Suggested citation: Hassan, Q.K. 2018. Lecture note on: Scaling issues in environmental modelling, *In Environmental Modelling*, Calgary, AB, Canada.

Environmental Modelling
(ENGO 583/ENEN 635)

Lecture Note
on:
Scaling Issues in Environmental Modelling

Dept. of Geomatics Engineering; and Centre for Environmental Engineering Research and Education
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Review on Last Topics

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Topics of Discussion

- **What is scale?**
  - **Observation/measurement scale**
  - **Modelling scale**
  - **Operational scale**
  - **Geographic scale**
  - **Policy scale**
  - **Cartographic scale**
  - **Remarks**
- **Scaling**
  - **Down-scaling example**
  - **Up-scaling example**
- **Causes of scale effects**
- **Scaling sensitivity**
- **Example of scale sensitivity**

What is Scale?

- **Scale is an attribute that refers to the magnitude of the event of interest. It is often associated with issues related to spatial and/or temporal dimensions.**
- **In the field of scientific research, scale can broadly be categorized into the following six groups (Wu and Li, 2009):**
  - **Observation/measurement scale**
  - **Modelling scale**
  - **Operational scale**
  - **Geographic scale**
  - **Policy scale**
  - **Cartographic scale**
- **In the field of remote sensing and its application to environmental modelling, the terms 'scale' and 'resolution' are often used interchangeably. For example:**
  - **Spatial resolution/scale**
  - **Temporal resolution/scale**

Observation Scale

- **It is also known as measurement scale. It can be defined as the scale employed to collect measurements or observations in relation to an event of interest.**
- **Such observation/measurement scale corresponds to the *spatial and/or temporal extent* of a dataset. The spatial dimension is critical to geospatial modelling.**
- **It is very important that the observation scale should match the operational scale for a better comprehension of the issue of interest.**

Modelling Scale (1)

- **It is also known as working scale. At this scale, an environmental model is constructed.**
- **The modeling scale should agree with both the observation/measurement and operational scale.**
- **In case of hydrological models:**
  - **The spatial resolution can be at local/plot scale, the catchment scale, and the regional scale.**
  - **On the contrary, the temporal resolution can be daily, weekly, bi-monthly, monthly, annually, and so on.**

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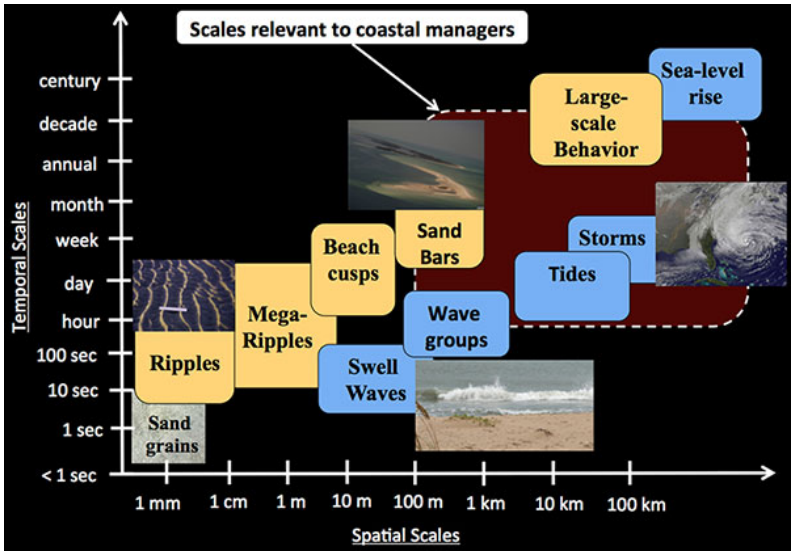
Modelling Scale (2)

- The modelling scale primarily relies on both spatial and temporal resolution of an environmental process.
- For example, coastal planners and managers are mainly interested in the range of scales indicated by the dashed box.



Credit: U.S. Geological Survey; https://marine.usgs.gov/coastalchangehazards/research/data-integration.html

Operational Scale

- It is also known as process scale. It can be defined as the scale at which a particular process is supposed to take place.
- This scale is connected with the ***spatial and temporal resolution*** depending on the nature of the process. For example:
  - Agricultural crop growth within a 1-3 day interval from sowing to maturity-level for a particular crop of interest;
  - Hurricane between a 15-30 minute interval, in order to find the direction and magnitude of its movement.
- Thus, an environmental phenomenon is best observed/measured at its operational scale.

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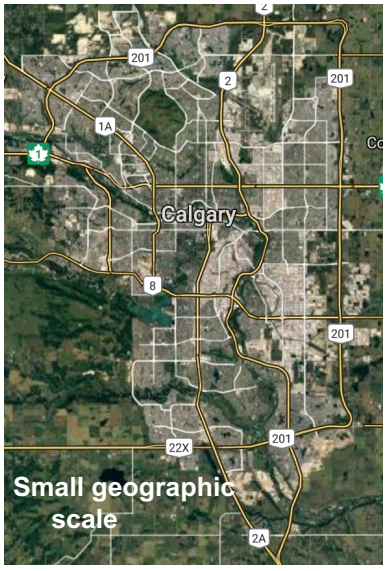
Geographic Scale (1)

- **Geographic scale is the related to the physical size or spatial extent of the study area.**
- **A large geographic scale deals with a larger area,**
  - **i.e., the Province of Alberta**
- **A small geographic scale covers a smaller area.**
  - **i.e., Calgary Region**

Geographic Scale (2)



Imagery ©2017 TerraMetrics, Map data ©2017 Google

Policy Scale

- **Policy scale is often associated with the jurisdiction at which a decision is taken for implementation.**
- **Such policy scale can be formulated and implemented at various level depending on the nature of the issue. For example:**
  - **Climate change policy: global level**
  - **Immigration and citizenship: country level**
  - **Education and health care: provincial/state level in Canada and US**
  - **Land use zonation policy: municipality level**

Cartographic Scale

- **It represents the ratio between the distance on a map and to the corresponding distance on the ground or reality.**
- **A large scale map refers to a smaller area that provides detailed information over an area of interest:**
  - **i.e., scale 1: 10 000 (this is a commonly used scale to generate base maps across the world)**
- **On the contrary, a small scale map refers to a larger area that provides coarser information about the area of interest:**
  - **i.e., scale 1: 250 000**

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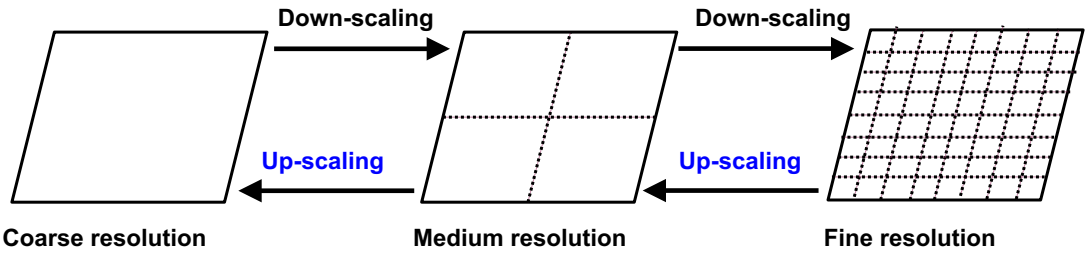
Remarks

- **When implementing an environmental model, a modeller must consider the following four scales:**
  - **Geographic scale of the study area**
  - **Temporal scale related to the time period of the research**
  - **Observation/measurement scale of parameters**
  - **Model scale associated with both spatial and temporal resolution**
- **In ecological modelling, the ecologists often mention 'scale' as grain and extent**
  - **grain relates to the smallest spatial sampling (i.e., spatial resolution)**
  - **extent relates to the total area over (i.e., geographic scale)**

Scaling

- **Scaling is the act of transferring data/information from one scale to another**
- **It focuses on what happens to the characteristics of an object or a system when its scale is changed**
- **Downscaling is the act of transferring data from a coarse resolution to a fine resolution upon exploiting knowledge at coarser scale**
- **Upscaling is the act of transferring data from a fine resolution to a coarse resolution based on extrapolated knowledge at finer scale**



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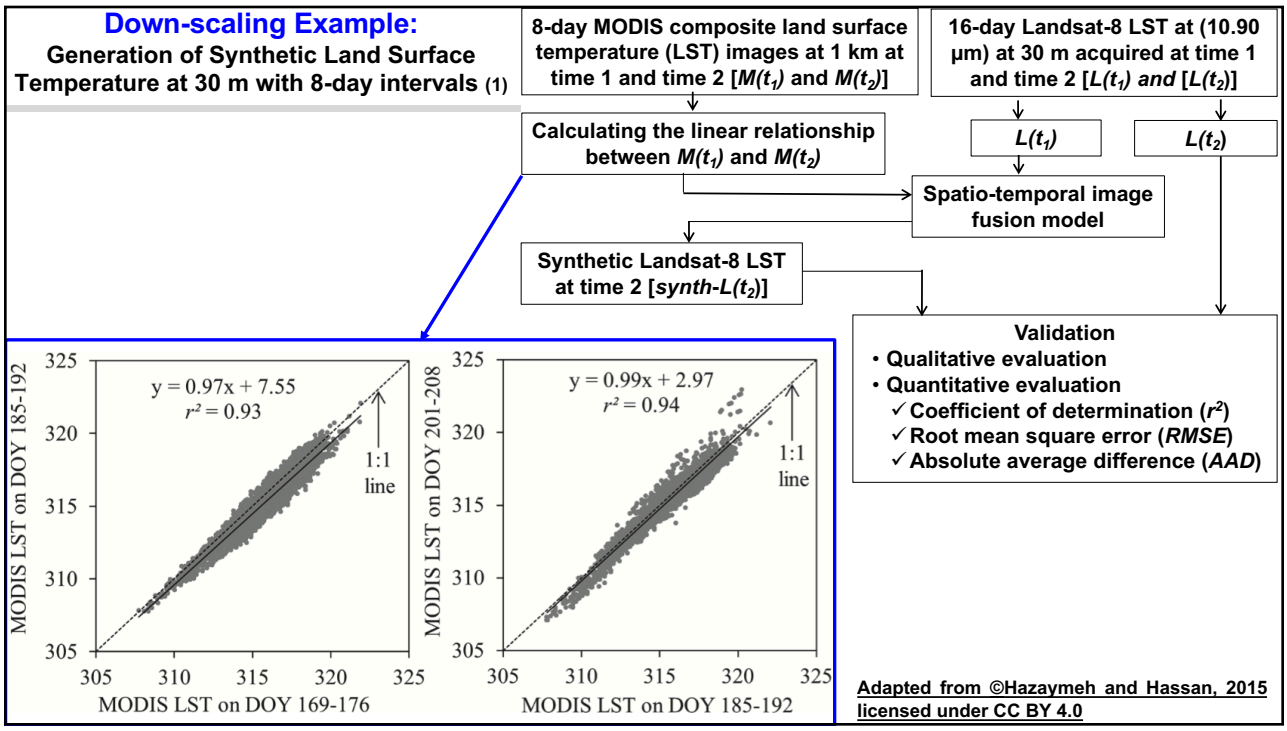

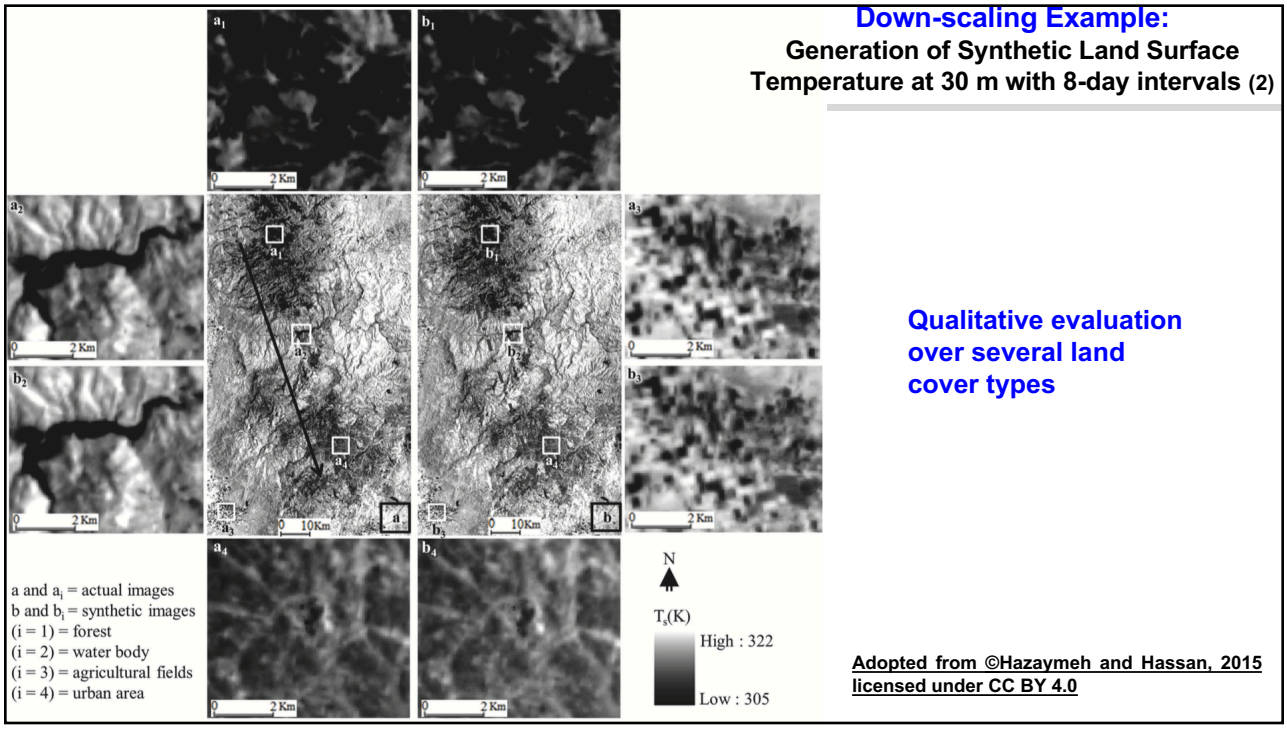

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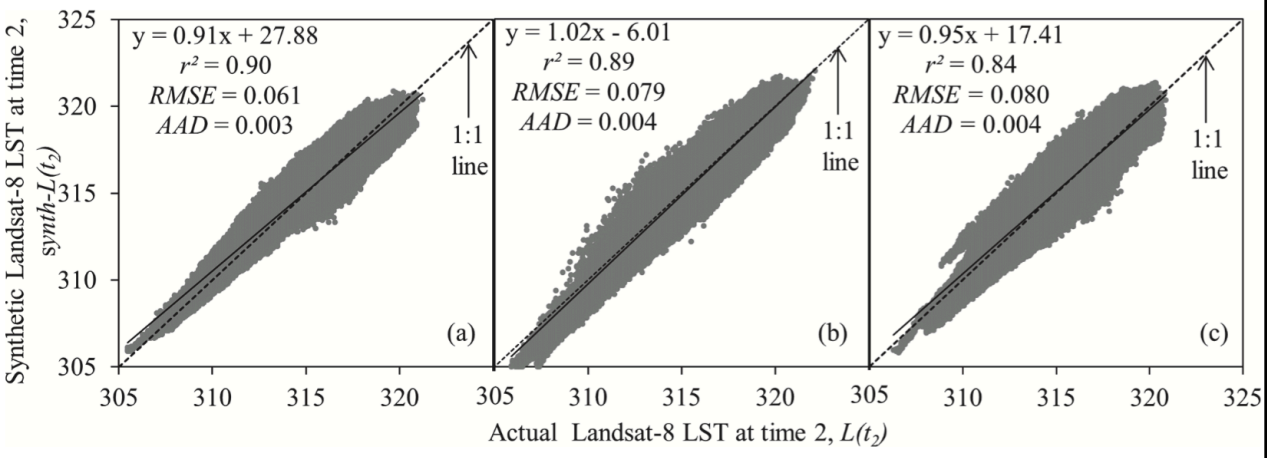
Down-scaling Example:

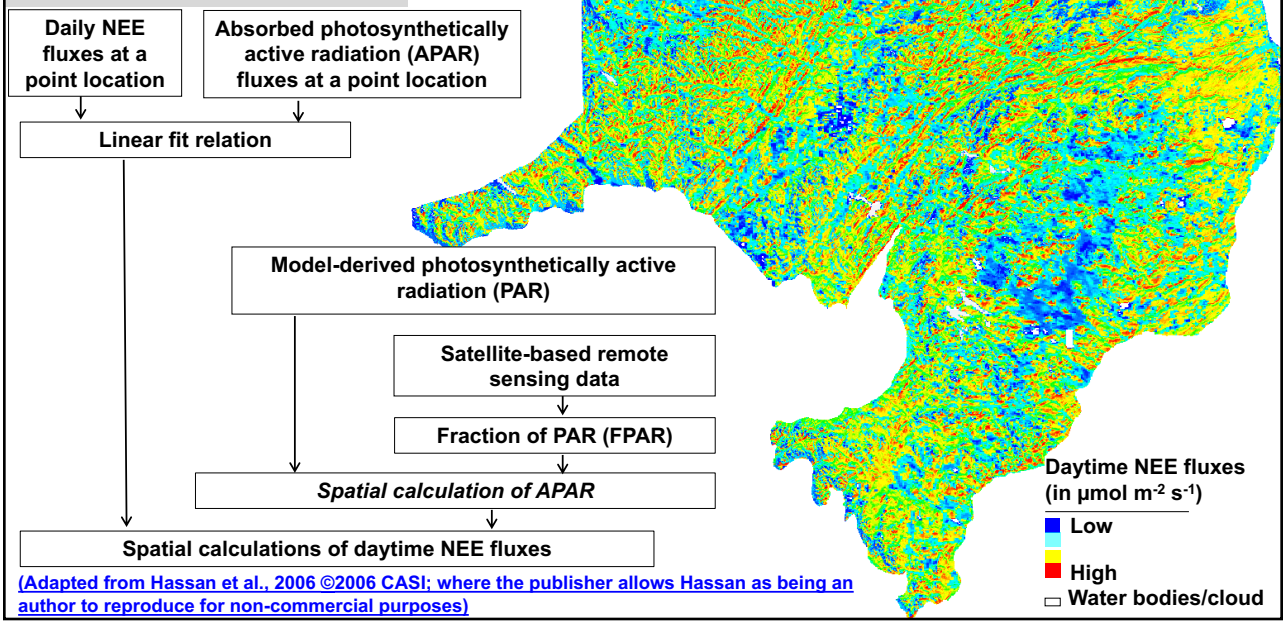
Generation of Synthetic Land Surface Temperature at 30 m with 8-day intervals (3)

Quantitative evaluation



Up-scaling Example:

Up-scaling Tower-based Net Ecosystem CO_2 Exchange (NEE) to Landscape Level



Causes of Scale Effects

Wu and Li (2009) summarized three main reasons behind the scale effect as follows:

i. **Limitation of measurement relates to the fact that equipment can only acquire information at a particular scale. For example: a hand-held spectroradiometer provides reflection regimes from a small area, on the other hand the satellite-based ones provide the same over a relatively large area.**

ii. **Applicability of a given relationship across the various spectra, e.g., a model at the scale of one tree may not be applicable to the stand-scale. Thus, we may have to revisit the model when applying to any other scale apart from the originally proposed one.**

iii. **Existence of both spatial heterogeneity and relevant process nonlinearities, e.g., temperature varies in both spatial and temporal dimensions. In general, temperature is primarily defined by the incident solar radiation; however, land cover types also influence its magnitude.**

Scaling Sensitivity

- **In general, the magnitude of a given parameter in an heterogeneous environment is usually dependent on the measurement scale**
  - **These parameters are called to be scale dependent, such as the measurement of soil water content**
- **If the parameter values do not change significantly across a range of scales, this parameter is said to be scale invariant, e.g.,**
  - **reflection from fresh snow measured at any scale**

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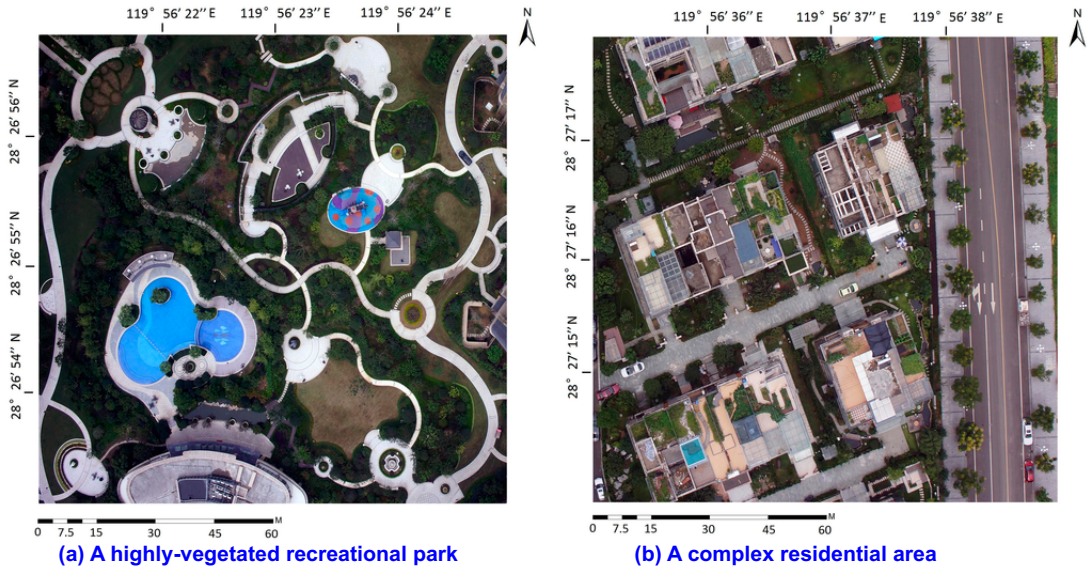
Example of Scale Sensitivity (1)

- **Feng et al. (2015) used unmanned aerial vehicle (UAV)-based remote sensing images to evaluate the effect of up-scaling on the overall accuracy of the classification.**
- **The original spatial resolution of these images was 7 cm. Then Feng et al. (2015) employed nine different moving windows to analyze how classification accuracy changes. These texture window size included:**
  - **3 × 3, 5 × 5, 7 × 7, 9 × 9, 11 × 11, 15 × 15, 21 × 21, 31 × 31, and 51 × 51.**
- **The targeted classes were: grass, trees, shrubs, bare soil, water, and impervious surface.**

Example of Scale Sensitivity (2)



(a) A highly-vegetated recreational park

(b) A complex residential area

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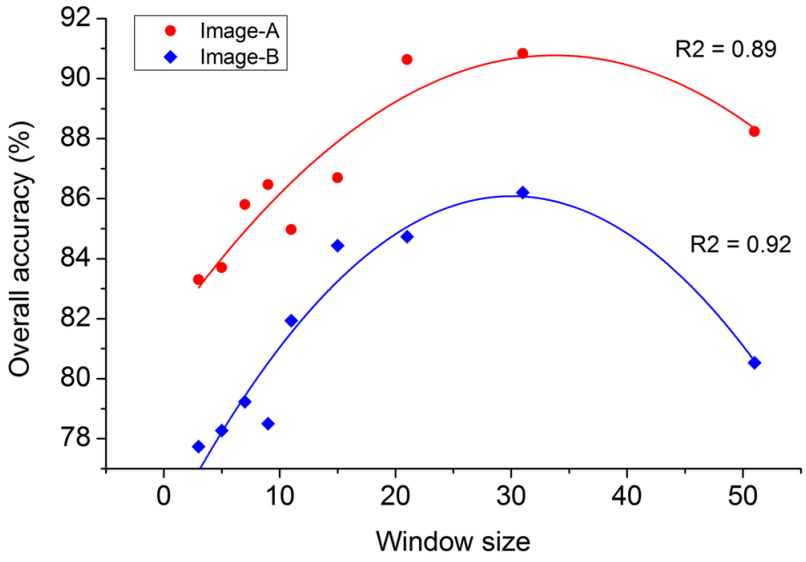
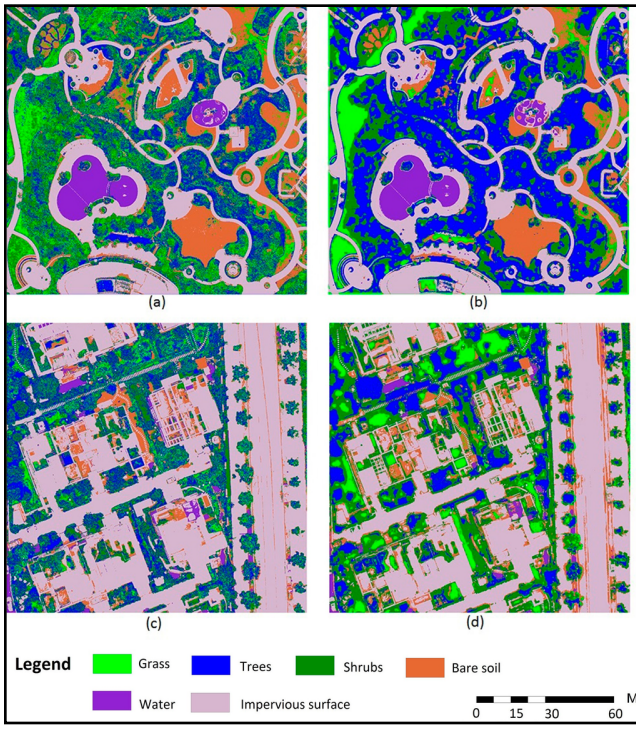
Example of Scale Sensitivity (3)

- **With the enlargement of texture window size, the accuracy increases until the optimal texture scale (i.e., 31 x 31 for both of the images) is reached.**
- **As the UAV image has a ground resolution of 7 cm, the actual size of the optimal scale is 2.17 m.**
- **However, from a universality perspective, it might be difficult to determine the optimal scale through a formula. It may also take some time to do a series of experiments, which is a drawback of the proposed method.**



Example of Scale Sensitivity (4)



- **Classification results for RGB-only and RGB+Texture with 31 x 31 window. (a) Image-A RGB-only; (b) Image-A RGB+Texture with 31 x 31 window 1; (c) Image-B RGB-only; (d) Image-B RGB+Texture with 31 x 31 window.**
- **When classifying RGB-only images, both Image-A and Image-B show some "salt and pepper" effects. A large amount of trees were misclassified into grass and shrubs severely.**
- **The inclusion of texture improves the classification accuracy from a visual point of view.**

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References

- **Feng, Q., Liu, J., Gong, J. (2015) UAV Remote Sensing for Urban Vegetation Mapping Using Random Forest and Texture Analysis. *Remote Sensing*, 7, 1074-1094.**
- **Hassan, Q.K., Bourque, C.P.-A., Meng, F.-R. (2006) Estimation of daytime net ecosystem CO2 exchange over balsam fir forests in eastern Canada: combining averaged tower-based flux measurements with remotely sensed MODIS data. *Canadian Journal of Remote Sensing*, 32, 405-416.**
- **Hazaymeh, K., Hassan, Q.K. (2015) Fusion of MODIS and Landsat-8 surface temperature images: A new approach. *PLoS One*, 10, e0117755.**
- **Wu, H., Li, Z.-L. (2009) Scale Issues in Remote Sensing: A Review on Analysis, Processing and Modeling. *Sensors*, 9, 1768-1793.**

Sample Review Questions

- **Define scale. What are the commonly used meanings of scale in environmental modelling? Provide examples.**
- **Define scaling. Describe the basis of both up-scaling and down-scaling in environmental modelling. Provide example for each of the cases.**
- **What are the causes of scale effects?**
- **What is the difference between scale dependent and scale invariant?**
- **What is scale sensitivity? Consider an environmental model is given. Determine the type of scaling and comment on the results of performing certain scaling.**