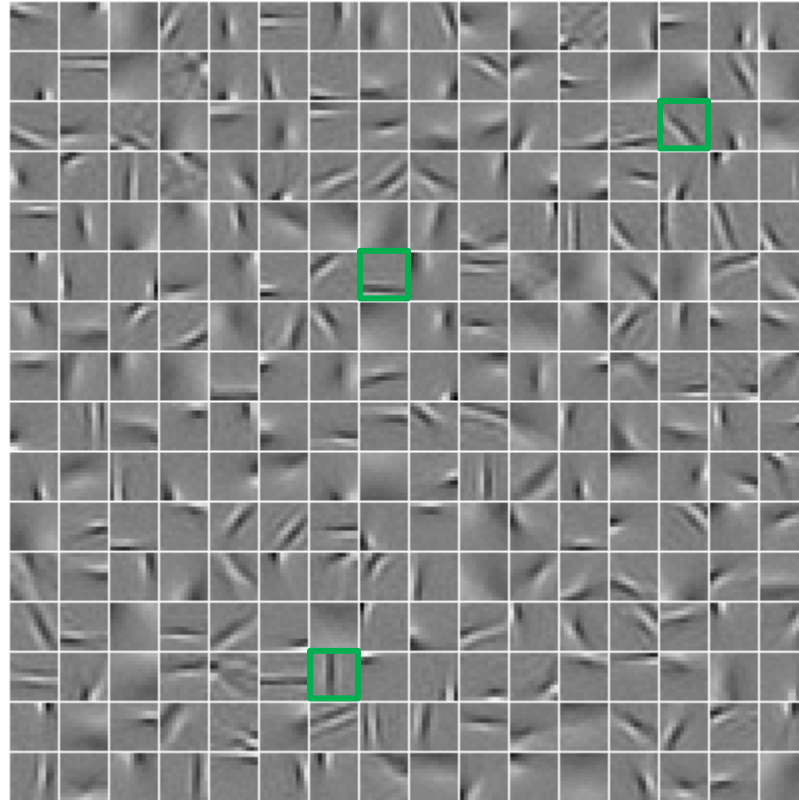
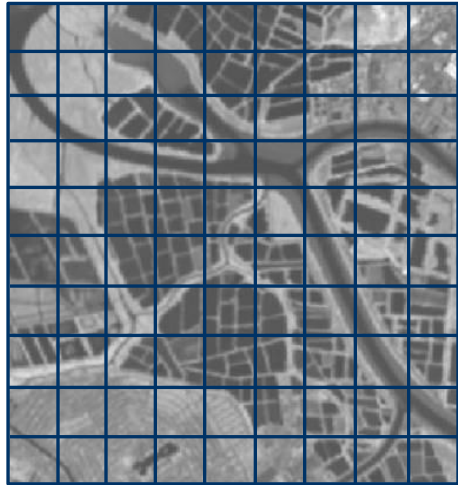


Sparse Representation

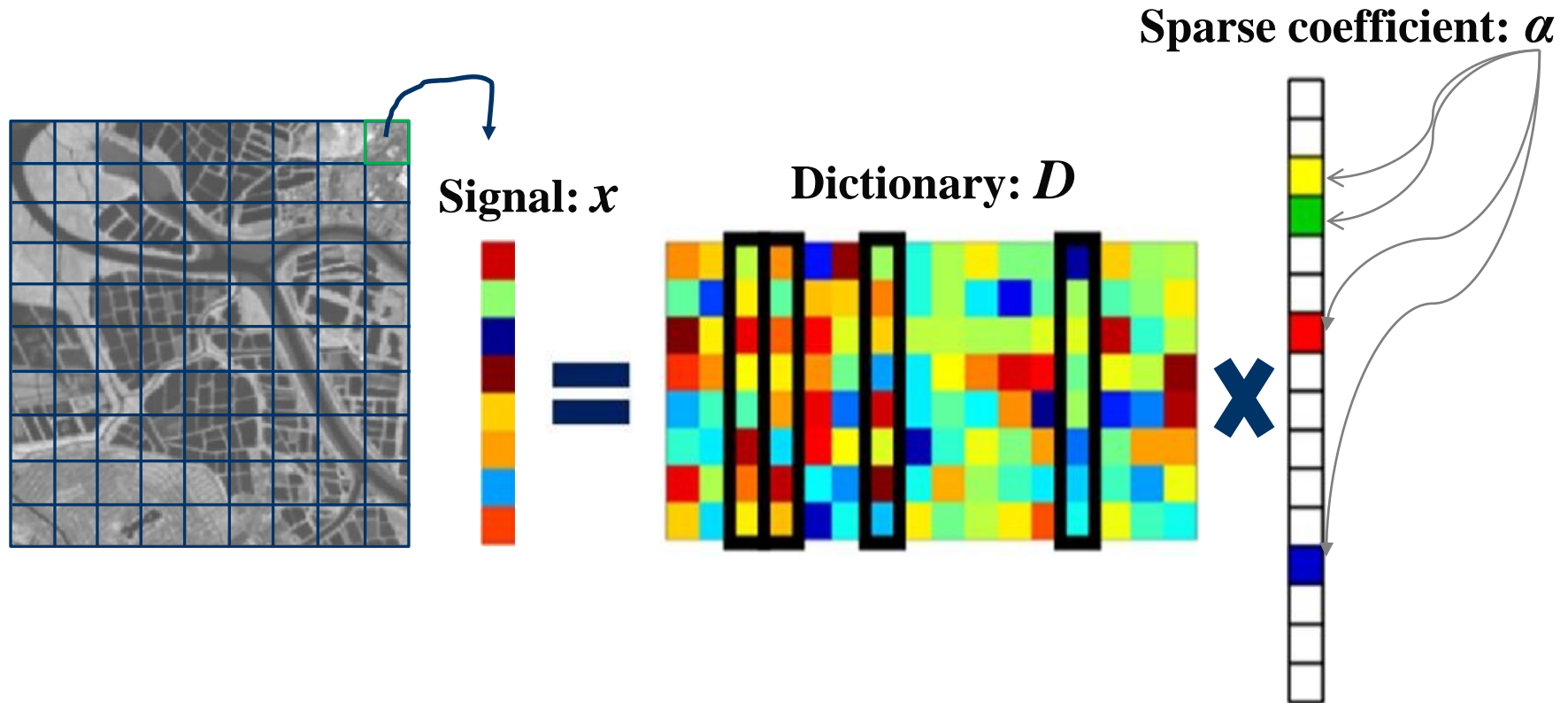
$$f_{\Lambda} = D\alpha \quad \begin{cases} f_{\Lambda} : \text{signal to be represented} \\ D : \text{Dictionary containing } |\Gamma| \text{ atoms} \\ \alpha : \text{representation coefficients} \end{cases}$$



Dictionary Construction



Sparse Representation



Sparse Representation

➤ Two steps:

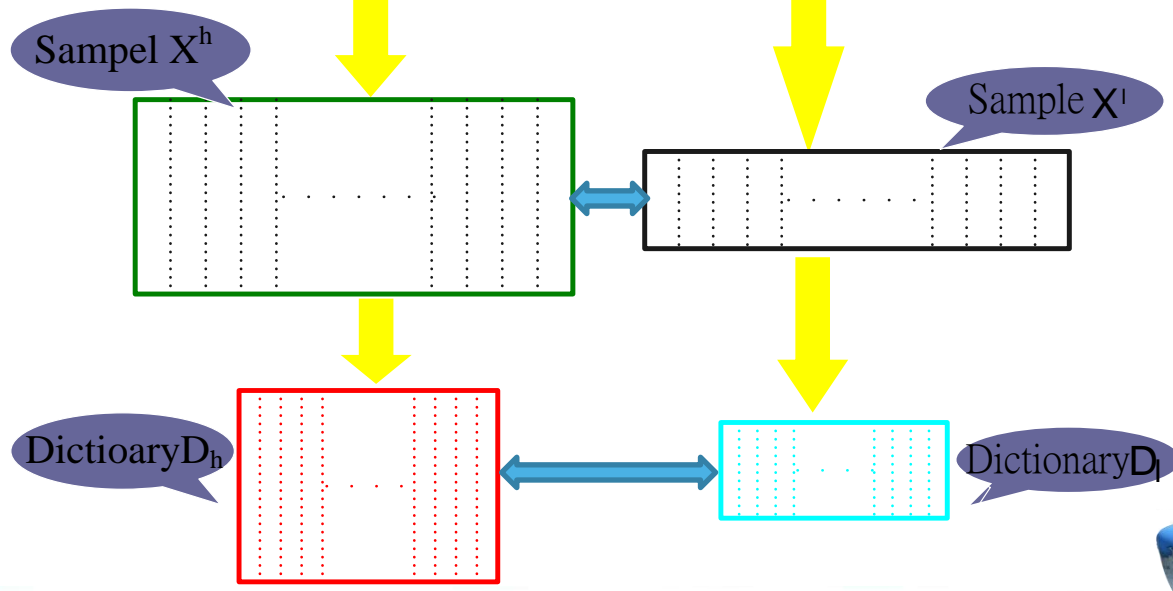
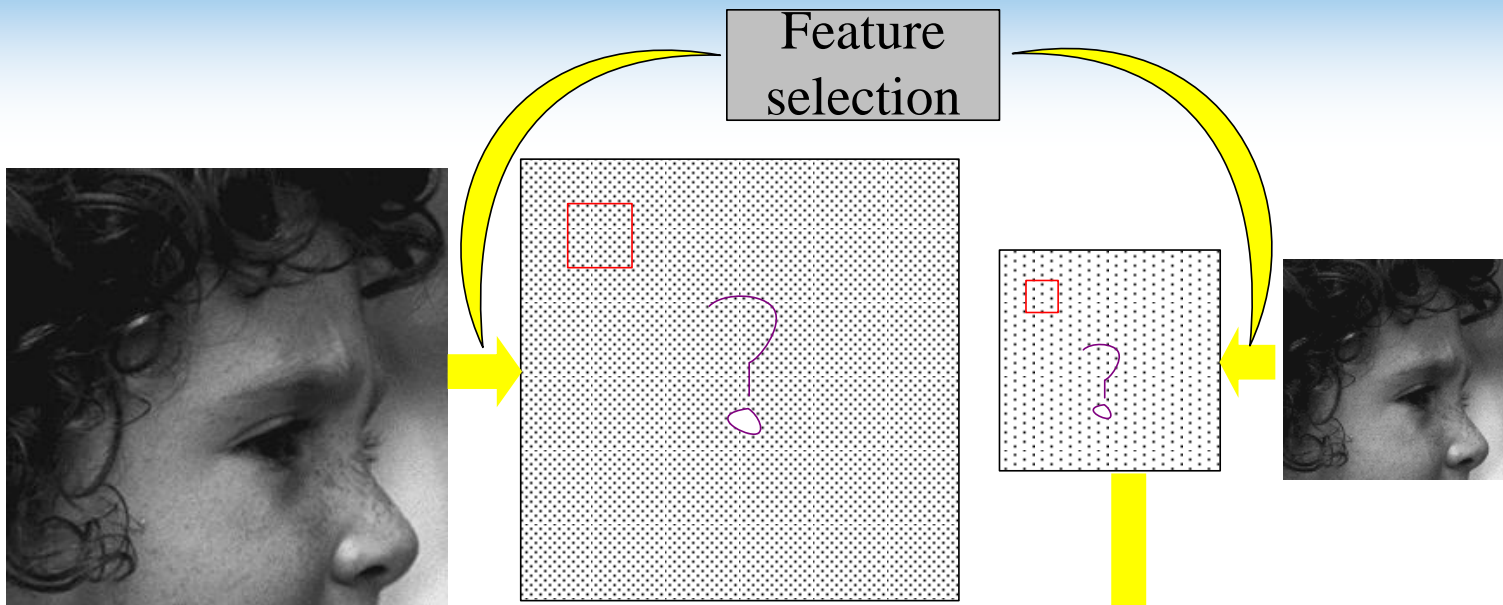
❖ Dictionary training

- To obtain dictionary D from training samples.
- Many developed algorithms available, such as maximum likelihood (ML) dictionary learning method, K-SVD method.

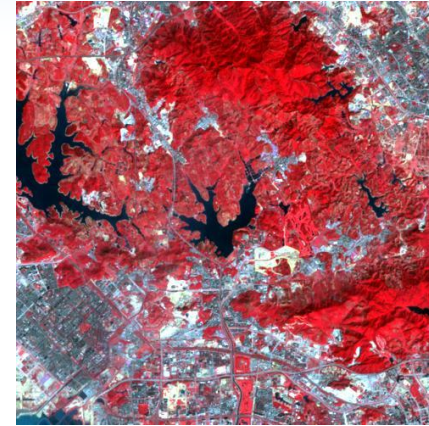
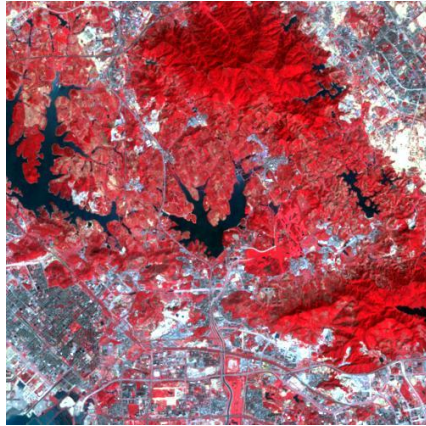
❖ Sparse coding

- To solve representation coefficients α ;
- Many developed algorithms available, such as orthogonal matching pursuit (OMP), homotopy, iterative-shrinkage thresholding (IST);





Land-cover (type) Change



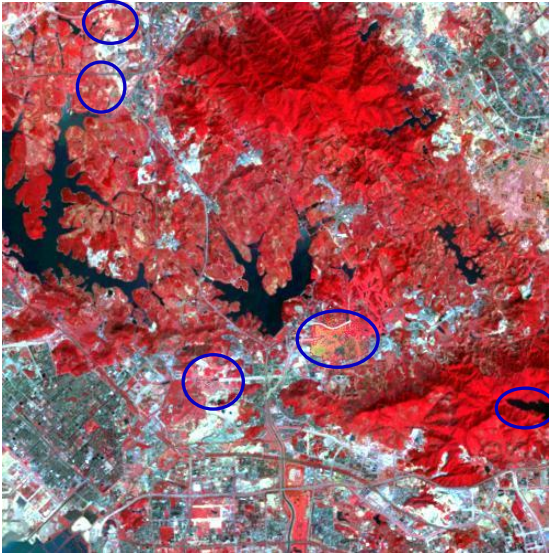
2000

2002

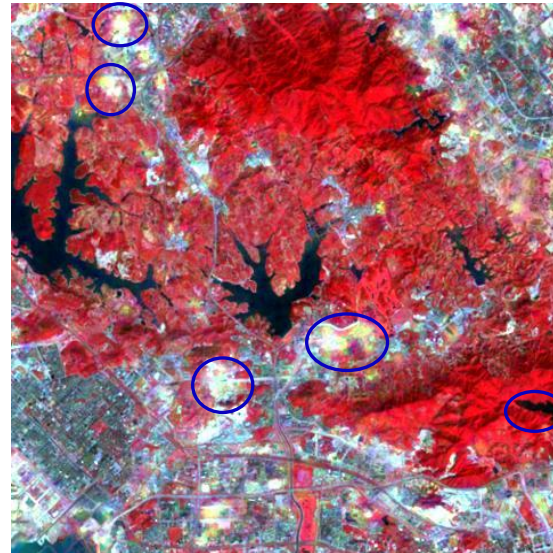


Song, H. and **Huang, B.**, 2013. Spatiotemporal satellite image fusion through one-pair image learning. *IEEE Transactions on Geoscience and Remote Sensing*, 51(4): 1883-1896

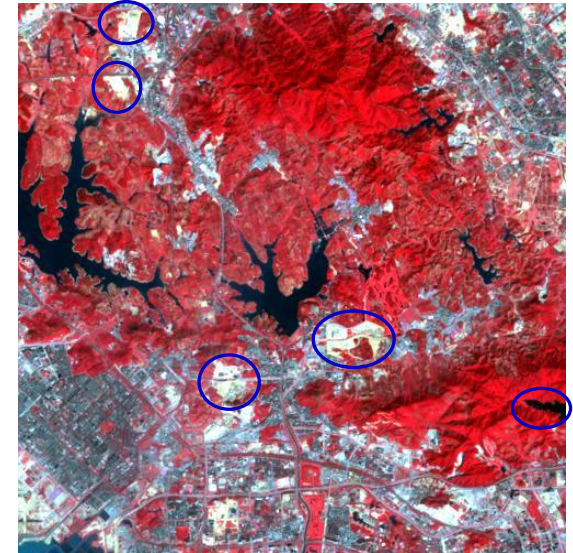
Result Comparison



(a) STARFM result



(b) Our result



(c) Actual image

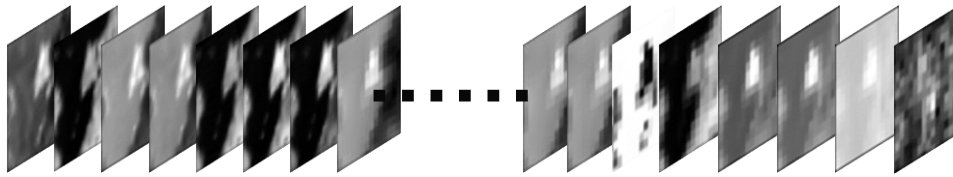


Quantitative Evaluation

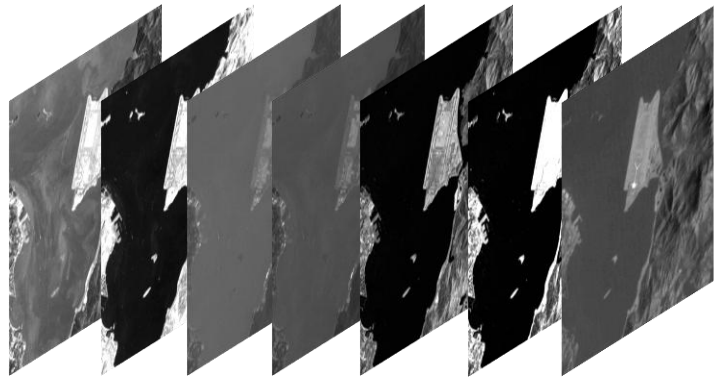
| Method | AAD | RMSE | SSIM | ERGA S | SAM |
|-----------------------|---------------|---------------|---------------|---------------|---------------|
| STARFM | 0.0132 | 0.0208 | 0.7635 | 1.9229 | 3.0838 |
| Our method | 0.0107 | 0.0163 | 0.7799 | 1.4687 | 2.6645 |



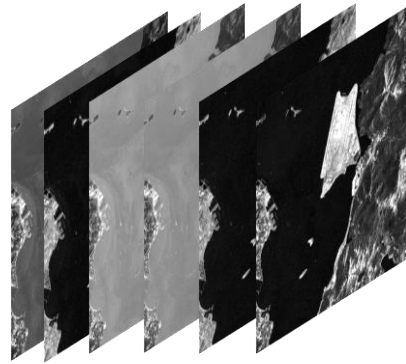
Spatio-spectral Image Fusion



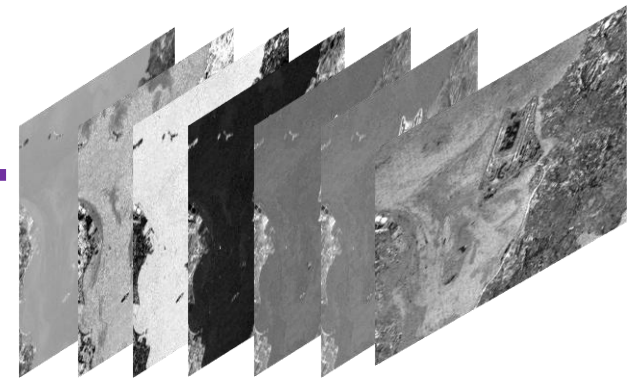
36 bands with 500/1000 m spatial resolution



7 bands with 30 m spatial resolution



36 bands with 30 m spatial resolution

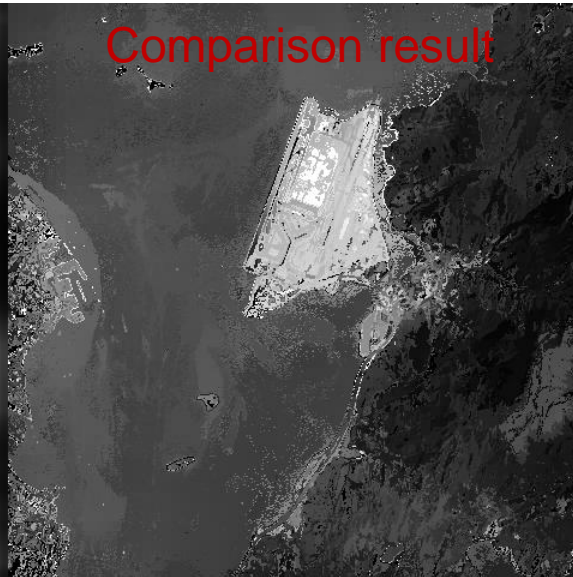
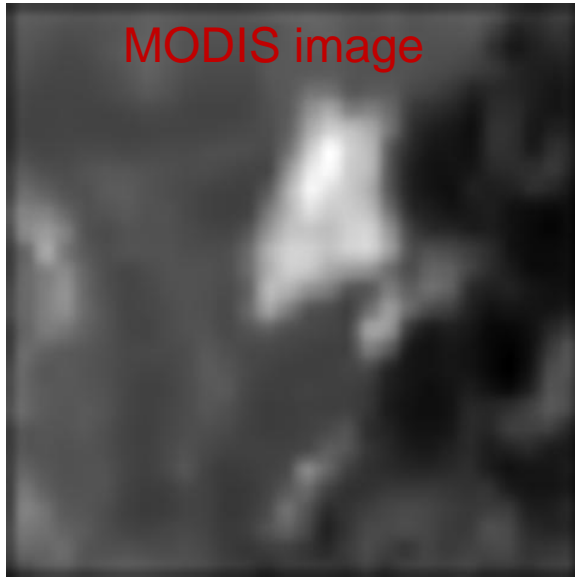


Huang *et al.*, 2014,. Spatial and spectral image fusion using sparse matrix factorization. *IEEE Transactions on Geoscience and Remote Sensing*, 52(3): 1693-1704.

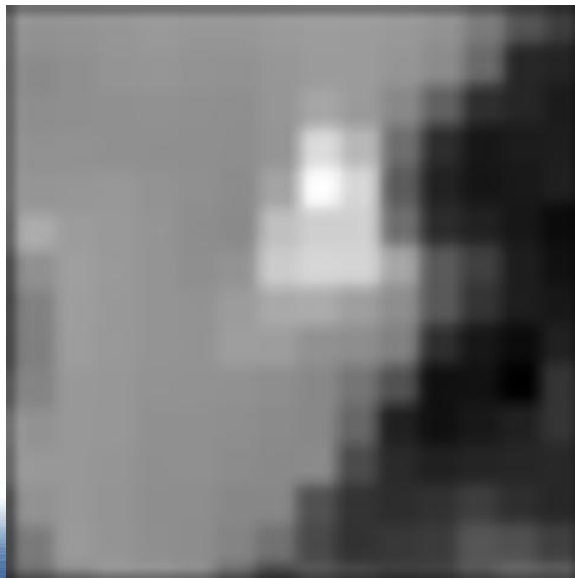


Result Comparison

Band
1

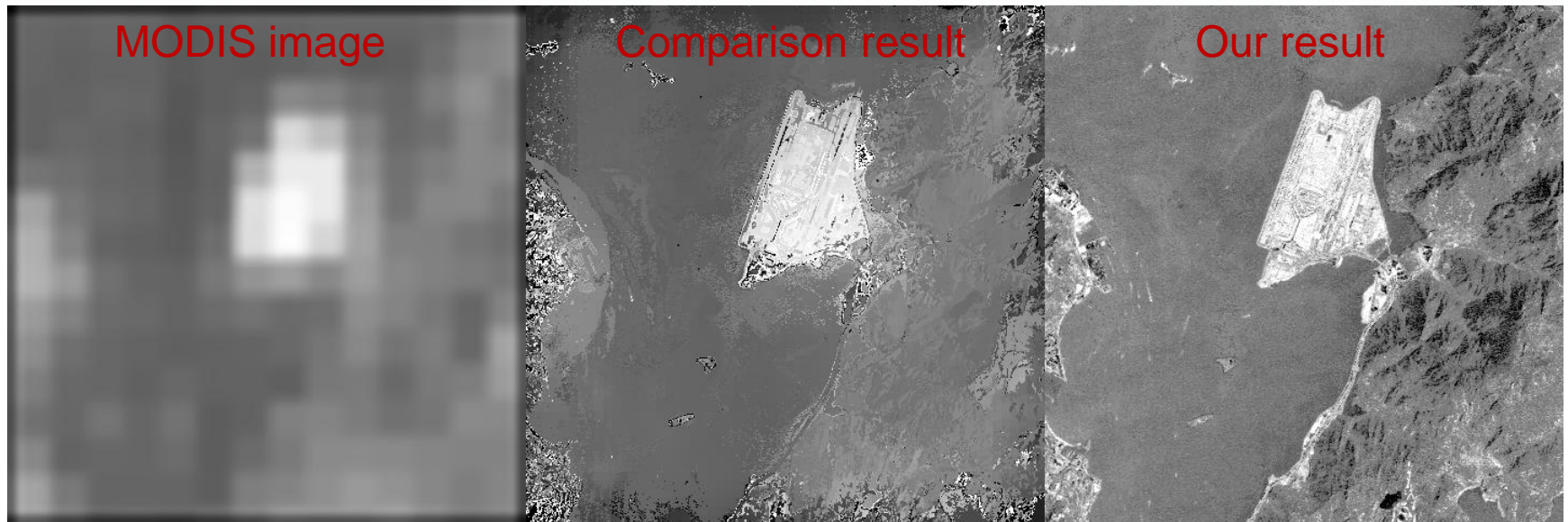


Band
11



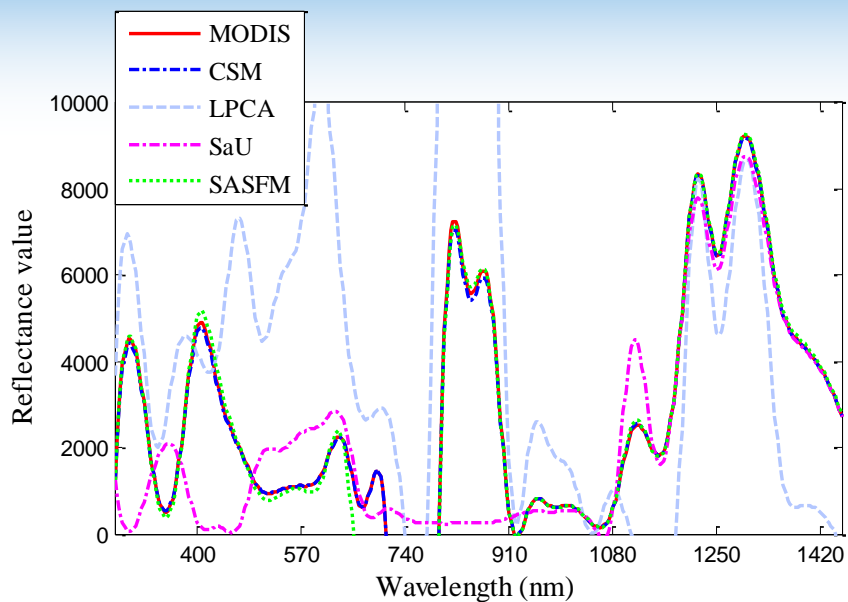
Result Comparison

Band
21

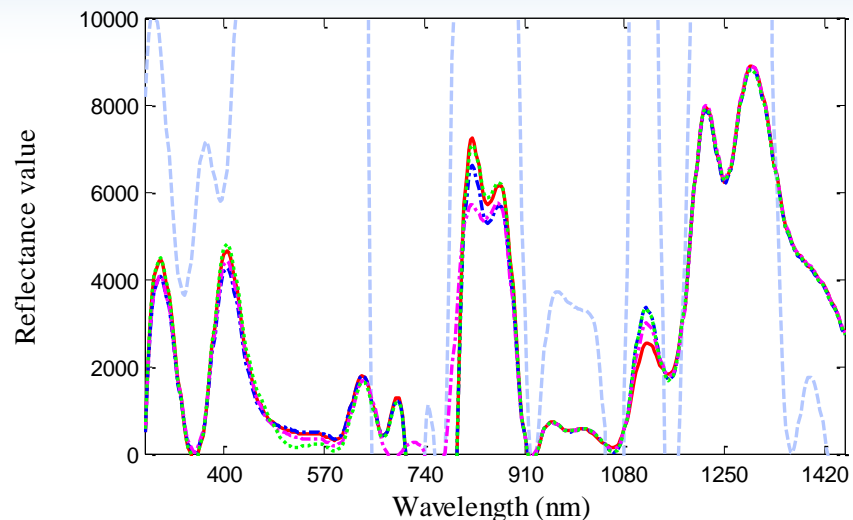


Band
29

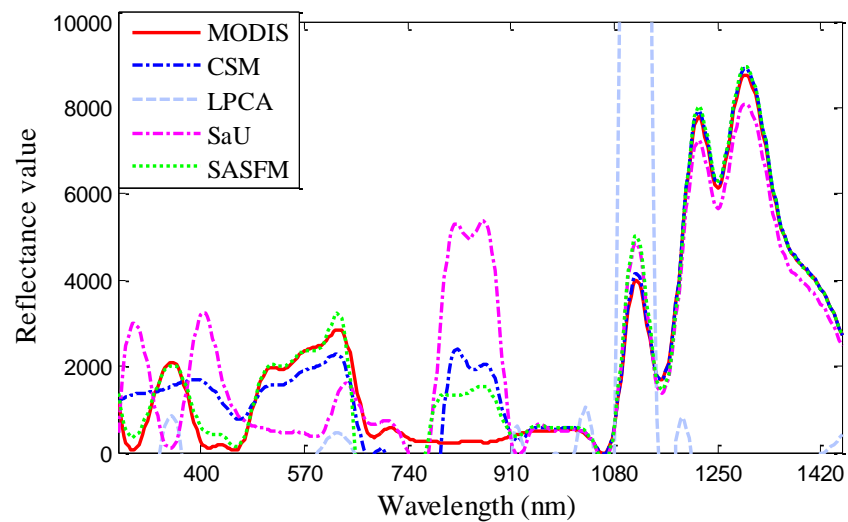




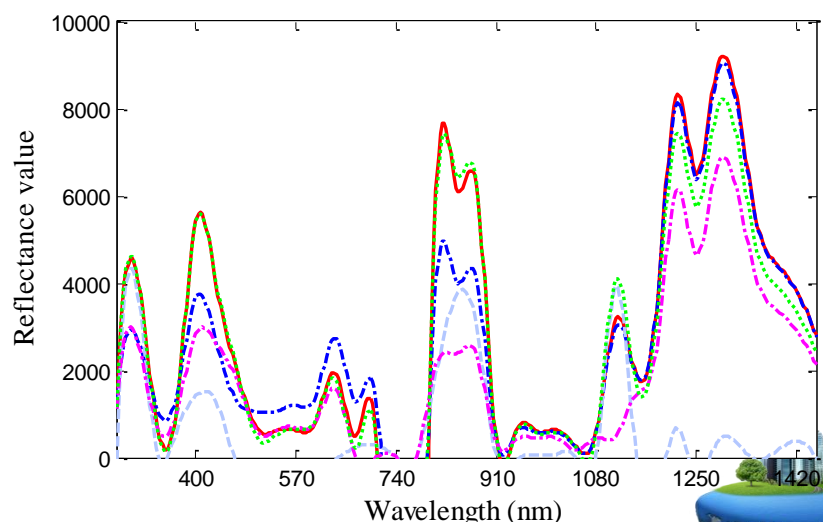
(a)



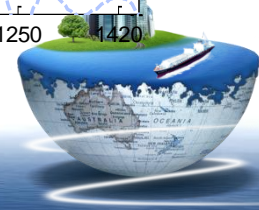
(b)



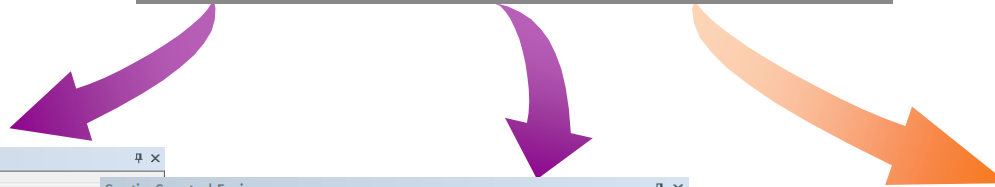
(c)



(d)



ImgFusion Analyst



Spatio-Temporal Fusion

Coarse resolution Fine resolution Prediction

Low Spatial Resolution : 250 m Class Number : 5

High Spatial Resolution : 30 m Window Size : 23

Save Prediction to:

Load Save As Run Cancel

Processing Information:

Spatio-Spectral Fusion

Input Low-Spatial but High-Spectral Resolution Image

Input High-Spatial but Low-Spectral Resolution Image

Output High Spatio-Spectral Resolution Image

Low Spatial Resolution : 1000 m High Spatial Reso

Load Save As Run

Processing Information:

Evaluation

Step 1: Select layers

Predicted layer: []

Observed layer: []

Step 2: Select bands

Band (pred.) as Y: []

Band (obs.) as X: []

Sampling Interval: 10

Min/Max Value: 0 to 10000

Draw plot Clear

Step 3: Select indicators

Full bands Plotted band

CC RMSE ERGAS SAM

Calculate Clear

Information:

Plots:

Statistics:

| Band | CC | RMSE | ERGAS | SAM | AAD | AD |
|------|----|------|-------|-----|-----|----|
| | | | | | | |



Spatiotemporal Image Fusion

The screenshot shows the ArcMap interface with the 'Spatio-Temporal Fusion' dialog box open. The main map area displays a red-toned satellite image of a landscape with a large body of water. The dialog box on the right is titled 'Spatio-Temporal Fusion' and contains a table for selecting input files, resolution settings, and a 'Run' button.

| Coarse resolution | Fine resolution | Prediction |
|---------------------------|----------------------|-------------------------------------|
| MOD09_2000306_SZ_250m.tif | L72000306_SZ_30m.tif | <input type="checkbox"/> |
| MOD09_2002311_SZ_250m.tif | | <input checked="" type="checkbox"/> |

Low Spatial Resolution : 250 m Class Number : 5
High Spatial Resolution : 30 m Window Size : 23

Save Prediction to: E:\Results\STF_SZ_Result.tif

Buttons: Load, Save As, Run, Cancel

Processing Information:
Please wait for prediction...

Clear

822900.638 2511253.682 Meters



Spatiotemporal Image Fusion

The screenshot displays the ArcMap interface with the Spatio-Temporal Fusion tool. A message dialog is open, asking to add the prediction layer to ArcMap. The Spatio-Temporal Fusion dialog shows the following configuration:

| Coarse resolution | Fine resolution | Prediction |
|---------------------------|----------------------|-------------------------------------|
| MOD09_2000306_SZ_250m.tif | L72000306_SZ_30m.tif | <input type="checkbox"/> |
| MOD09_2002311_SZ_250m.tif | | <input checked="" type="checkbox"/> |

Additional parameters in the dialog include:

- Low Spatial Resolution: 250 m
- High Spatial Resolution: 30 m
- Class Number: 5
- Window Size: 23
- Save Prediction to: E:\Results\STF_SZ_Result.tif

The processing information section shows: "Please wait for prediction... Prediction has been completed."

826406.375 2511253.682 Meters



Fusion Result

SZ_STF.mxd - ArcMap

File Edit View Bookmarks Insert Selection Geoprocessing Customize Windows Help

1:4,000 100%

Table Of Contents

Layers

- STF_SZ_Result.tif
RGB
 - Red: Band_1
 - Green: Band_2
 - Blue: Band_3
- L72000306_SZ_30m.tif
RGB
 - Red: Band_1
 - Green: Band_2
 - Blue: Band_3
- MOD09_2000306_SZ_250m.tif
RGB
 - Red: Band_1
 - Green: Band_2
 - Blue: Band_3
- MOD09_2002311_SZ_250m.tif
RGB
 - Red: Band_1
 - Green: Band_2
 - Blue: Band_3

ImgFusion Analyst

ST Fusion SS Fusion Evaluation Help

Spatio-Temporal Fusion

| Coarse resolution | Fine resolution | Prediction |
|---------------------------|----------------------|-------------------------------------|
| MOD09_2000306_SZ_250m.tif | L72000306_SZ_30m.tif | <input type="checkbox"/> |
| MOD09_2002311_SZ_250m.tif | | <input checked="" type="checkbox"/> |

Low Spatial Resolution : 250 m Class Number : 5

High Spatial Resolution : 30 m Window Size : 23

Save Prediction to: E:\Results\STF_SZ_Result.tif

Load Save As Run Cancel

Processing Information:

Please wait for prediction...
Prediction has been completed.

Clear

381.25 500.069 Meters



Spatio-spectral Image Fusion

The screenshot displays the ArcMap interface with the 'Spatio-Spectral Fusion' dialog box open. The main map area shows a fused image with a red, green, and blue color scheme. The 'Layers' panel on the left lists the following layers:

- SSF_SZ_Result.tif (RGB)
 - Red: Band_2
 - Green: Band_1
 - Blue: Band_4
- L72002311_B123457_30m.tif (RGB)
 - Red: Band_4
 - Green: Band_3
 - Blue: Band_2
- MOD09_2002311_17Bands_1000m.tif (RGB)
 - Red: Band_1
 - Green: Band_2
 - Blue: Band_3

The 'Spatio-Spectral Fusion' dialog box contains the following settings:

- Input Low-Spatial but High-Spectral Resolution Image: MOD09_2002311_17Bands_1000m.tif
- Input High-Spatial but Low-Spectral Resolution Image: L72002311_B123457_30m.tif
- Output High Spatio-Spectral Resolution Image: E:\Results\SSF_SZ_Result.tif
- Low Spatial Resolution: 1000 m
- High Spatial Resolution: 30 m
- Buttons: Load, Save As, Run, Cancel
- Processing Information: Please wait for prediction... Prediction has been completed.
- Clear button

797647.334 2510158.67 Meters

Result Evaluation

The screenshot shows the ArcMap interface with the 'Evaluation' dialog box open. The dialog box is divided into three steps:

- Step 1: Select layers**
 - Predicted layer: STF_SZ_Result.tif
 - Observed layer: L72002311_SZ_3k
- Step 2: Select bands**
 - Band (pred.) as Y: Band_1
 - Band (obs.) as X: Band_1
 - Sampling Interval: 10
 - Min/Max Value: 0 to 10000
- Step 3: Select indicators**
 - Full bands Plotted band
 - CC
 - RMSE
 - ERGAS
 - SAM

The 'Plots' section shows a scatter plot with 'Observed' on the x-axis and 'Predicted' on the y-axis, both ranging from 0 to 10000. A diagonal line represents the 1:1 relationship, and blue data points are clustered around it, indicating high accuracy.

The 'Statistics' table is as follows:

| Band | CC | RMSE | ERGAS | SAM | AAD | AD |
|--------|--------|----------|---------|--------|----------|----------|
| Band_1 | 0.8990 | 306.3418 | 13.9686 | 1.8267 | 217.5402 | 71.8736 |
| Band_2 | 0.8624 | 284.5666 | 31.6999 | 1.7517 | 188.8914 | -0.7003 |
| Band_3 | 0.8641 | 222.5710 | 27.3121 | 1.7717 | 157.1122 | -30.5799 |

Information: Calculation completed!

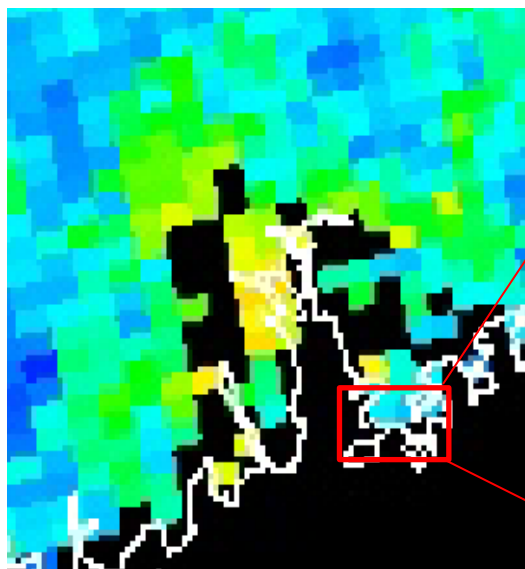


Applications

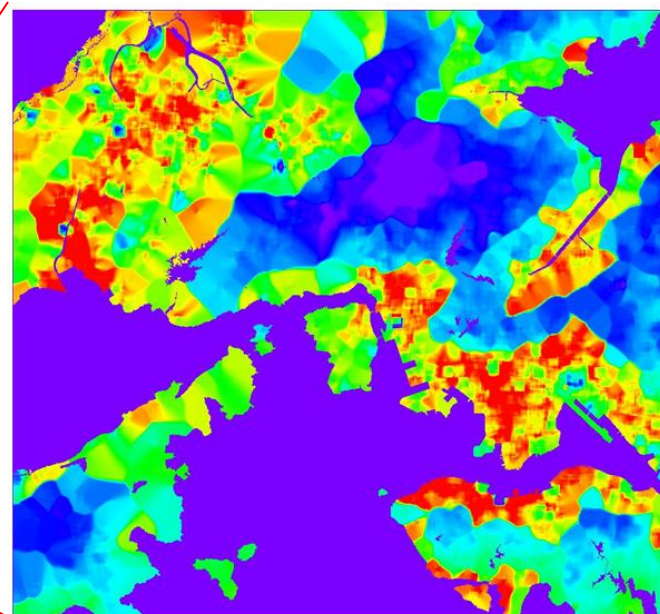


Retrieval of Aerosol Optical Depth (AOD)

Generating High Resolution (30 m) Daily Aerosol Optical Depth Image



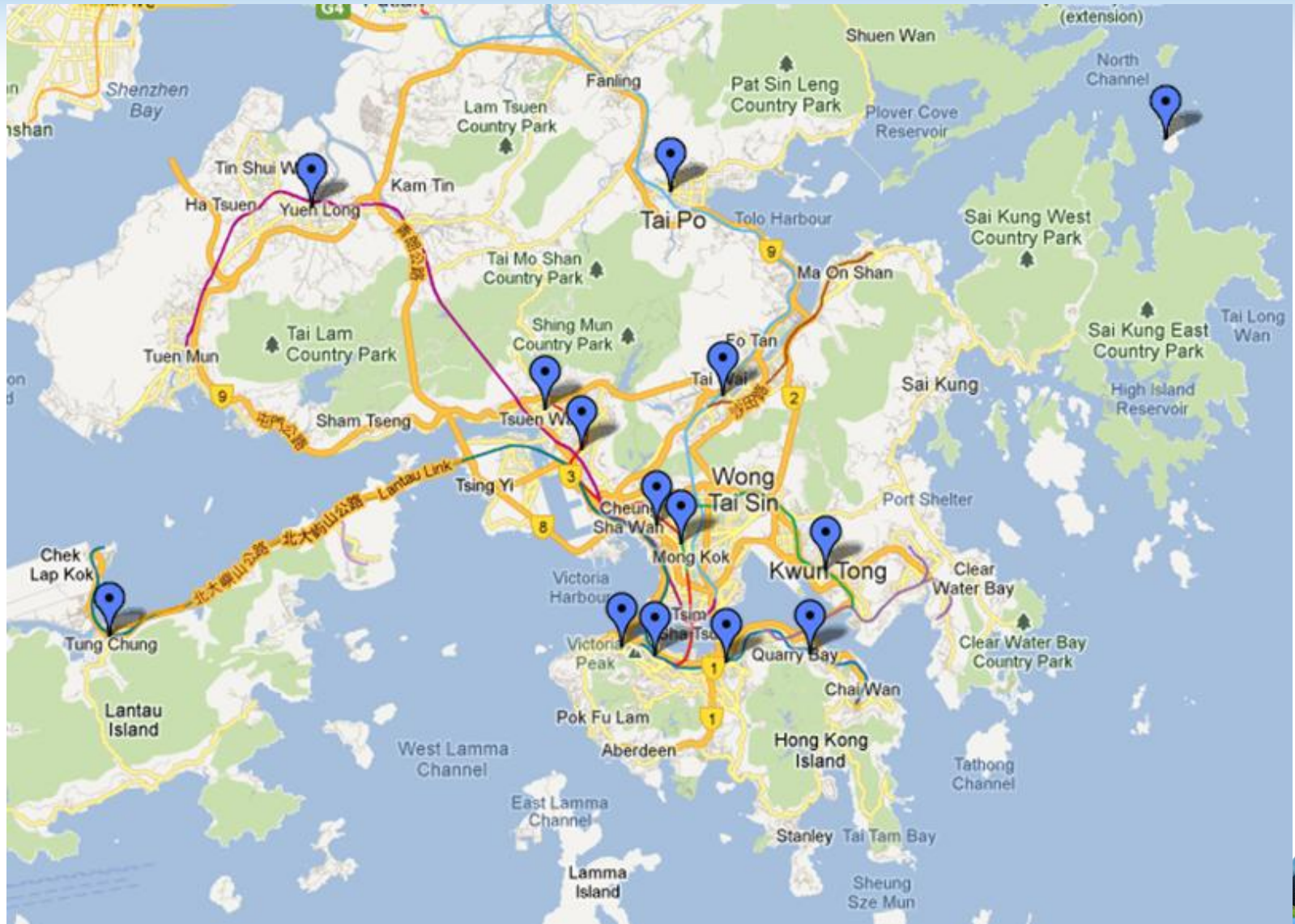
AOD retrieved from MODIS



0 Aerosol Optical Depth(AOD) 0.8
AOD distribution at 10:40 am on Nov 23, 2005 ($\lambda = 0.55 \mu\text{m}$)

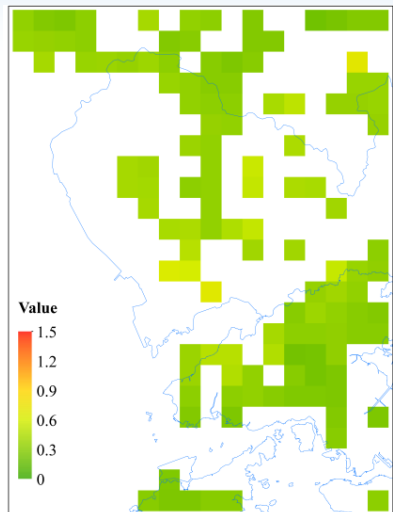
AOD retrieved from predicted ETM+



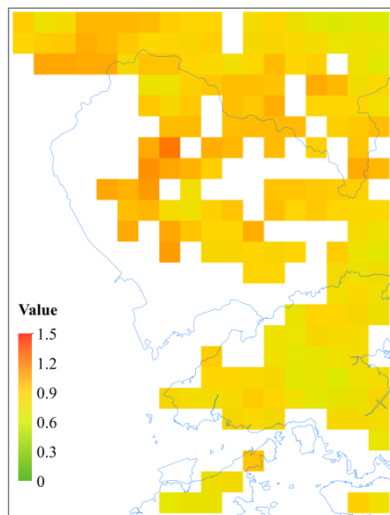
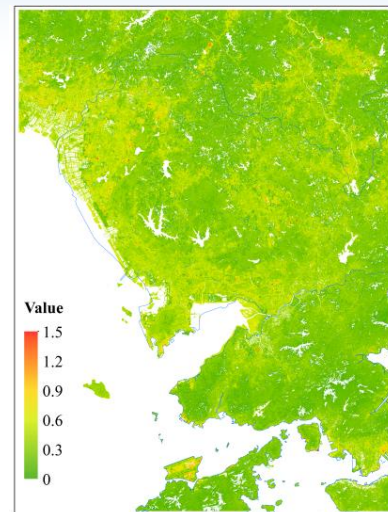
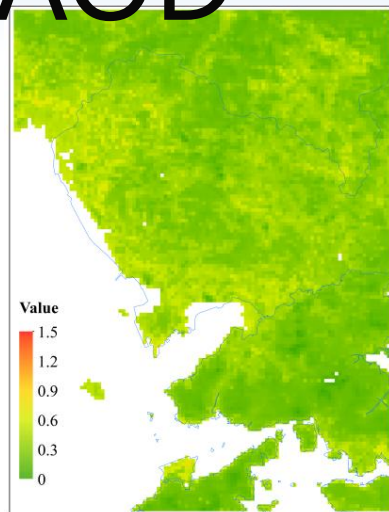


High Spatiotemporal Resolution

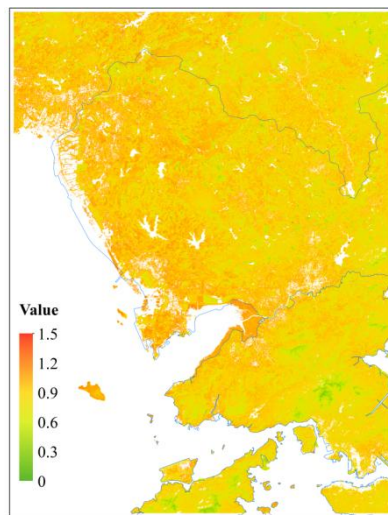
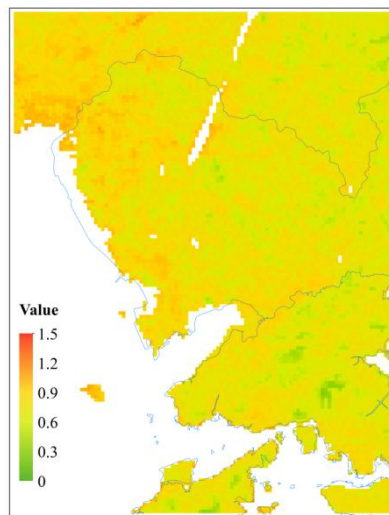
AOD



Nov 20,
2001



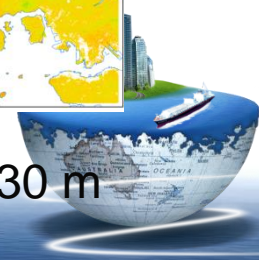
Jan 7,
2002



MOD04 AOD 3 km

MODIS AOD 500 m

ETM+ AOD 30 m



A Mobile App for Real-time Air Pollution

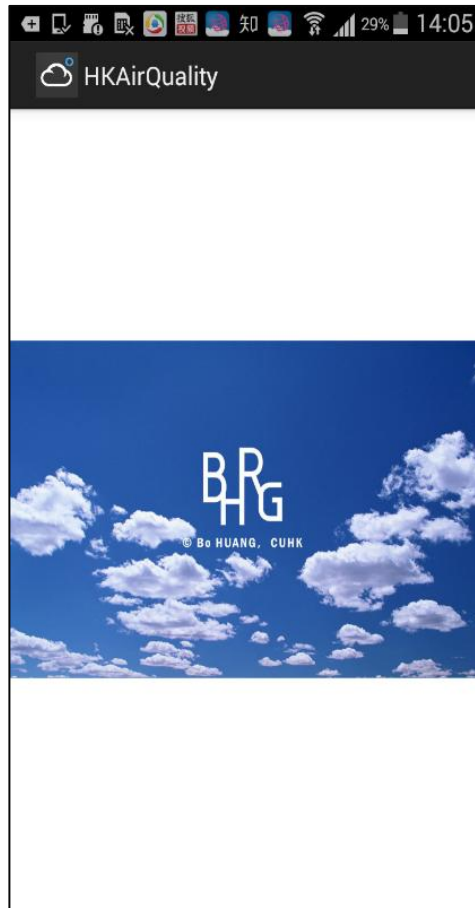


Air Quality App

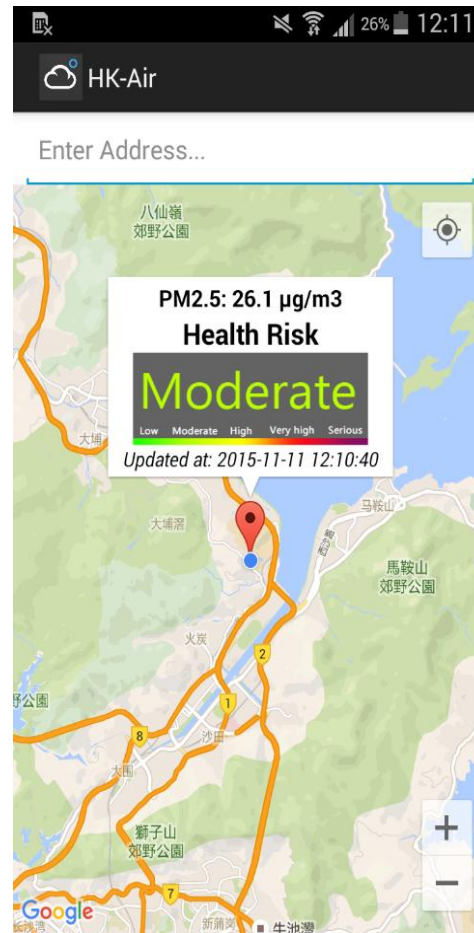
- ❖ The App allows you to access air pollution concentrations **at any location any time** in a city
- ❖ Crawls **environmental monitoring station data and meteorological data** from the web
- ❖ Interpolates (/predicts) the missing data using a **complex spatiotemporal regression** model



Initial interface



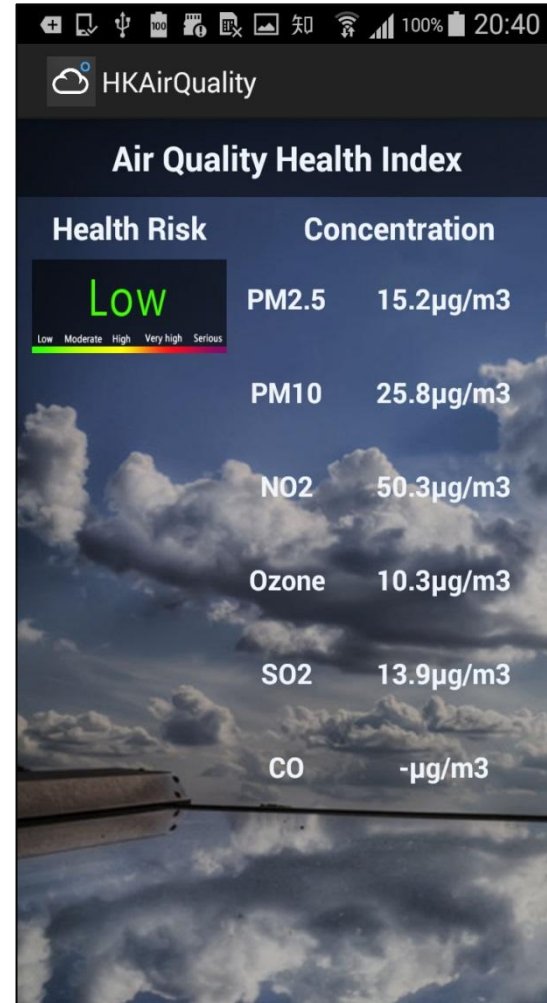
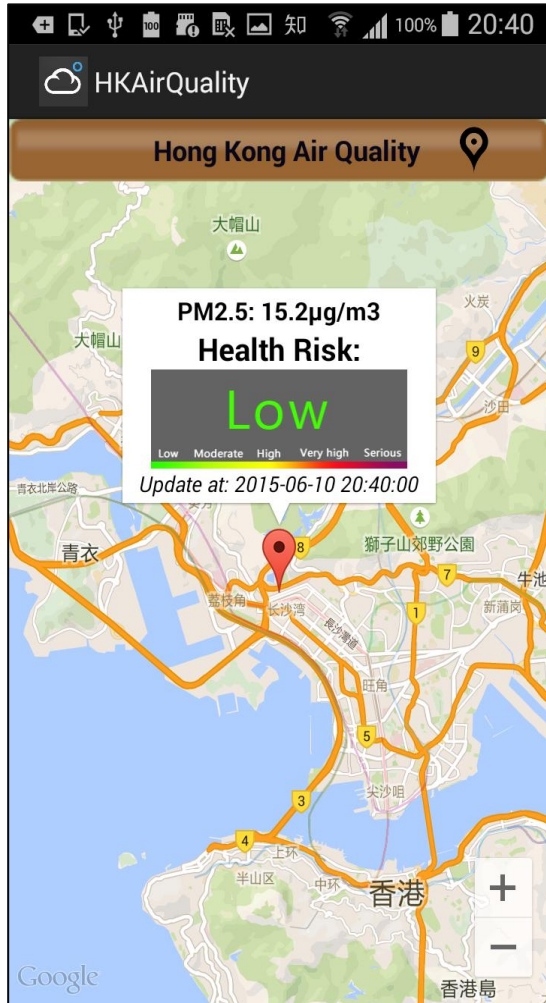
Android platform



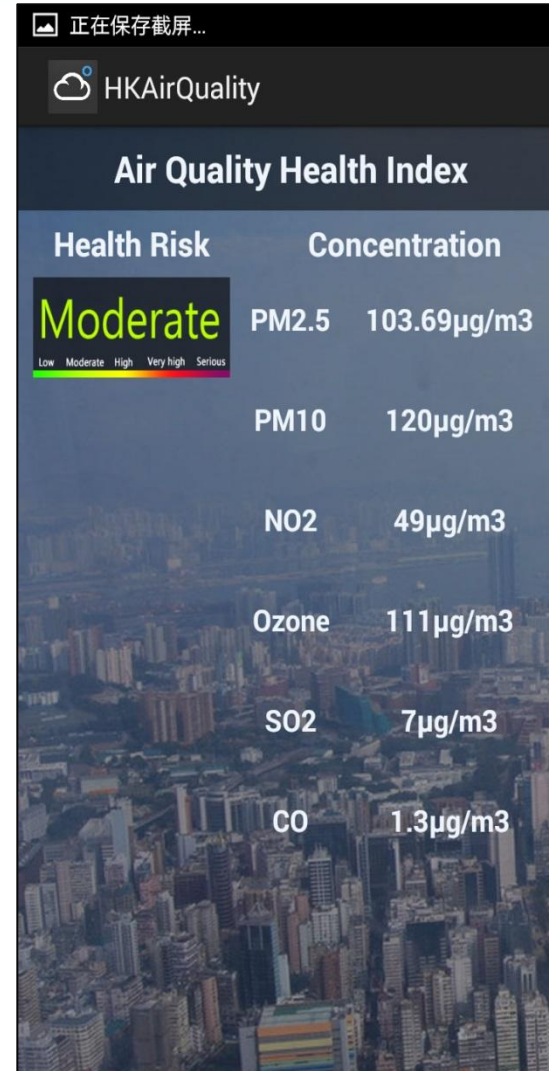
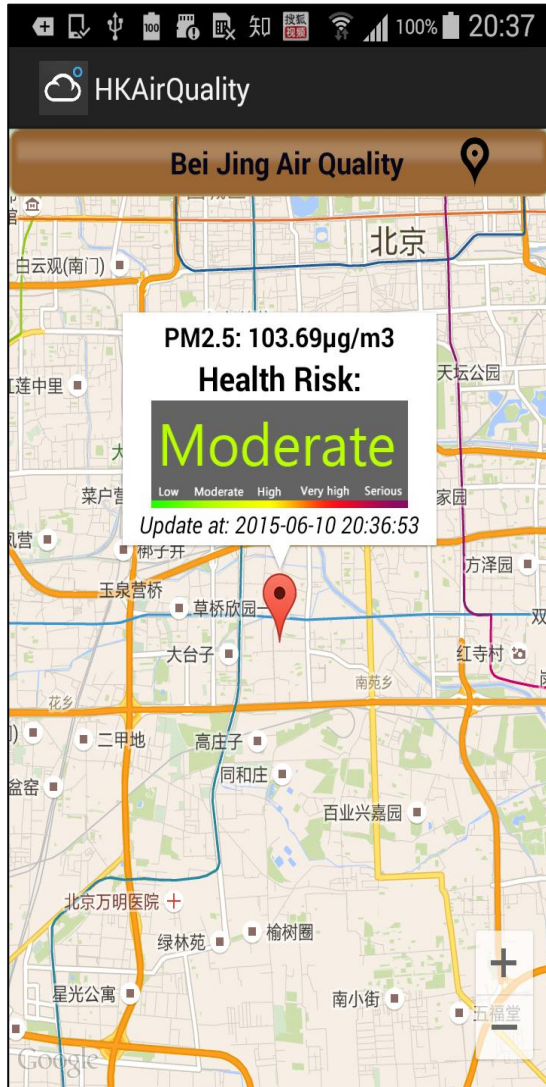
iOS platform



PM2.5 and other pollutants – Hong Kong



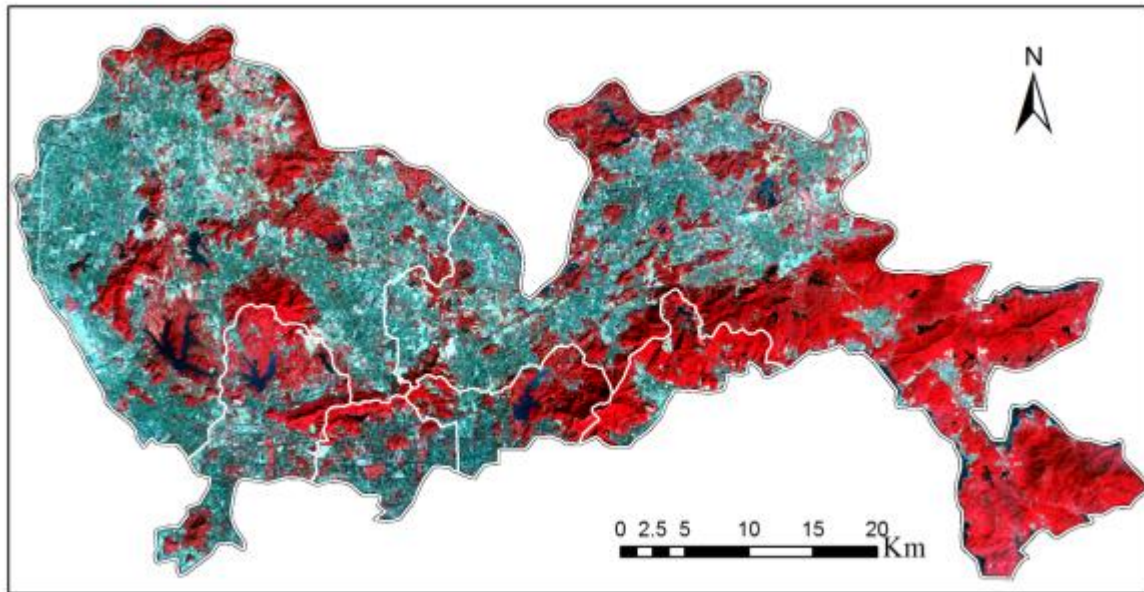
PM2.5 and other pollutants - Beijing



Fine Land Cover Classification in Shenzhen



Study site



Identified Land cover types:

- (1) Water;
- (2) Forest;
- (3) Arable land;
- (4) Bare land;
- (5) Impervious area;
- (6) Shrub.

Study area and the nir-red-green composite of mosaic Landsat OLI images acquired on Nov. 16, 2014.



Fine land cover classification

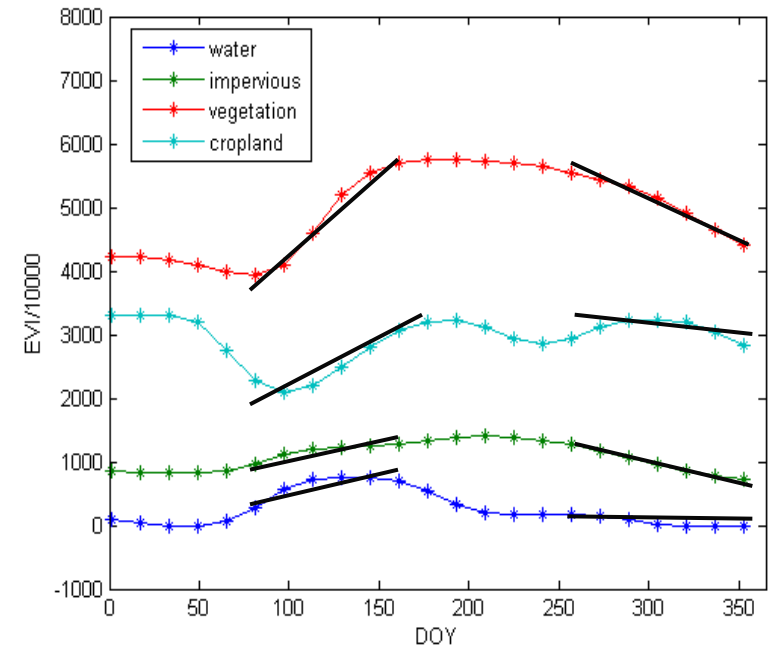
Through spatiotemporal fusion

Time-series fused Landsat-like images

Feature extraction

Max/min Enhanced Vegetation Index (EVI)

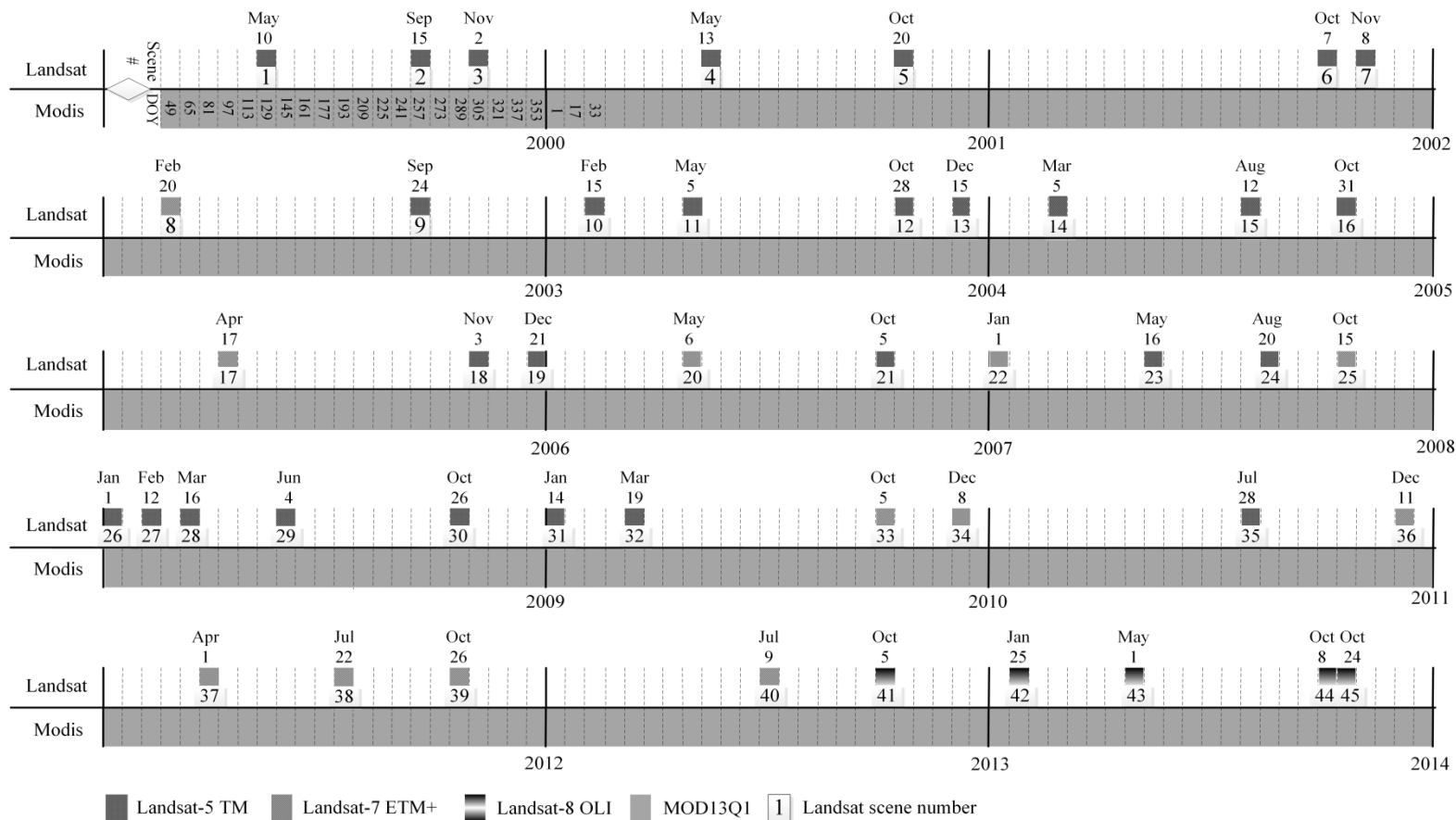
Growing/senescence mean/std value



Supervised classification using maximum likelihood/SVMs



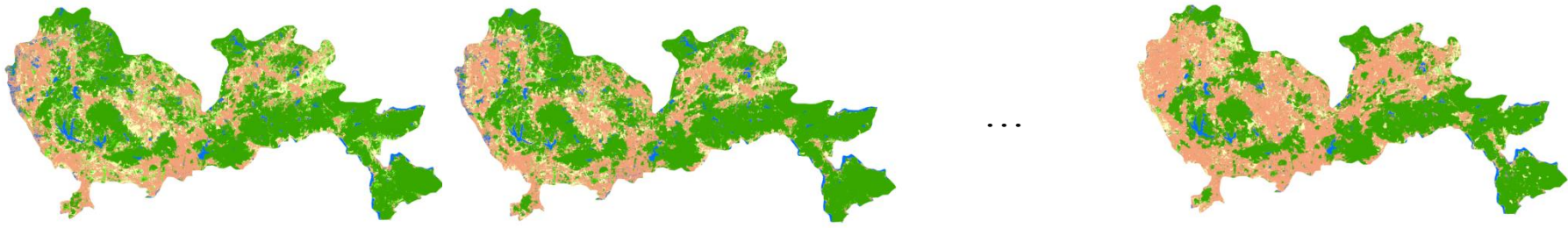
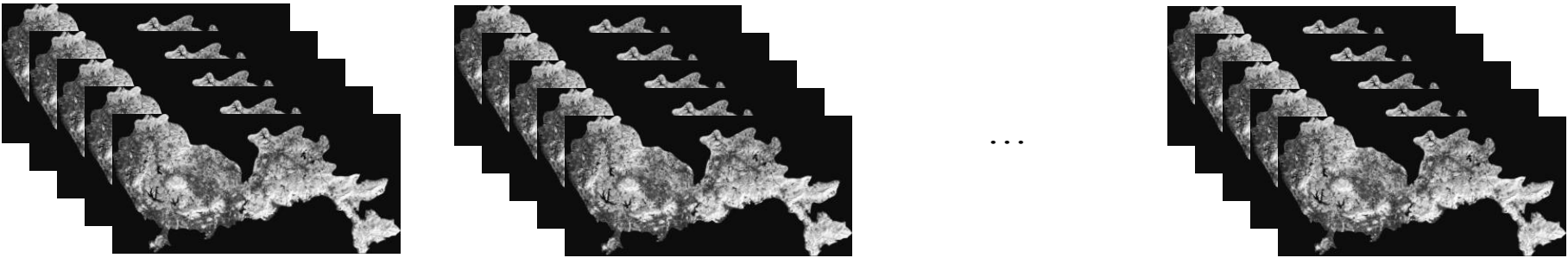
Acquired remotely sensed data



15 years data



Continuous Landsat EVI (30 m, 16-day)



Annual land cover classification map (30 m)



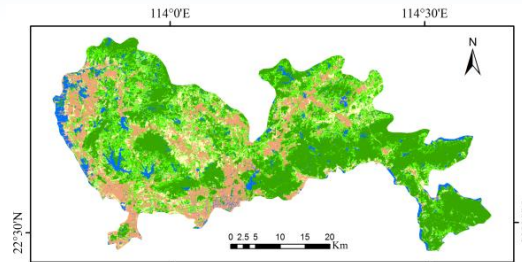
Classification accuracy comparison

(left) Classification results using Landsat only

(right) Classification results using fused time-series Landsat data

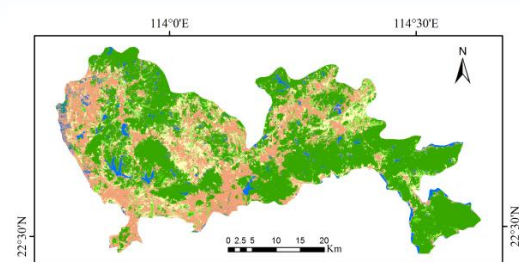
Overall accuracy

2000

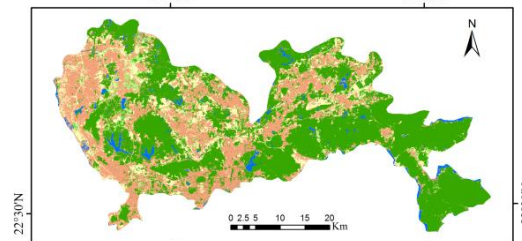


84.2 %

91.8 %

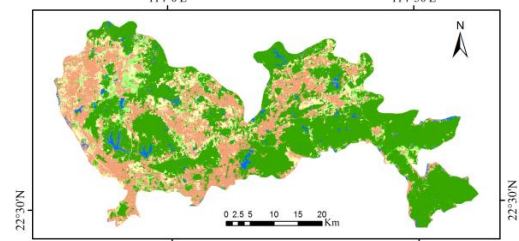


2005

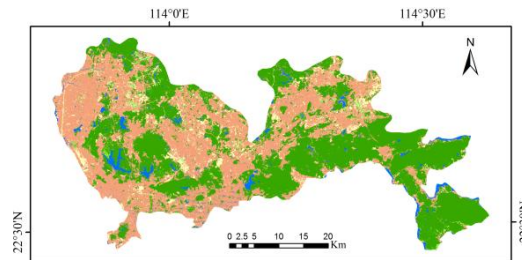


88.5 %

93.6 %

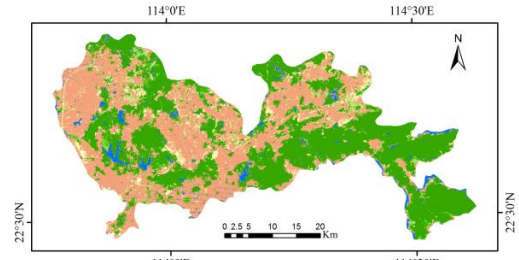


2010

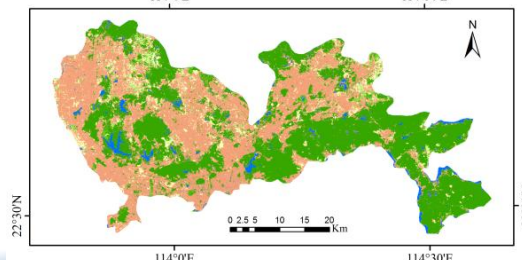


86.2 %

92.1 %

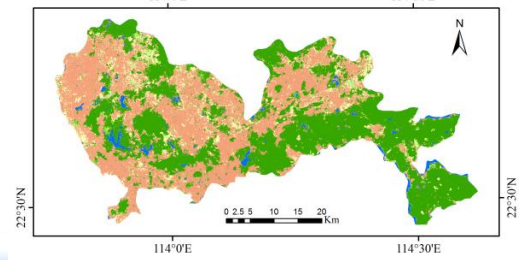


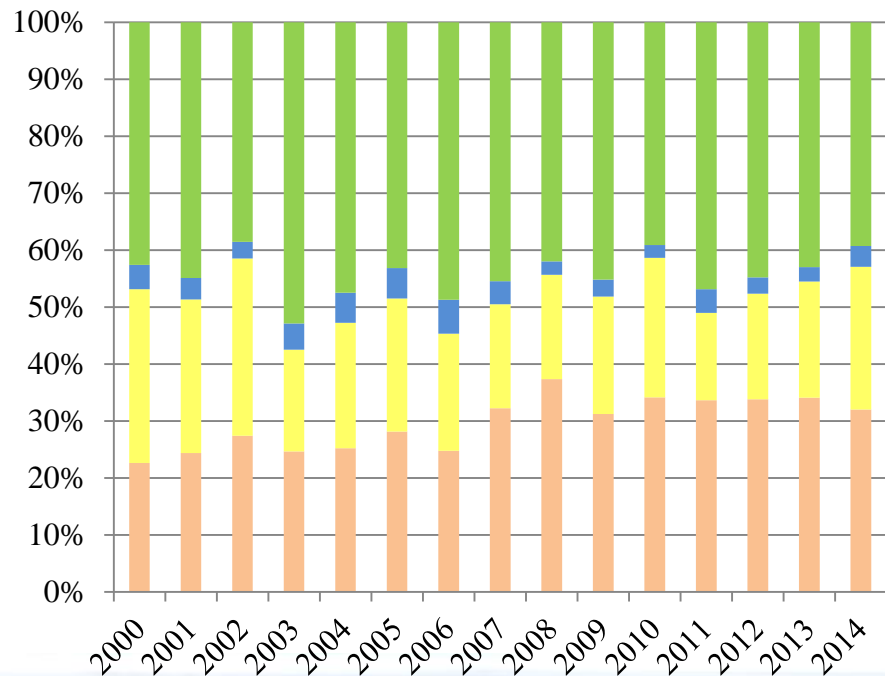
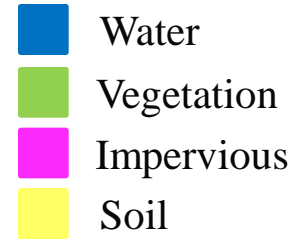
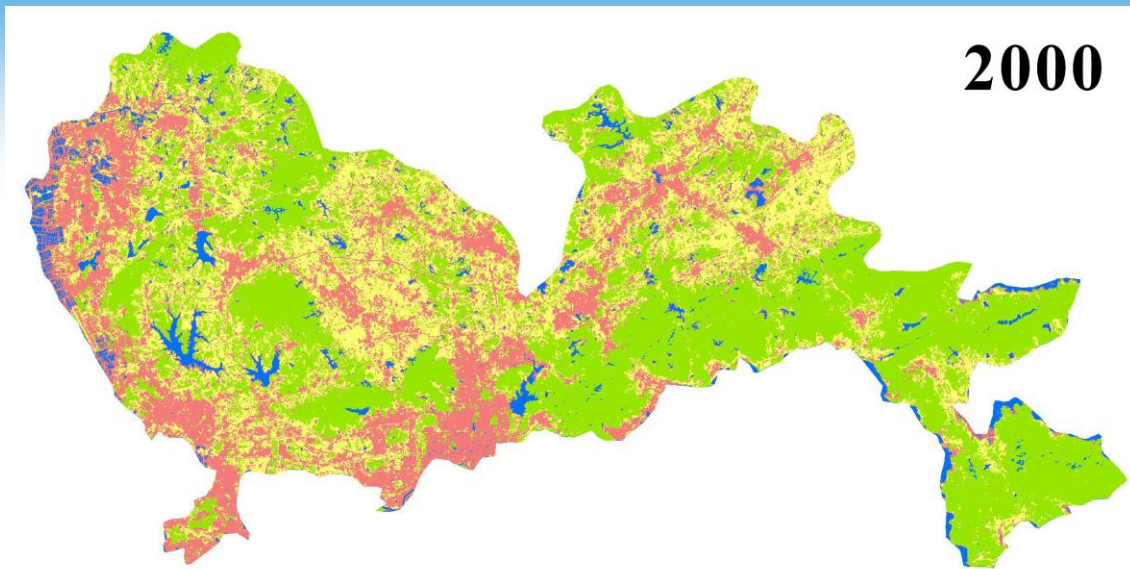
2014



89.5 %

94.8 %





- Impervious urban expands by 10%;
- The fast expansion period is 2000-2002 and 2006-2008;
- Water bodies keep stable;
- The major forest part keeps stable, while other green lands change a lot.



Land Use Change Modeling and Analysis

Funded by:
863-Hightech Program of China
Hong Kong Research Grants Council



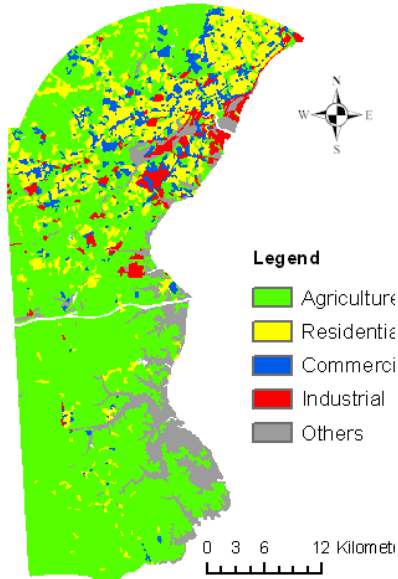
Change modeling and analysis

- ❖ Seeks to understand the complex spatio-temporal change process
- ❖ To **identify** the factors driving the dynamic processes of change and to **explore their relative importance**, and to **simulate “what-if” decision making** under alternative change scenarios

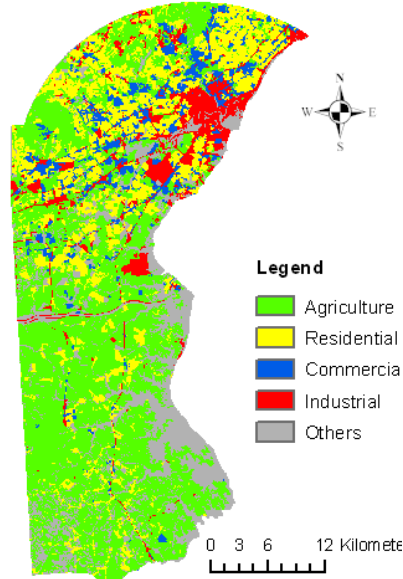


Land Use Change in New Castle County

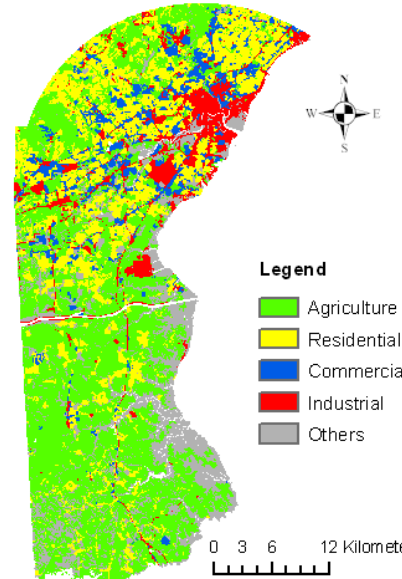
Land Use/Land Cover of New Castle County in 1984 Land Use/Land Cover of New Castle County in 1992 Land Use/Land Cover of New Castle County in 1997 Land Use/Land Cover of New Castle County in 2002



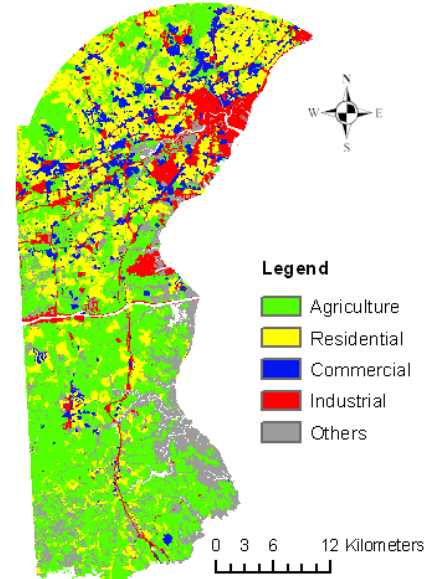
1984



1992



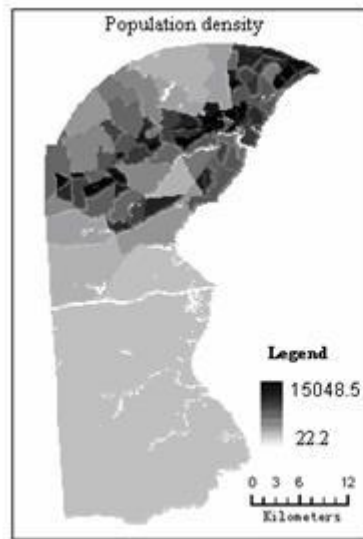
1997



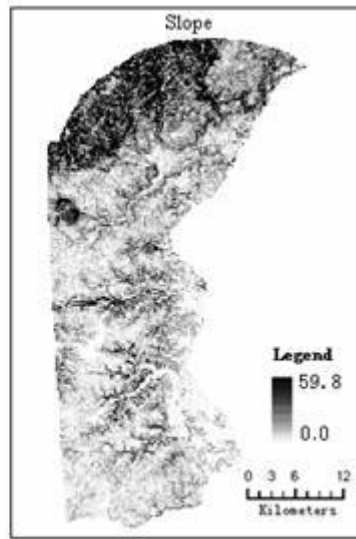
2002



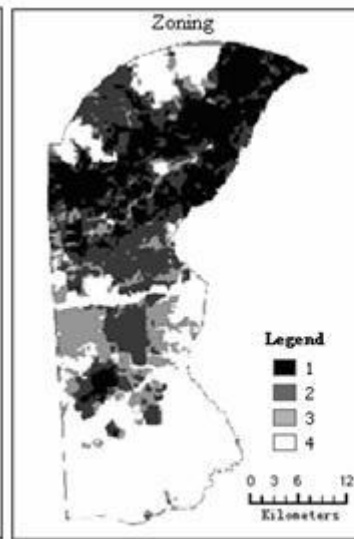
Spatial distribution of predictors



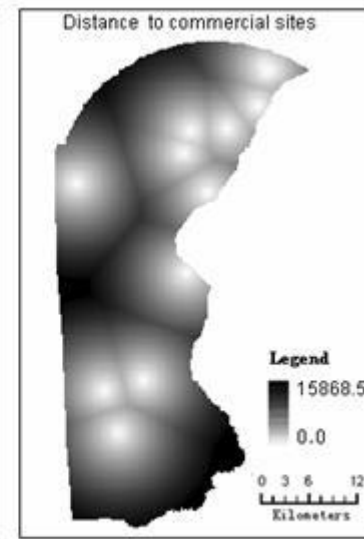
(a)



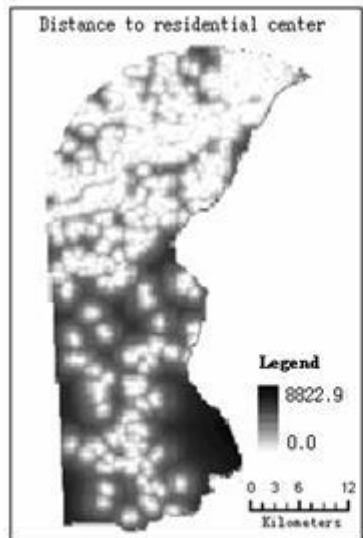
(b)



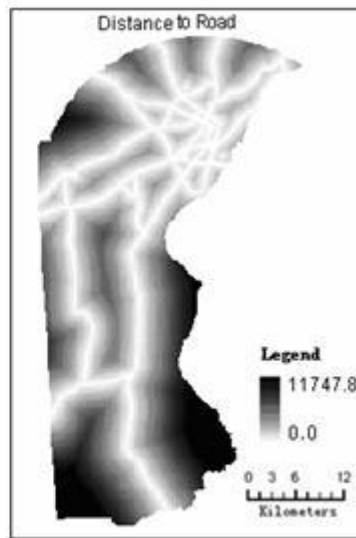
(c)



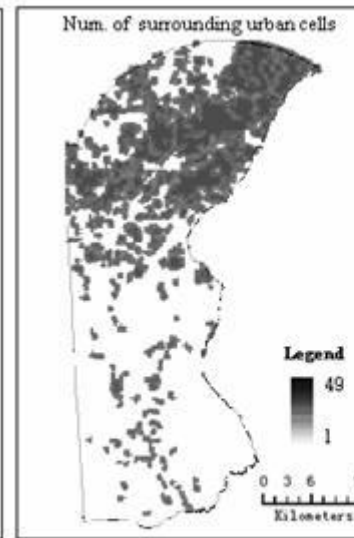
(d)



(e)



(f)



(g)



Spatial Logit Model

$$prob(y_{it}^j = 1) = \frac{\exp(\beta^j x_{i,t-1} + \mu_{it}^j)}{\sum_{j=0}^J \exp(\beta^j x_{i,t-1} + \mu_{it}^j)}, j = 1, \dots, J; t = 1, \dots, T$$

| Category [↵] | Variable [↵] | Description [↵] |
|---|-------------------------------|---|
| Site-specific [↵] | <u>Dens Pop</u> [↵] | Population density of the cell [↵] |
| | Slope [↵] | Slope of the cell [↵] |
| | Zoning [↵] | Zoning plan for development control [↵] |
| Proximity extent [↵] | <u>Dist Com</u> [↵] | Distance from the cell to the nearest commercial site [↵] |
| | <u>Dist Res</u> [↵] | Distance from the cell to the nearest residential center [↵] |
| | <u>Dist Road</u> [↵] | Distance from the cell to the nearest road [↵] |
| Neighborhood characteristics [↵] | <u>Per Urb</u> [↵] | Percentage of urban land use in the surrounding area [↵] |



Implementation

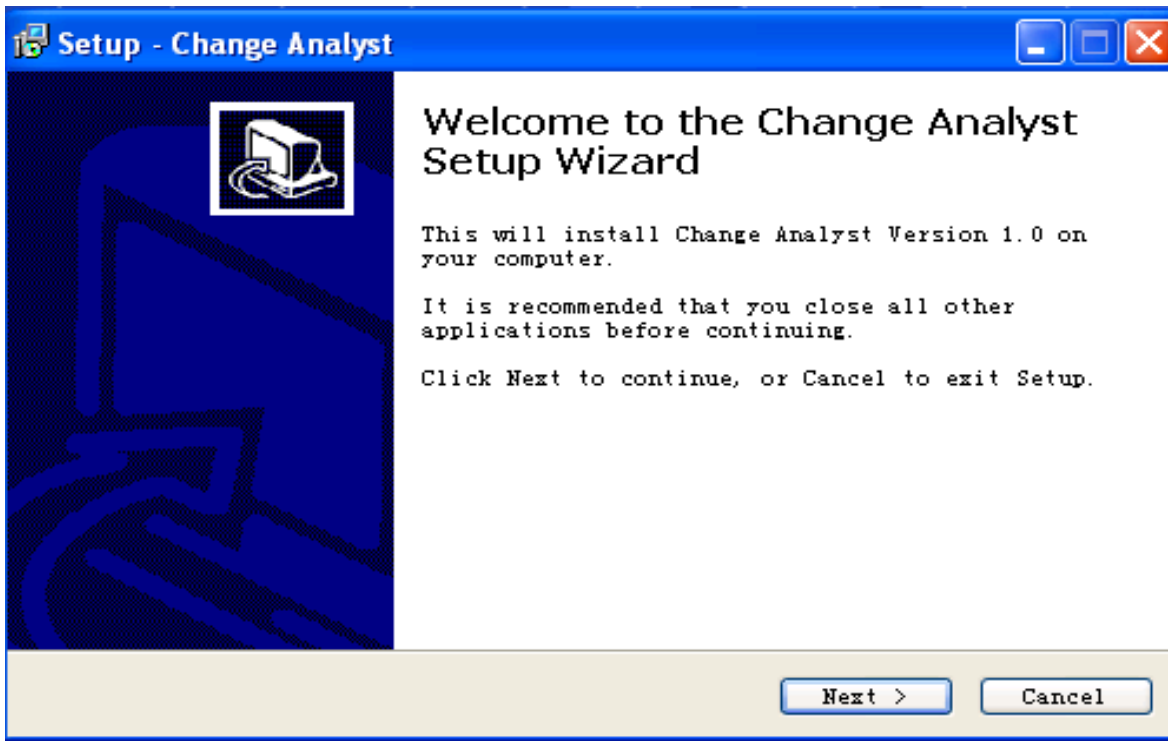
- ❖ Development of ChangeAnalyst
 - An ArcGIS extension for change analysis and prediction
- ❖ Help files
- ❖ Friendly user interface
- ❖ Available at

Huang, Bo, Zhang, Li and Wu, Bo (2009) 'Spatiotemporal analysis of rural-urban land conversion', *International Journal of Geographical Information Science*, 23:3,379 — 398

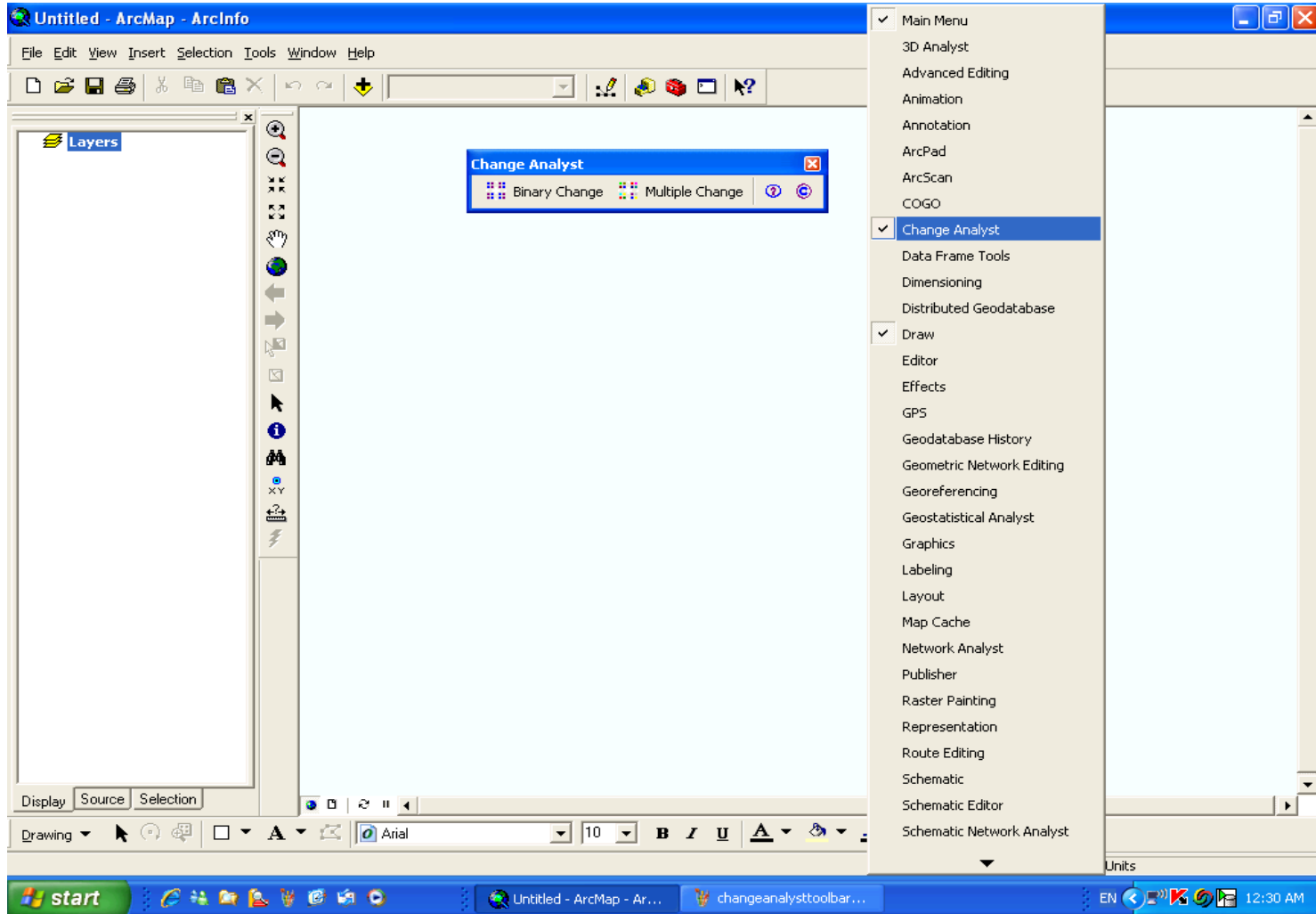
http://www.grm.cuhk.edu.hk/~huang/ChangeAnalyst_setup.exe



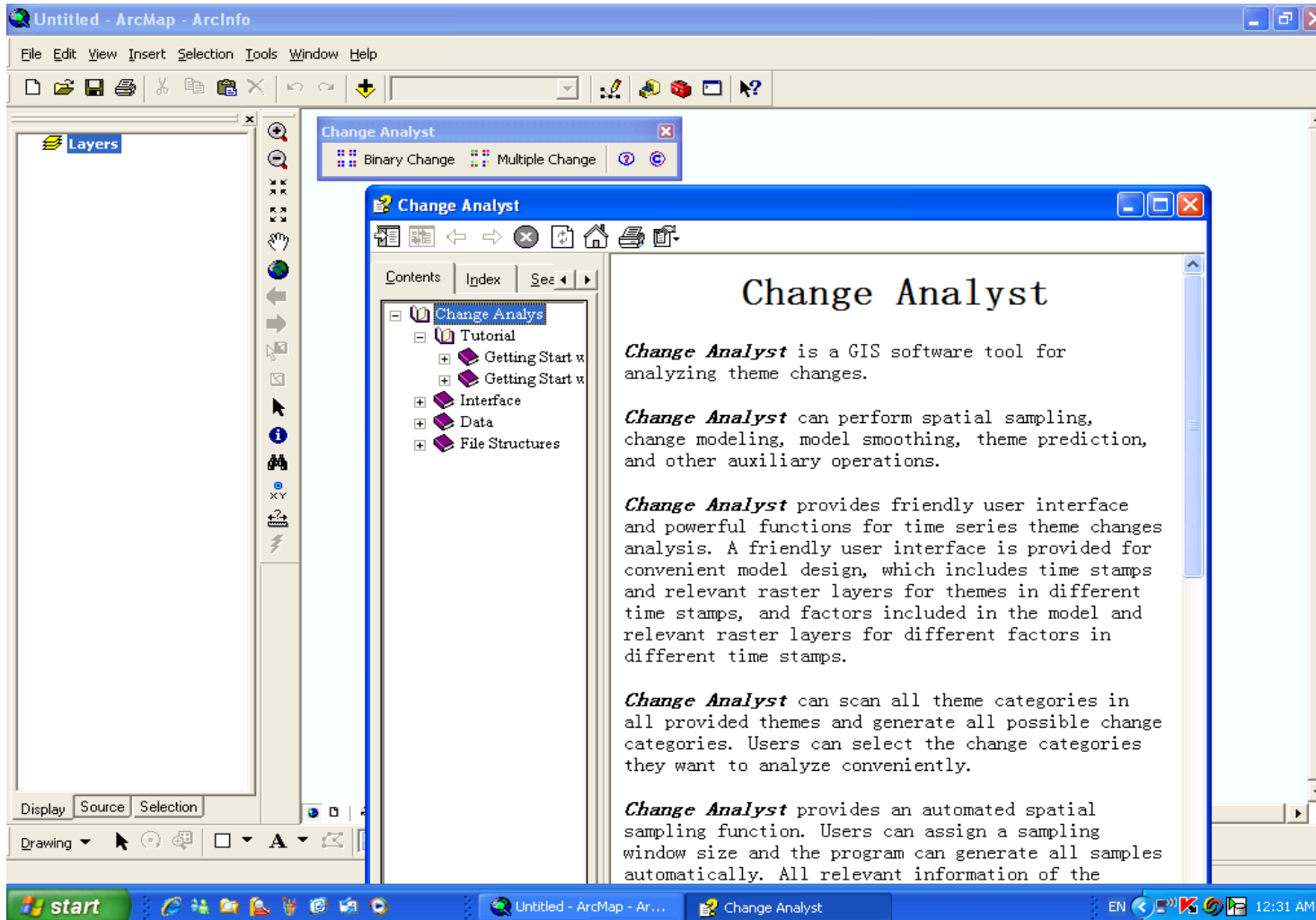
Easy installation (ChangeAnalyst 1.0)



Launching ChangeAnalyst



Help file



A **binary** change application

- Urban sprawl in Newcastle County



Input time-series maps

The screenshot displays the ArcMap interface with a map showing a semi-circular area with a color gradient from green to orange. The 'Layers' panel on the left lists several layers, including 'Eva_1992-1997', 'BLU1997New', 'BLU1992New', and 'BLU1984New'. The 'Binary Change Analyst' dialog box is open, showing the 'Themes' tab. The 'Theme to be Analyzed' is set to 'LandUse'. The 'Time Stamps' section shows a list of years and corresponding layers: 1984 -> BLU1984New, 1992 -> BLU1992New, and 1997 -> BLU1997New. The 'Output Folder' is set to 'D:\ChangeAnalyst\OutputNew1'. The 'Change Analyst' dialog box also shows 'Binary Change' and 'Multiple Change' options.

binary1 - ArcMap - ArcInfo

File Edit View Insert Selection Tools Window Help

1:437,648

Layers

- Eva_1992-1997
 - 0
 - 1
- BLU1997New
 - 0
 - 1
- BLU1992New
 - 0
 - 1
- BLU1984New
 - 0
 - 1
- Dens_Pop1984
 - Value
 - High : 15048.5
 - Low : 22.18
- Dens_Pop1992
- Dist_Ind84
- Dist_Ind92
- Dist_Munc
- Dist_PRoad
- Dist_Rail
- Dist_Schl
- Dist_Shpc
- Dist_SRoad
- Per_Avail84
- Per_Avail92
- Planning
 - Value
 - High : 4
 - Low : 1

Change Analyst

- Binary Change
- Multiple Change

Binary Change Modeling - newcastlebin1

Themes | Categories | Factors | Sampling | Regression | Prediction

Theme :

Theme to be Analyzed : LandUse

Time Stamps :

Year Month Day

1997

- 1984 -> BLU1984New
- 1992 -> BLU1992New
- 1997 -> BLU1997New

Delete Delete All

Output :

Output Folder : D:\ChangeAnalyst\OutputNew1

<<Prev Next>> Reset Load Save Save As Close

Display Source Selection

Drawing

Arial 10 B I U

470579.32 4347994.212 Meters

start binary1 - ArcMap - Ar... EN 10:26 PM



Scanning of changes

The screenshot shows the ArcMap interface with several dialog boxes open. The 'Change Analyst' dialog is set to 'Binary Change'. The 'Binary Change Modeling' dialog shows the following categories and cell counts:

| Category | Cell Count |
|------------------------------|--------------|
| Category (0) | 205427 cells |
| Category (0) -> Category (0) | 65451 cells |
| Category (0) -> Category (1) | 11348 cells |
| Category (1) | 150363 cells |
| Category (1) -> Category (0) | 293018 cells |
| Category (1) -> Category (1) | 220626 cells |

The 'Chart' dialog displays a bar chart with the following data:

| Category | Cell Count |
|----------|------------|
| 0 | 293018 |
| 0 | 220626 |
| 1 | 110400 |
| 1 | 152400 |



Input causal factors

The screenshot shows the ArcMap interface with a map of a coastal area. The 'Layers' panel on the left lists several layers, including 'Eva_1992-1997', 'BLU1997New', 'BLU1992New', 'BLU1984New', 'Dens_Pop1984', 'Dens_Pop1992', 'Dist_Ind84', 'Dist_Ind92', 'Dist_Munc', 'Dist_PRoad', 'Dist_Rail', 'Dist_Schl', 'Dist_Shpc', 'Dist_SRoad', 'Per_Avail84', 'Per_Avail92', and 'Planning'. The 'Change Analyst' dialog is open, showing 'Binary Change' selected. The 'Binary Change Modeling - newcastlebin1' dialog is also open, displaying a table of factors and raster layers for the years 1984 and 1992.

| Factor Name | 1984 | 1992 |
|---------------|--------------|--------------|
| Dens_Pop | Dens_Pop1984 | Dens_Pop1992 |
| Planning | Planning | Planning |
| SurroundingLU | Per_Avail84 | Per_Avail92 |
| Dist_Industry | Dist_Ind84 | Dist_Ind92 |
| Dist_SRoad | Dist_SRoad | Dist_SRoad |
| Dist_Munc | Dist_Munc | Dist_Munc |
| Dist_PRoad | Dist_PRoad | Dist_PRoad |
| Dist_Shpc | Dist_Shpc | Dist_Shpc |



Spatial sampling

The screenshot displays the ArcMap interface with several key components:

- Layers Panel:** Lists various data layers including 'Eva_1992-1997', 'BLU1997New', 'BLU1992New', 'BLU1984New', 'Dens_Pop1984', 'Dens_Pop1992', 'Dist_Ind84', 'Dist_Ind92', 'Dist_Munc', 'Dist_PRoad', 'Dist_Rail', 'Dist_Schl', 'Dist_Shpc', 'Dist_SRoad', 'Per_Avail84', 'Per_Avail92', and 'Planning'. The 'BLU' layers are checked and show a legend with values 0 (green) and 1 (orange).
- Main Map Area:** Displays a spatial sampling window (a semi-circle) overlaid on a map.
- Change Analyst Dialog:** Shows options for 'Binary Change' and 'Multiple Change'.
- Binary Change Modeling - newcastlebin1 Dialog:** Configured for 'Sampling' with a 'Sampling Window Size' of 7 cells. It includes a 'Sampling Files List' table.
- LandUse_Sample1984-1992(0) - Notepad:** Displays a table of sampled data.

| Period | BaseCategory | Size | Sample File |
|-------------|--------------|------|--------------------------------|
| 1984 - 1992 | 0 | 5268 | LandUse_Sample1984-1992(0).txt |
| 1984 - 1997 | 0 | 5247 | LandUse_Sample1984-1997(0).txt |
| 1992 - 1997 | 0 | 4363 | LandUse_Sample1992-1997(0).txt |

| Dens_Pop | Planning | SurroundingLU | Dist_Industry | Dist_SRoad | Dist_Mun | | | |
|----------|----------|---------------|---------------|------------|----------|---------|---------|---|
| 97.37 | 4 | 25 | 4812.74 | 50 | 9808.16 | 2094.04 | 4904.08 | 1 |
| 97.37 | 4 | 29 | 4681.88 | 300 | 9473.25 | 2394.26 | 4569.74 | 0 |
| 97.37 | 4 | 32 | 4574.11 | 50 | 9139.47 | 2706.01 | 4237.92 | 0 |
| 97.37 | 4 | 48 | 4491.1 | 200 | 8806.96 | 3018.69 | 3909.28 | 0 |
| 97.37 | 4 | 28 | 4434.24 | 111.803 | 8475.85 | 3332.04 | 3584.69 | 0 |
| 174.74 | 4 | 32 | 4402.56 | 0 | 7818.57 | 2657.54 | 2952.96 | 0 |
| 174.74 | 4 | 45 | 4428.32 | 269.258 | 7492.83 | 2316.25 | 2650 | 0 |
| 174.74 | 4 | 48 | 4481.35 | 180.278 | 7169.38 | 1972.94 | 2360.08 | 0 |
| 174.74 | 4 | 47 | 4560.7 | 0 | 6848.54 | 1627.88 | 2088.66 | 0 |
| 174.74 | 4 | 46 | 4665.03 | 111.803 | 6530.7 | 1285.5 | 1843.91 | 0 |
| 174.74 | 4 | 49 | 4792.7 | 304.138 | 6216.31 | 948.683 | 1637.83 | 0 |
| 174.74 | 4 | 48 | 4941.91 | 223.607 | 5905.93 | 626.498 | 1486.61 | 0 |
| 174.74 | 4 | 42 | 5110.77 | 254.951 | 5600.22 | 304.138 | 1408.01 | 0 |
| 174.74 | 3 | 41 | 5297.4 | 316.228 | 5326.58 | 0 | 1414.21 | 1 |
| 1178.71 | 2 | 11 | 5500 | 100 | 5034.38 | 269.258 | 1504.16 | 0 |
| 1178.71 | 2 | 28 | 5482.93 | 111.803 | 4474.93 | 921.954 | 1876.83 | 0 |
| 97.37 | 3 | 31 | 5485.66 | 0 | 10747.3 | 583.095 | 6534.91 | 1 |
| 97.37 | 4 | 41 | 5255.95 | 111.803 | 10686.1 | 813.941 | 6189.71 | 0 |
| 97.37 | 4 | 46 | 5040.09 | 320.156 | 10636 | 1060.66 | 5845.08 | 0 |
| 97.37 | 4 | 21 | 4657.52 | 0 | 10053.1 | 1612.45 | 5158 | 1 |



Regression modeling of changes

The screenshot shows the ArcMap interface with the 'Binary Change Modeling - newcastlebin1' dialog box open. The 'Regression' tab is selected, showing a threshold value of 0.320000 and a list of input files: 'LandUse_BLR1984-1992.txt', 'LandUse_BLR1984-1997.txt', and 'LandUse_BLR1992-1997.txt'. A 'Change Analyst' window is also visible, showing a map with a green and orange pattern. A 'Notepad' window in the foreground displays the output of the regression analysis.

Binary Change Modeling - newcastlebin1

Themes | Categories | Factors | Sampling | **Regression** | Prediction

Threshold Value:

Change (category 0 -> category 1): 0.320000 (0-1)

Change (category 1 -> category 0): NULL (0-1)

Binary Logistic Regression:

Perform Regression Evaluation (opt.)

LandUse_BLR1984-1992.txt
LandUse_BLR1984-1997.txt
LandUse_BLR1992-1997.txt

Text Map

Display S Drawing

Change Analyst

Binary Change Multiple Change

LandUse_BLR1984-1992 - Notepad

File Edit Format View Help

* Binary Logistic Regression
* 1984 to 1992

Base Category : 0

Binary Logistic Regression

Descriptive Statistics

Case of change from 0 to 0 : 4155
Case of change from 0 to 1 : 1113
Total = 5268

| Variable | Label | Average | Std.Dev. |
|----------|---------------|--------------|--------------|
| 1 | Dens_Pop | 185.166061 | 337.484076 |
| 2 | Planning | 2.985004 | 1.049444 |
| 3 | surroundingLU | 38.958238 | 10.974333 |
| 4 | Dist_Industry | 5142.106565 | 4213.806479 |
| 5 | Dist_SRoad | 166.565943 | 157.854607 |
| 6 | Dist_Munc | 6285.743005 | 2968.794570 |
| 7 | Dist_PRoad | 2235.611467 | 1970.551648 |
| 8 | Dist_Shpc | 19597.987708 | 11888.585304 |

Iteration History

Log Likelihood = -2716.4014 (Null Model)
Log Likelihood = -2130.2784
Log Likelihood = -2003.4957
Log Likelihood = -1980.3641
Log Likelihood = -1979.1745
Log Likelihood = -1979.1707
Log Likelihood = -1979.1707
Converged

Overall Model Fit : Chi Square = 1474.4616 with df = 8 and P-Val

Coefficients and Standard Errors (with preliminary data)

| Variable | Label | Coeff. | StdErr | z_value | T_Test(p) |
|----------|----------|--------|--------|---------|-----------|
| | Constant | 2.2238 | | | |

start binary1 - Arc... sampling - P... LandUse_Sa... LandUse_BL... EN 10:36 PM



Evaluation of regression models

The screenshot shows the ArcMap interface with several windows open. The 'Change Analyst' window is active, showing 'Binary Change' selected. The 'Binary Change Modeling - newcastlebin1' dialog box is open, with the 'Regression' tab selected. The 'Threshold Value' section shows 'Change (category 0 -> category 1)' set to 0.200000 and 'Change (category 1 -> category 0)' set to NULL. The 'Binary Logistic Regression' section has 'Perform Regression' and 'Evaluation (opt.)' buttons. Below these are two lists of files, with 'LandUse_BLR1992-1997.txt' and 'LandUse_ModEval1992-1997.txt' selected in the right list. The 'Notepad' window displays the following text:

```

*****
* Regression Model Evaluation
* 1992 to 1997
*****
Base Category : 0
Case Changing from :0 to 1

Observed      Predicted      Total
0              1              202044
0              200309        1735
1              9640          349
Total          209949        2084
                212033

Threshold value : 0.2
Correct Prediction : 200658
Wrong Prediction : 11375
Percentage of Correct Prediction (PCP) : 94.64%

Total:
Observed      Predicted      Total
0              1              202044
0              200309        1735
1              9640          349
Total          209949        2084
                212033

Correct Prediction : 200658
Wrong Prediction : 11375
Percentage of Correct Prediction (PCP) : 94.64%
    
```

The ArcMap interface also shows a 'Layers' panel with 'Eva_1992-1997', 'BLU1997New', and 'BLU1992New' layers. A map window shows a spatial distribution of data points in green and orange. The status bar at the bottom indicates coordinates: 475905.865 4349962.718 Meters. The taskbar shows the Start button, several application icons, and the system clock at 11:22 PM.



Interpolation of a theme (time in between input times)

The screenshot shows the ArcMap interface with the 'Binary Change Modeling - newcastlebin1' dialog box open. The dialog has several tabs: Themes, Categories, Factors, Sampling, Regression, and Prediction. The 'Prediction' tab is active, showing the following settings:

- Prediction Setting:
- Predicted Time: 1989
- Change Rate: High
- Scale Factor: 0.8
- Max Dominant Category Percentage (0-1): 1.0
- Output File: D:\ChangeAnalyst\OutputNew\1989

Below the settings is a 'Perform Prediction' button. Underneath, the 'Output Theme Statistics' section displays the following data:

Theme of 1984:
Number of cells of category 0 : 293018 (72.63%)
Number of cells of category 1 : 110407 (27.37%)

Theme of 1989:
Number of cells of category 0 : 266155 (65.97%)
Number of cells of category 1 : 137270 (34.03%)

The background map shows a spatial distribution of categories 0 (green) and 1 (orange/yellow) for the year 1989. The 'Layers' panel on the left lists various data layers, including '1989', 'BLU1984New', 'Eva_1992-1997', 'BLU1997New', 'BLU1992New', 'Dens_Pop1984', 'Dens_Pop1992', 'Dist_Ind84', 'Dist_Ind92', 'Dist_Munc', 'Dist_PRoad', 'Dist_Rail', 'Dist_Schl', 'Dist_Shpc', 'Dist_SRoad', 'Per_Avail84', 'Per_Avail92', and 'Planning'.

Forecasting a future theme

The screenshot displays the ArcMap interface with a land use map. The 'Layers' panel on the left shows several layers, including '2002', 'BLU1997New', 'BLU1984New', '1989', 'Eva_1992-1997', 'BLU1992New', 'Dens_Pop1984', 'Dens_Pop1992', 'Dist_Ind84', 'Dist_Ind92', 'Dist_Munc', 'Dist_PRoad', 'Dist_Rail', 'Dist_Schl', 'Dist_Shpc', 'Dist_SRoad', and 'Per_Avail84'. The 'Change Analyst' dialog box is open, showing 'Binary Change' and 'Multiple Change' options. The 'Binary Change Modeling - newcastlebin1' dialog box is also open, showing the 'Prediction' tab. The 'Prediction Setting' section includes 'Predicted Time' (2002), 'Change Rate' (High), 'Scale Factor' (0.8), and 'Max Dominant Category Percentage (0-1)' (1.0). The 'Output File' is 'D:\ChangeAnalyst\OutputNew1\2002'. The 'Output Theme Statistics' section shows the following data:

| Theme | Category | Number of cells | Percentage |
|---------------|----------|-----------------|------------|
| Theme of 1997 | 0 | 207579 | 55.66% |
| | 1 | 165362 | 44.34% |
| Theme of 2002 | 0 | 199555 | 53.51% |
| | 1 | 173386 | 46.49% |

The Windows taskbar at the bottom shows the Start button, several application icons, and the system tray with the time 11:25 PM.



A multinomial change application

- Land use change in Calgary



Input of multi-temporal multinomial themes

The screenshot displays the ArcMap interface for a project named "CalgaryLU". The main map area shows a land use map with various colors representing different land use categories. A "Change Analyst" dialog box is open, showing options for "Binary Change" and "Multiple Change". A "Multinomial Change Modeling" dialog box is also open, showing the "Themes" tab. The "Themes" tab is active, and the "theme:" field is set to "LandUse". The "Time Stamps:" section shows "Year" selected, with "2001" entered in the "Year" field. Below this, a list of time stamps is shown: "1985 --> LU1985" and "2001 --> LU2001". The "Output:" section shows the "Output Folder:" set to "D:\ChangeAnalyst\Outputnew2".

Layers

- LU1985
 - Residential and Commercial
 - Industrial
 - Transportation
 - Parks
 - Vacant Area
 - Water Bodies
- LU2001
- LU1990
- LU1992
- LU1999
- LU2000
- BLU1985
- BLU1990
- BLU1992
- BLU1999
- BLU2000
- BLU2001
- Pop_Dens85
- Pop_Dens90
- Pop_Dens92
- Pop_Dens99
- Pop_Dens00
- Pop_Dens01
- Slope
- Dist_Road
- Dist_LRTSta
- Dist_CityCen
- Dist_Amenity
- Dist_CommServ
- Dist_Shopping
- Per_Avail85

Multinomial Change Modeling

Themes | Categories | Factors | Sampling | Regression | Prediction

theme: _____

theme to be Analyzed: LandUse

Time Stamps:

Year Month Day

2001 [Nil] [Nil] [Nil]

1985 --> LU1985

2001 --> LU2001

Delete Delete All

Output:

Output Folder: D:\ChangeAnalyst\Outputnew2

<<Prev Next>> Reset Load Save Save As Close



Scanning of multinomial change

CalgaryLU - ArcMap - ArcInfo

File Edit View Insert Selection Tools Window Help

1:284,690

Layers

- LU2001
- LU1985
 - Residential and C
 - Industrial
 - Transportation
 - Parks
 - Vacant Area
 - Water Bodies
- LU1990
- LU1992
- LU1999
- LU2000
- BLU1985
- BLU1990
- BLU1992
- BLU1999
- BLU2000
- BLU2001
- Pop_Dens85
- Pop_Dens90
- Pop_Dens92
- Pop_Dens99
- Pop_Dens00
- Pop_Dens01
- Slope
- Dist_Road
- Dist_LRTSta
- Dist_CityCen
- Dist_Amenity
- Dist_CommServ
- Dist_Shopping
- Per_Avail85

Change Analyst

Binary Change Multiple Change

Multinomial Change Modeling

Themes Categories Factors Sampling Regression Prediction

Change Categories to be Analyzed:

Scan Change Categories

- Category (1)
 - Category (1) -> Category (1) [198259 cells]
 - Category (1) -> Category (2) [17 cells]
 - Category (1) -> Category (3) [14567 cells]
 - Category (1) -> Category (5) [88 cells]
 - Category (1) -> Category (6)
- Category (2)
 - Category (2) -> Category (1) [31 cells]
 - Category (2) -> Category (2) [41911 cells]
 - Category (2) -> Category (3)
 - Category (2) -> Category (4)
 - Category (2) -> Category (5)
 - Category (2) -> Category (6)
- Category (3)
 - Category (3) -> Category (1)
 - Category (3) -> Category (2)

<<Prev Next>> Reset Load Save Save As Close

Display Source Selection

Drawing Arial 10 B I U

-17990.33 5658681.33 Meters

start CalgaryLU - ... 3 Notepad prediction - ... calgary - Go... EN 12:24 AM



Selection of factors

multinomial1 - ArcMap - ArcInfo

File Edit View Insert Selection Tools Window Help

1.284,658

Layers

- LU1985
 - Residential and Comm
 - Industrial
 - Transportation
 - Parks
 - Vacant Area
 - Water Bodies
- LU2001
- Per_Avail85
- Pop_Dens85
- Dist_Road
- Dist_CityCen
- Slope
- Dist_LRTSta
- Dist_Shopping

Change Analyst

- Binary Change
- Multiple Change

Multinomial Change Modeling - multiCalgary1

Themes | Categories | **Factors** | Sampling | Regression | Prediction

Factors and Raster Layers :

| Factor Name | 1985 |
|---------------|--------------|
| Surrounding | Per_Avail85 |
| Pop_Dens | Per_Avail85 |
| Dist_Road | Pop_Dens85 |
| Dist_CityCen | Dist_Road |
| Slope | Dist_CityCen |
| Dist_LRTSta | Slope |
| Dist_Shopping | Dist_LRTSta |

Add Factor Delete

Raster Information :

Number of Cols: 1391 Number of Rows: 1391

Lower Left Corner X: -23161.592123 Lower Left Corner Y: 5635434.569077

Cell Size: 28,500,000 Value for NoData: -2147483647.00

<<Prev Next>> Reset Load Save Save As Close

840.185 5634732.763 Meters

start Microsoft PowerPoint ... multinomial1 - ArcMap... untitled - Paint EN 1:12 AM



Multinomial change sampling

The screenshot displays the ArcMap interface for a project named 'CalgaryLU'. The main map area shows a land use map with various colors representing different categories. The 'Layers' panel on the left lists several layers, including 'LU1985' and various 'Pop_Dens' and 'Dist' layers. The 'Change Analyst' dialog is open, showing 'Binary Change' and 'Multiple Change' options. The 'Multinomial Change Modeling' dialog is also open, with the 'Sampling' tab selected. It shows a 'Sampling Window Size' of 6x6 cells and a 'Sampling Files List' table. A 'Notepad' window is open in the foreground, displaying a data table with columns: 'Surrounding', 'Pop_Dens', 'Dist_Road', 'Dist_CityCen', 'slope', 'Dist_LRTSta', and 'Dis'. The table contains 30 rows of numerical data.

| Period | BaseCategory | Size | Sample File |
|-------------|--------------|-------|--------------------------------|
| 1985 - 2001 | 1 | 5885 | LandUse_Sample1985-2001(1).txt |
| 1985 - 2001 | 5 | 15036 | LandUse_Sample1985-2001(5).txt |

| Surrounding | Pop_Dens | Dist_Road | Dist_CityCen | slope | Dist_LRTSta | Dis |
|-------------|----------|-----------|--------------|----------|-------------|---------|
| 16 | 738.264 | 0 | 12684.3 | 1.96146 | 8177.31 | 5848.13 |
| 36 | 176.168 | 171 | 14504.9 | 1.96146 | 6858.09 | 7906.07 |
| 17 | 199.073 | 342 | 14411.6 | 1.75439 | 6773.71 | 7805.57 |
| 38 | 508.954 | 171 | 11910.3 | 6.32553 | 8607.05 | 5102.22 |
| 14 | 512.842 | 228 | 11934.8 | 2.23641 | 8527.41 | 5107.94 |
| 22 | 609.311 | 0 | 11718.5 | 7.49474 | 8540.54 | 4931.24 |
| 11 | 600.387 | 57 | 11765.8 | 0.620269 | 8375.75 | 4937.17 |
| 30 | 1243.7 | 318.64 | 10789.6 | 6.32553 | 8306.22 | 4182.61 |
| 20 | 1460.4 | 90.1249 | 10171 | 5.61678 | 6349.62 | 5119.38 |
| 28 | 0 | 142.5 | 10761.2 | 2.55744 | 6156.33 | 4102.61 |
| 7 | 0 | 142.5 | 10815.4 | 0 | 6107.05 | 4201.21 |
| 0 | 0 | 114 | 10872 | 0 | 6062.2 | 4304.35 |
| 29 | 1416.04 | 85.5 | 10022.3 | 4.16089 | 5172.02 | 4887.56 |
| 21 | 1576.79 | 171 | 9820.43 | 5.33576 | 5150.31 | 4805.1 |
| 30 | 3726.49 | 120.915 | 9659.31 | 5.33576 | 6006.47 | 4776.62 |
| 24 | 1751.48 | 102.758 | 9688.03 | 4.96215 | 4909.04 | 4576.54 |
| 4 | 1829.56 | 191.184 | 9652.75 | 7.49474 | 5022.88 | 4652.58 |
| 4 | 5158.86 | 90.1249 | 9467.19 | 0 | 6579.74 | 3912.92 |
| 5 | 1943.09 | 0 | 9521.09 | 7.84585 | 4781.29 | 4422.74 |
| 0 | 2112.53 | 28.5 | 9485.19 | 5.00077 | 4898.1 | 4501.38 |
| 6 | 4817.63 | 228 | 9332.91 | 3.50877 | 5657.16 | 4704.66 |
| 7 | 5225.85 | 207.483 | 9318.28 | 1.96146 | 5791.67 | 4565.87 |
| 7 | 5462.05 | 57 | 9306.77 | 3.10135 | 5928.07 | 4429.34 |
| 20 | 5550.52 | 0 | 9293.14 | 3.77295 | 6150.98 | 4163.93 |
| 4 | 5525.75 | 28.5 | 9291.04 | 3.92293 | 6244.56 | 4035.54 |
| 2 | 5522.6 | 28.5 | 9296.20 | 2.16376 | 6441.25 | 3788.80 |



Multinomial regression modeling

The screenshot displays the ArcMap interface for a project named 'CalgaryLU'. The main map shows a land use classification with a legend on the left. The legend includes categories such as Residential and Commercial, Industrial, Transportation, Parks, Vacant Area, and Water Bodies, along with various LU (Land Use) and BLU (Binary Land Use) codes for different years (1985, 1990, 1992, 1999, 2000, 2001).

Two dialog boxes are open:

- Change Analyst:** Shows 'Binary Change' and 'Multiple Change' options.
- Multinomial Change Modeling:** Shows the 'Regression' tab with 'Perform Regression' and 'Evaluation (opt.)' buttons. The regression statistics window is open, showing the file 'LandUse_MLR1985-2001.txt'.

A Notepad window titled 'LandUse_MLR1985-2001 - Notepad' displays the following regression results:

```

File Edit Format View Help
Log Likelihood = -1145.3398
Converged

Overall Model Fit : Chi Square = 5867.6627 with df = 21 and P-value = 0.0000

Coefficients and standard Errors
Variable      Label      Coeff.      StdErr      z_value      T_Test(p)      Odds_Rate      95% Confidence Interval
Logit 1: (1 --> 5)
              Constant  -2.8517      0.005960     15.954431     0.0000         1.099760       1.0870 1.1127
              Surrounding  0.095092     0.000076     -7.253736     0.0000         0.999448       0.9993 0.9996
              Pop_Dens    -0.000552     0.000076     -0.000012     0.0001         1.000502       0.9999 1.0011
              Dist_Road    0.000502     0.000312     1.609038     0.1077         0.999988       1.0000 1.0000
              Dist_CityCen -0.000012     0.000017     -0.675343     0.4995         1.040374       1.0201 1.0610
              Slope      0.039580     0.010018     3.951109     0.0001         0.999891       0.9998 1.0000
              Dist_LRTSta -0.000109     0.000044     -2.492553     0.0127         1.000167       1.0001 1.0003
              Dist_Shopping 0.000167     0.000051     3.271792     0.0011
  
```

Data Training Accuracy (Base Category: 1)

| Observed | Predicted | | | | | | Total |
|----------|-----------|-----|-----|-----|-----|-----|-------|
| | 1 | 2 | 3 | 4 | 5 | 6 | |
| 1 | 5431 | N/A | N/A | N/A | 54 | N/A | 5485 |
| 2 | N/A | N/A | N/A | N/A | N/A | N/A | 0 |



Evaluation of regression model

The screenshot displays the ArcMap interface with a land use map of Calgary. The map shows various land use categories: Residential and Commercial (yellow), Industrial (red), Transportation (orange), Parks (green), Vacant Area (light green), and Water Bodies (blue). The map is overlaid with a grid. The 'Layers' panel on the left shows the following layers: Eva_1985-2001, LU2001, LU1985, LU1990, LU1992, LU1999, LU2000, BLU1985, BLU1990, BLU1992, BLU1999, BLU2000, BLU2001, Pop_Dens85, Pop_Dens90, Pop_Dens92, Pop_Dens99, Pop_Dens00, Pop_Dens01, and Slope.

The 'Change Analyst' window is open, showing 'Binary Change' and 'Multiple Change' options. The 'Multinomial Change Modeling' window is also open, showing 'Perform Regression' and 'Evaluation (opt.)' buttons. The 'Regression Statistics' window shows 'LandUse_MLR1985-2001.txt' and 'LandUse_ModEval1985-2001.txt'.

The 'LandUse_ModEval1985-2001 - Notepad' window displays the following text:

```

*****
* Regression Model Evaluation
* 1985 to 2001
*****

Base Category : 1
Case Changing from :1 to 5

Observed      Predicted
1      196546      2      N/A      3      N/A      4      N/A      5      1682      6      N/A
2      N/A      N/A      N/A      N/A      N/A      N/A
3      N/A      N/A      N/A      N/A      N/A      N/A
4      N/A      N/A      N/A      N/A      N/A      N/A
5      12837      N/A      N/A      N/A      N/A      1706      N/A
6      N/A      N/A      N/A      N/A      N/A      N/A      N/A
Total      209383      N/A      N/A      N/A      3388      N/A

Correct Prediction : 198252
Wrong Prediction : 14519
Percentage of Correct Prediction (PCP) : 93.18%

Base Category : 5
Case Changing from :5 to 1

Observed      Predicted
1      41680      2      766      3      N/A      4      N/A      5      76904      6      N/A
2      75      3144      N/A      N/A      10945      N/A
3      N/A      N/A      N/A      N/A      N/A      N/A
4      N/A      N/A      N/A      N/A      N/A      N/A

```



Prediction of a future theme

The screenshot shows the ArcMap interface with the following components:

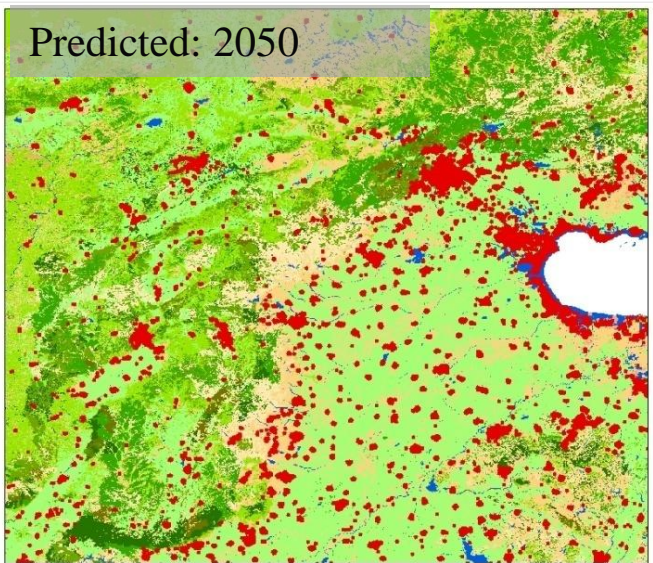
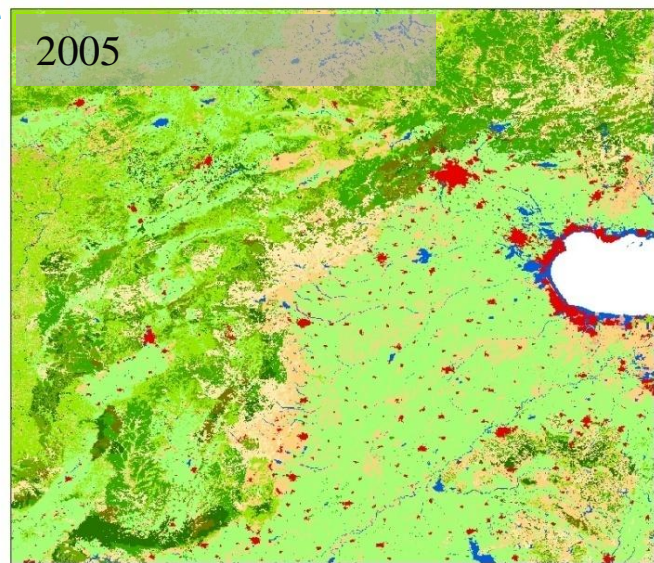
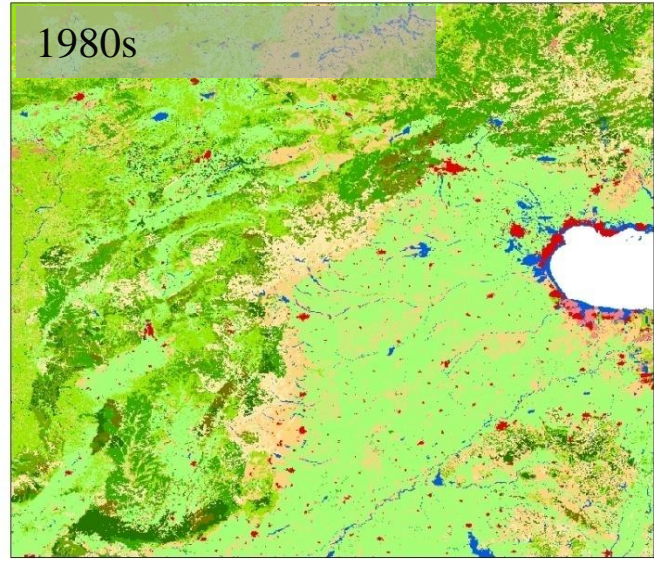
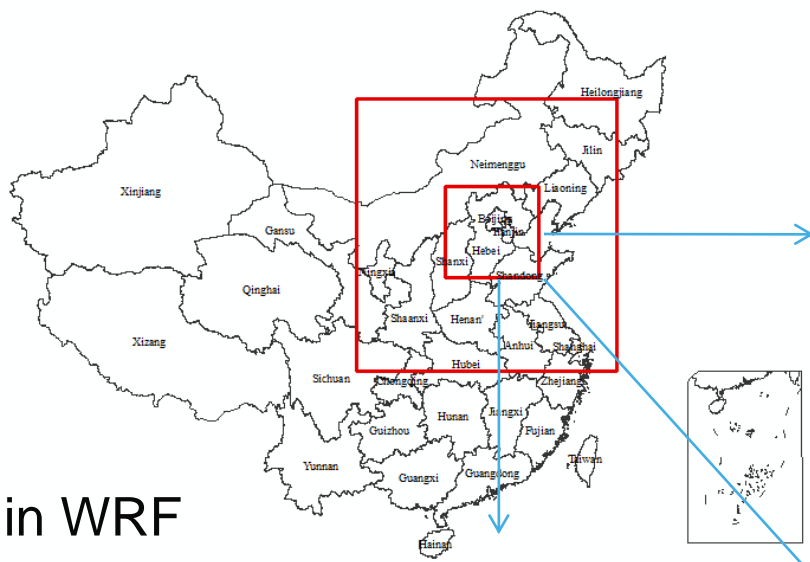
- Layers Panel:** Lists various land use layers including 'Eva_1985-2001', 'LU2001', and 'LU1985' through 'LU2000'. It also includes population density layers ('Pop_Dens85' to 'Pop_Dens01') and 'Slope'.
- Change Analyst Dialog:** Shows 'Binary Change' and 'Multiple Change' options.
- Multinomial Change Modeling Dialog:**
 - Prediction Setting:** Predicted Time: 2009, Change Rate: Low, Scale Factor: 1.0, Maximum Percentage Increased To [0-1]: 1.0.
 - Output Theme Statistics:**
 - theme of 2001:
 - Number of cells of category 1 : 318546 (36.13%)
 - Number of cells of category 2 : 56133 (6.37%)
 - Number of cells of category 3 : 52319 (5.93%)
 - Number of cells of category 4 : 16274 (1.85%)
 - Number of cells of category 5 : 424977 (48.21%)
 - Number of cells of category 6 : 13317 (1.51%)
 - theme of 2009 (ideal):
 - Number of cells of category 1 : 371353 (42.12%)
 - Number of cells of category 2 : 63228 (7.17%)



Land Use Change Impact Analysis

Wang, J., Huang, B., Zhang, X. Z., Fu, D. J. and Atkinson, P. M., 2016. Response of urban heat island to future urban expansion over the Beijing-Tianjin-Hebei metropolitan area. Accepted for publication in *Applied Geography*.





Nested design in WRF

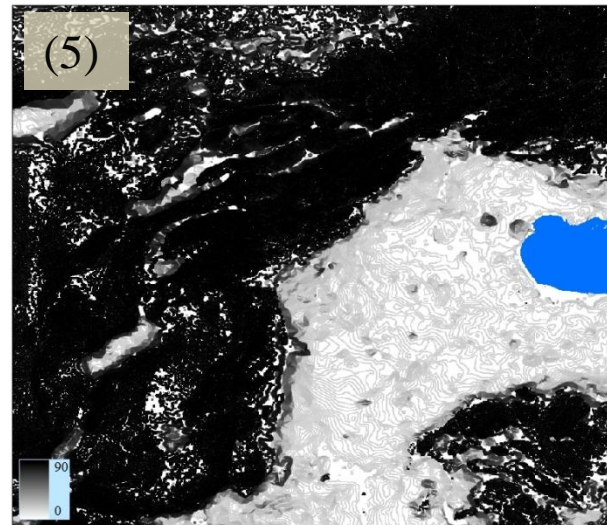
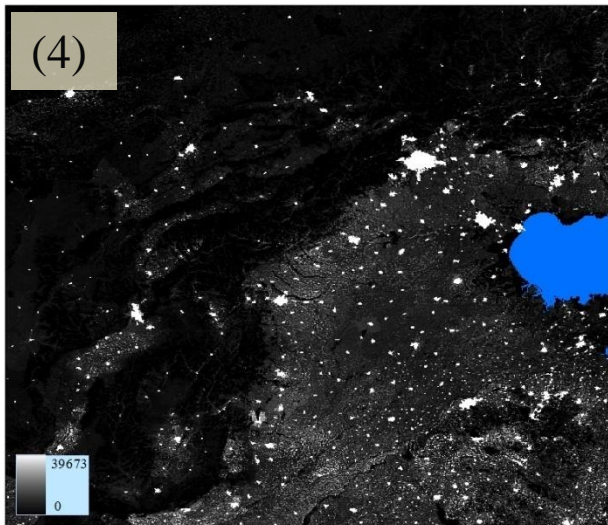
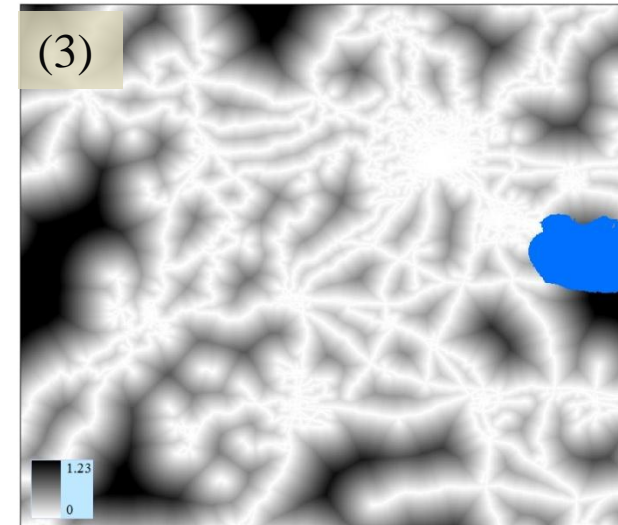
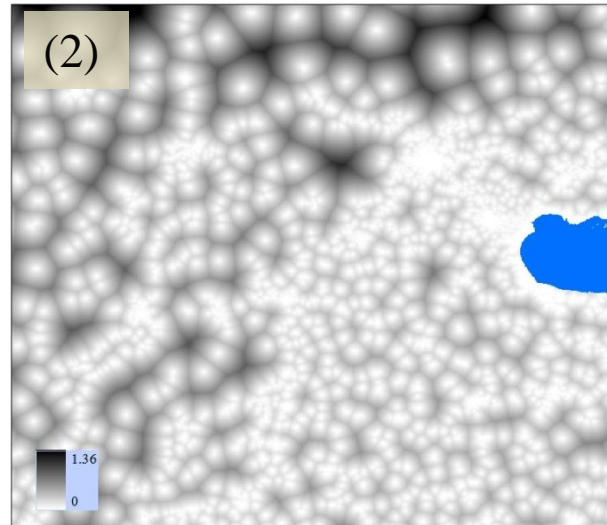
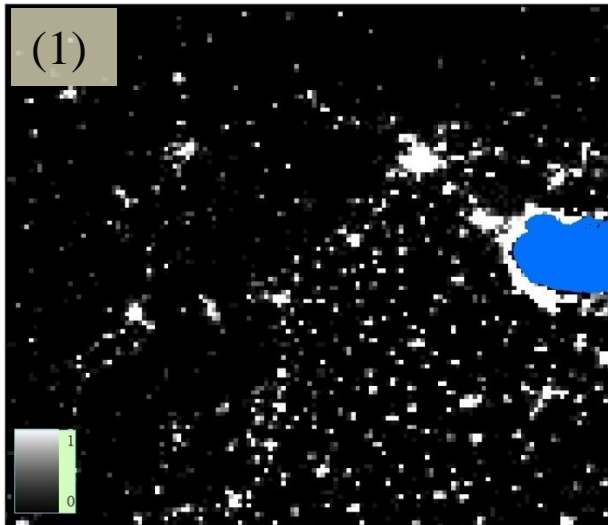
LULC Source:

1980s/2005: IGSNRR, CAS

2050: Change Analyst Model (Huang, 2009)

- | | | |
|--------------------------------|-----------------------------|------------------------------|
| Urban and Built-up Land | Shrubland | Mixed Forest |
| Dryland Cropland and Pasture | Savanna | Water Bodies |
| Irrigated Cropland and Pasture | Deciduous Broadleaf Forest | Herbaceous Wetland |
| Cropland/Grassland Mosaic | Deciduous Needleleaf Forest | Barren or Sparsely Vegetated |
| Cropland/Woodland Mosaic | Evergreen Broadleaf | Wooded Tundra |
| Grassland | Evergreen Needleleaf | Mixed Tundra |

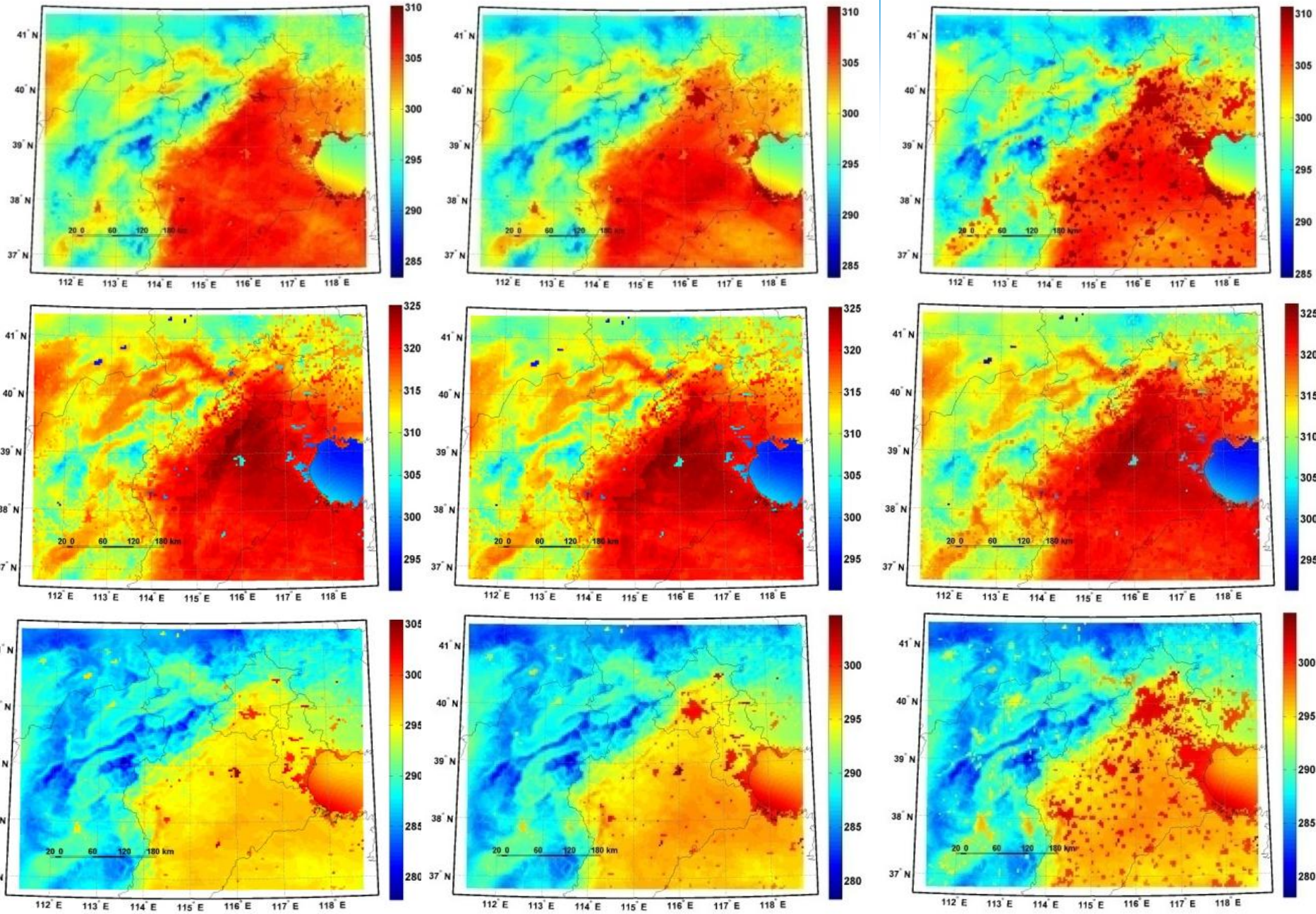




Factors for predicting LULC in 2050 using Change AnalysisTools (Huang, 2009)

- (1): Percentage of urban area
- (2): Euclidian distance to urban
- (3): Euclidian distance to road
- (4): Population (person/km²)
- (5): Slope





LST for non-rainy days, July in 1980s (left), 2005 (middle), 2050 (right). 1) Above: daily mean temperature; 2) Middle: daily maximum temperature; 3) below: daily minimum temperature

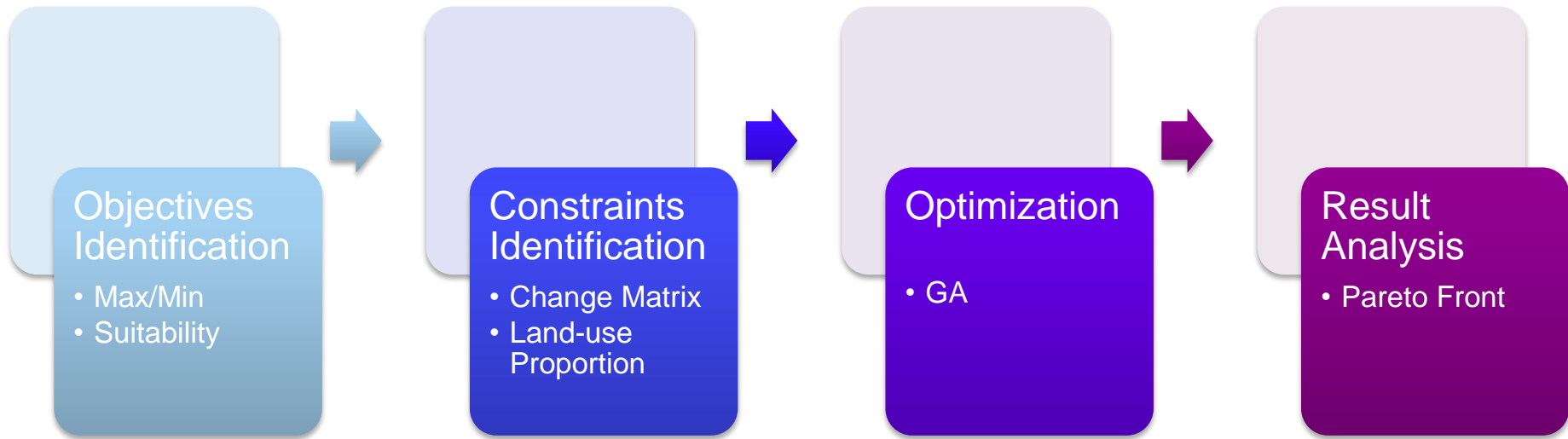
Multiobjective Spatial Optimization for Sustainable Land Use Planning

Funded by:

Hong Kong Research Grants Council
Shenzhen Municipal Government
Nansha New District Government



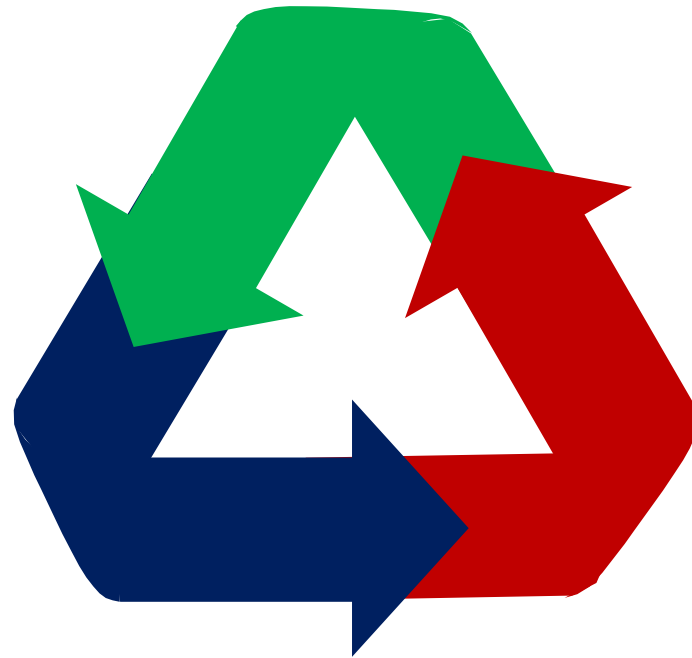
Multiobjective Optimization-based Planning Process



Sustainable development



Social equity



Sustainability



Ecology & Environment



Objectives

- ❑ Economic Gain
- ❑ Social Equity
- ❑ Environmental Impact

General Objectives

- ❑ GDP
- ❑ Energy Consumption
- ❑ Urban Pattern (Compactness)
- ❑ Compatibility
- ❑ Ecological Protection
- ❑ Resilience
- ❑ Environmental Impact
- ❑ Accessibility
- ❑ Conversion Cost/Defensible Development/Infill development
- ❑ More and better located public area
- ❑ ...

Specific Objectives



Genetic Algorithm (GA) representation

1st gene

| | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|-----|-----|---|---|---|
| 1 | 1 | 0 | 5 | 5 | 6 | 3 | 3 | 6 | 8 | 8 | 8 | 8 | 2 | 2 | ... | ... | 5 | 4 | 4 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|-----|-----|---|---|---|

| | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|-----|-----|---|---|---|
| 1 | 1 | 0 | 5 | 5 | 6 | 3 | 3 | 6 | 8 | 8 | 8 | 8 | 2 | 2 | ... | ... | 5 | 4 | 4 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|-----|-----|---|---|---|

.....

| | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|-----|-----|---|---|---|
| 0 | 0 | 0 | 8 | 8 | 8 | 6 | 2 | 2 | 8 | 8 | 8 | 8 | 2 | 2 | ... | ... | 3 | 0 | 0 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|-----|-----|---|---|---|

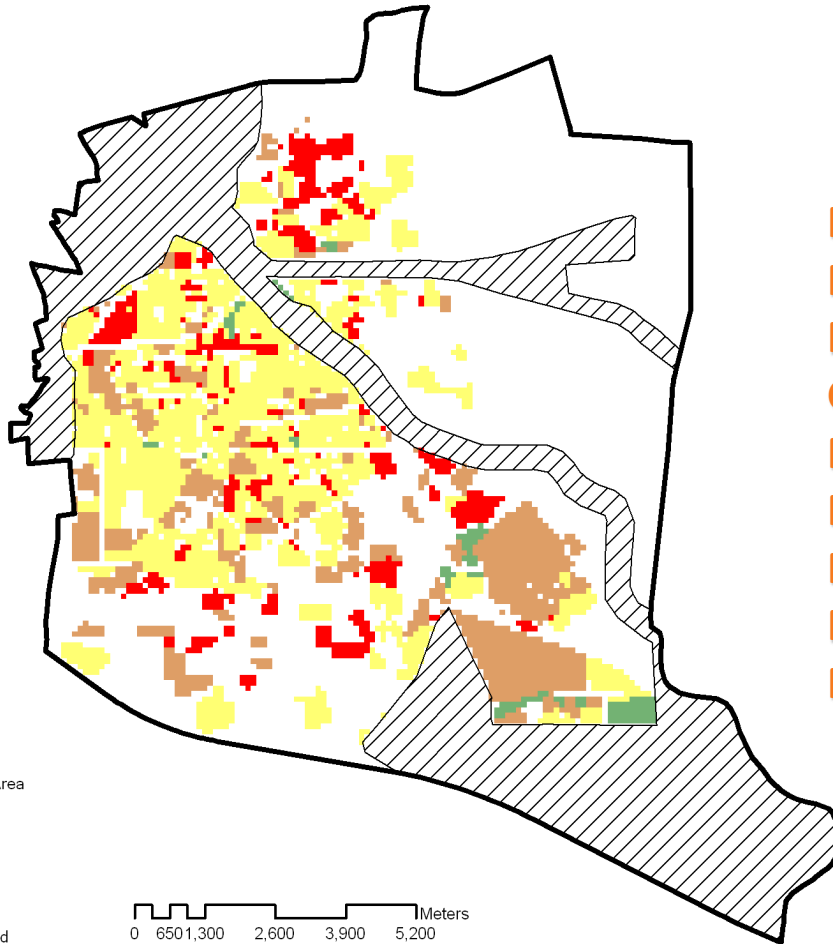
Last gene

Representation of a chromosome



Planning for Tongzhou Newtown

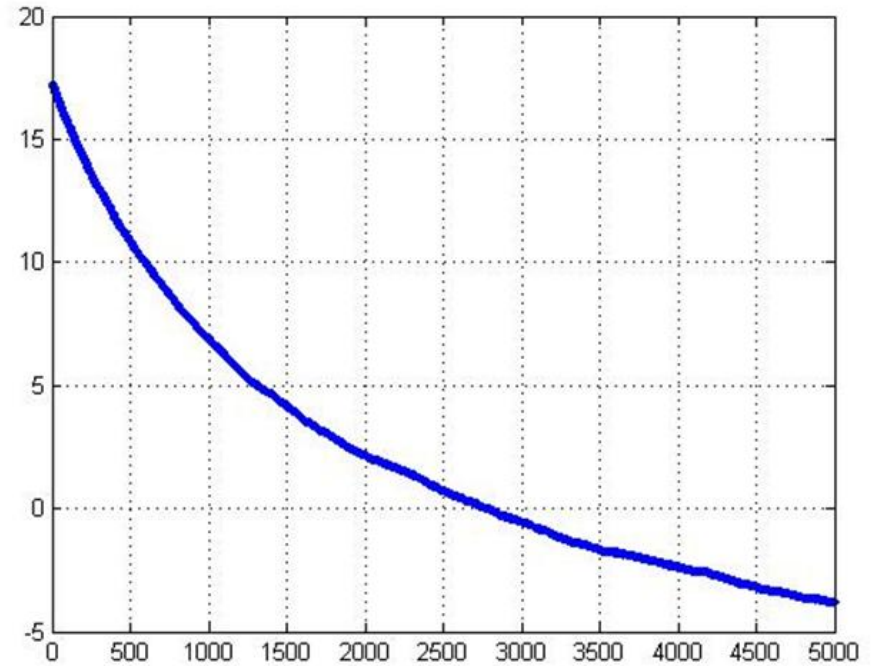
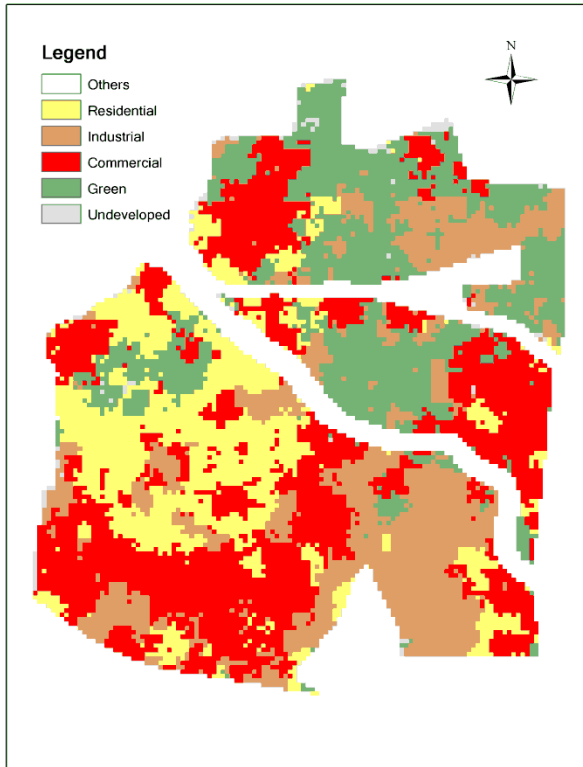
141*119 cells




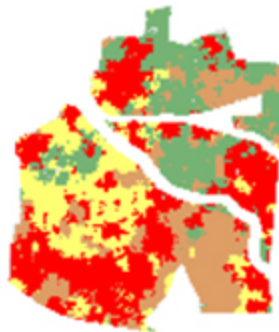
- Maximization of GDP (*obj-1*)
- Minimization of Conversion (*obj-2*)
- Maximization of Geomorphology and Geological Suitability (*obj-3*)
- Maximization of Ecological Suitability (*obj-4*)
- Maximization of Accessibility (*obj-5*)
- Minimization of NIMBY Influence (*obj-6*)
- Maximization of Compactness (*obj-7*)
- Maximization of Compatibility (*obj-8*)



Planned Land Use



Comparison of Optimal and Planned Scenarios

| | | Planned Scenario | Optimal Scenario | |
|------------|-------|--|---|---------|
| Figures | |  |  | |
| Objectives | Obj-1 | 815497 | 2011753 | 146.69% |
| | Obj-2 | 1425 | 2741 | 92.35% |
| | Obj-3 | 47762 | 57529 | 20.45% |
| | Obj-4 | 7352 | 13791 | 87.58% |
| | Obj-5 | 509218 | 718059 | 41.01% |
| | Obj-6 | 563381 | 547028 | -2.90% |
| | Obj-7 | 61392 | 68519 | 11.61% |
| | Obj-8 | 37600 | 41208 | 9.60% |



Nansha New District

❖ Location:

Guangzhou, Guangdong
Province, China

❖ Area:

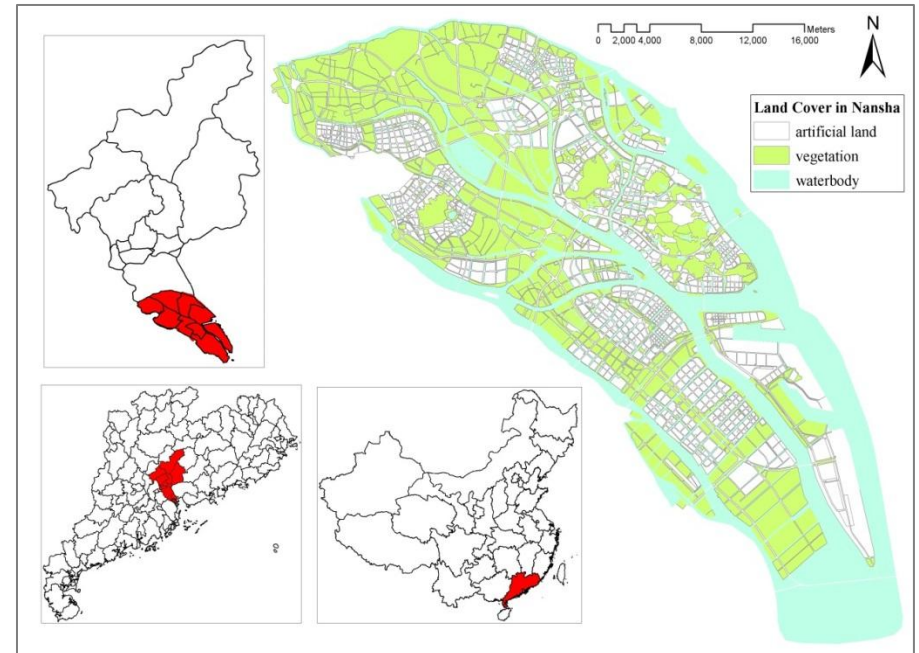
803 km²

❖ Population:

2.40 million

❖ Climate:

Subtropical Monsoon
Climate



Objectives



Land suitability

Resilience to flooding

Air pollution

Plot ratio/Population

Accessibility to Public Services

Accessibility to Greenbelts

Contiguity

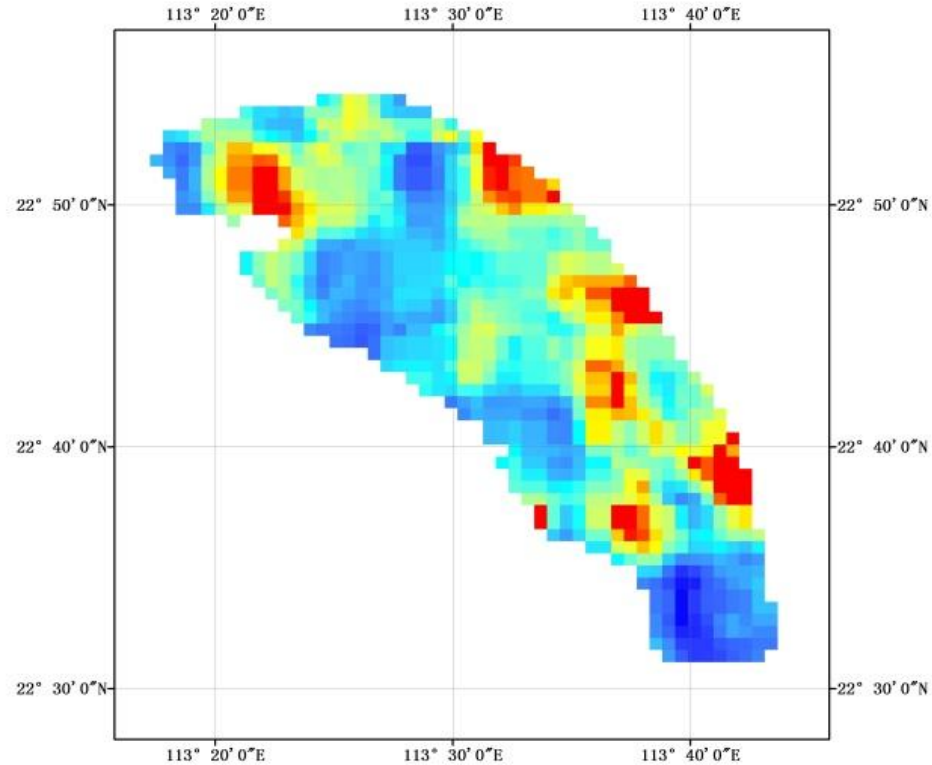
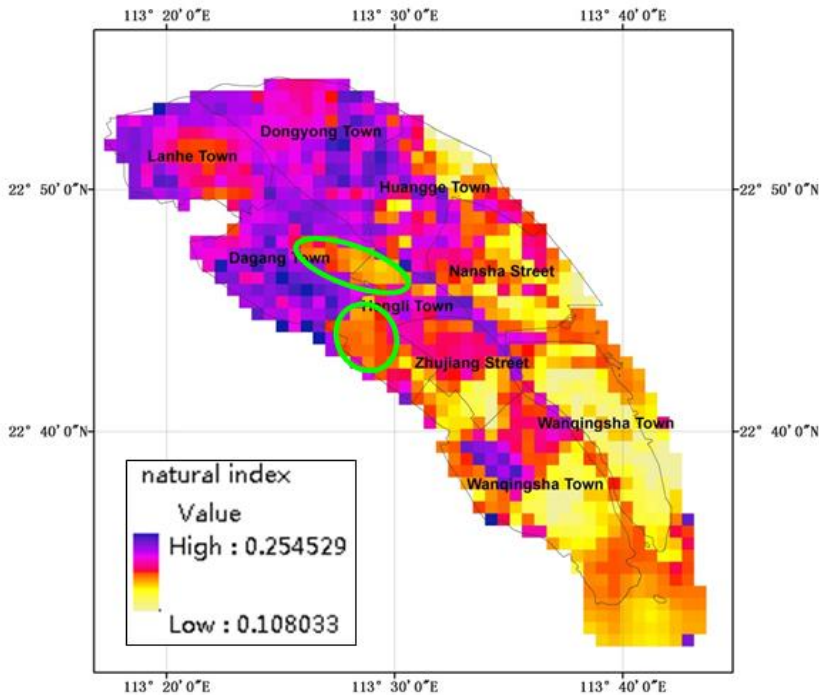
Compactness

...



Evaluation of Resilience

- ❖ Exposure
- ❖ Damage
- ❖ Recovery



Precipitation at 100-year return level



Summary

- ❖ Land use planning provides an effective means to urban resilience to natural disasters.
- ❖ Multiobjective optimization provides an open and effective framework to incorporate the resilience objective.
- ❖ Relationship between objectives and spatial patterns should be established before optimization.



Thank you!

