Suggested citation: Rahaman, K.R., and Hassan, Q.K. 2018. Lecture note on: Local warming modelling, *In Environmental Modelling*, Calgary, AB, Canada.

Environmental Modelling
(ENGO 583/ENEN 635)

Lecture Note
on:
Modelling of Local Warming Trends

Dept. of Geomatics Engineering; and Centre for Environmental Engineering Research and Education
Schulich School of Engineering
University of Calgary

Review of Last Topics

Suggested citation: Rahaman, K.R., and Hassan, Q.K. 2018. Lecture note on: Local warming modelling, *In Environmental Modelling*, Calgary, AB, Canada.

Topics of Discussion:
Local Warming Modelling

- Current status of local warming research
- Warming trends since industrialization

- Warming trends in Canadian context
- Implications of studying local warming

- A case study on:

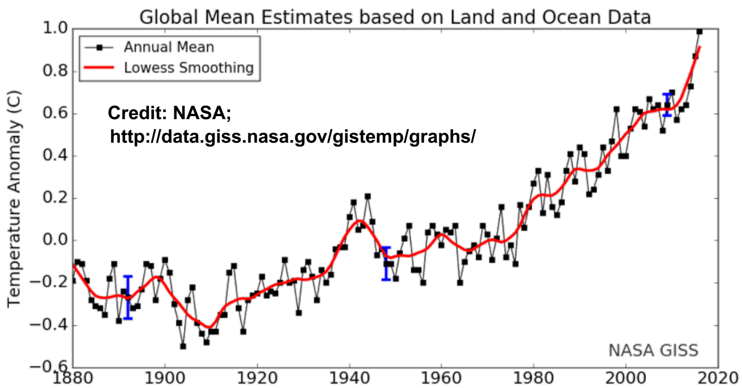
"Quantification of local warming trend: A remote sensing-based approach"

Current Status of Local Warming Research

- Both the global and regional warming trends are relatively well characterized in comparison to the local warming trends. Some example cases include:
  - Fritzsche (2013) analysed warming trends at 11 climatic regions in Canada using 330 station-specific temperature data over the period of 1948-2009.
  - Menne et al. (2010) studied warming trends over the conterminous United States over the period of 1980-2008.
  - Vanderbei (2012) conducted a local warming study by using temperature readings from a single undisturbed location at McGuire Air Force Base, New York over the period of 1955-2010.
  - Mahlstein et al. (2012) found the local warming did not follow the global trend in some specific locations due to having temperature anomalies at local level.

Warming Trends Since Industrialization

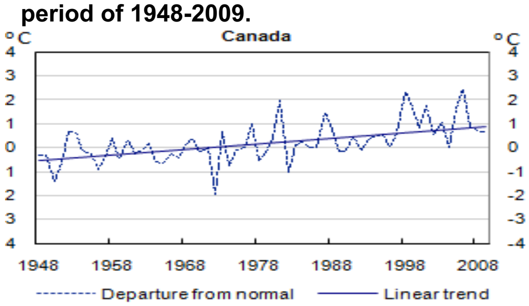
- **Climatic regimes are one of the most critical factors in defining the habitat for all living organisms including human beings. One of the major components of the recent climate change is manifested in the warming (i.e., increment in temperature) trends at global to regional to local-levels.**



The average global temperature was risen in the past 150 years. The anomalies were calculated against the average global temperature for 1961-90 period steadily increasing since 1980

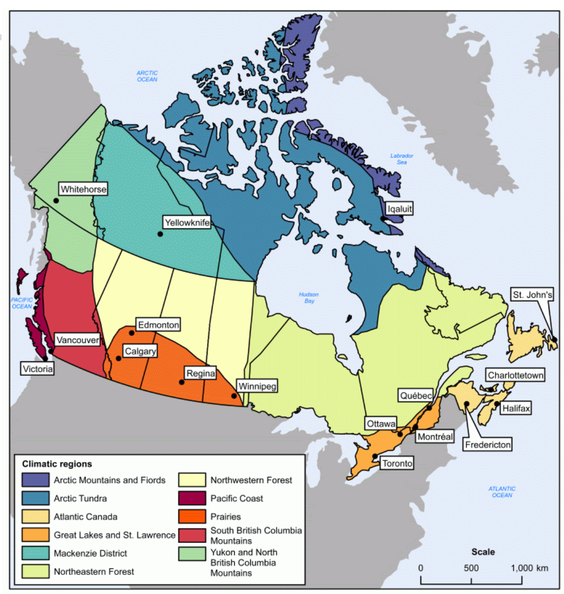
Warming Trends in Canadian Context (1)

Fritzsche (2013) analysed warming trends at 11 climatic regions in Canada using 330 station-specific temperature data over the period of 1948-2009.



Source(s): Environment Canada, 2010, *Climate Trends and Variations Bulletin (CTVB)*.
[Retrieved from http://www.statcan.gc.ca/pub/16-002-x/2011001/ct016-eng.htm on 21 February 2018]

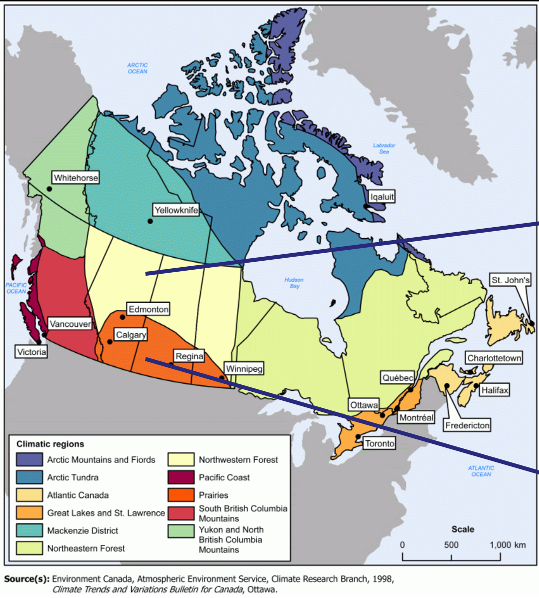
Annual mean temperature departures between 1948-2009 moved above the 1961-1990 normal beginning in 1973. The linear trend indicates an increase in mean temperature of 1.4°C over the 62 years in the record.



Source(s): Environment Canada, Atmospheric Environment Service, Climate Research Branch, 1998, *Climate Trends and Variations Bulletin for Canada*, Ottawa.
[Retrieved from http://www.statcan.gc.ca/pub/16-002-x/2011001/m001-eng.htm on 21 February 2018]

Suggested citation: Rahaman, K.R., and Hassan, Q.K. 2018. Lecture note on: Local warming modelling, *In Environmental Modelling*, Calgary, AB, Canada.

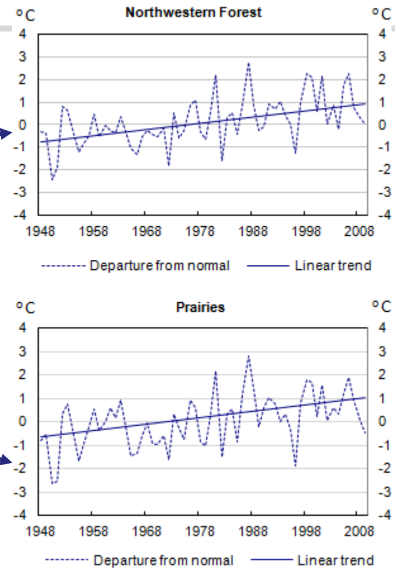
Warming Trends in Canadian Context (2)



Source(s): Environment Canada, Atmospheric Environment Service, Climate Research Branch, 1998, *Climate Trends and Variations Bulletin for Canada*, Ottawa.

[Retrieved from http://www.statcan.gc.ca/pub/16-002-x/2011001/m001-eng.htm on 21 February 208]

Note: Environment Canada that allows non-commercial reproduction. Such reproduction is a copy of an official work that is published by the Government of Canada and that the reproduction has not been produced in affiliation with, or with the endorsement of the Government of Canada.



Source(s): Environment Canada, 2010, *Climate Trends and Variations Bulletin (CTVB)*.
[Retrieved from http://www.statcan.gc.ca/pub/16-002-x/2011001/ct017-eng.htm on 21 February 2018]

Implications of Studying Local Warming (1)

- **Understanding the warming trends at both global and regional levels are critical; however, the development of relevant adaptation and mitigation policies at those levels are quite challenging. Those include:**
  - **the spatial distribution of required weather stations' data are usually uneven; and**
  - **building consensus among stakeholders is often difficult.**
- **On the other hand, policy developments at local level are relatively straightforward, as it requires limited number of weather stations' data and demands small number of stakeholders' involvement.**
- **Thus, it is critical for us to study local warming in order to comprehend the scientific issues, which will play a significant role in developing and implementing both adaptation and mitigation strategies.**

(Adopted from ©Rahaman et al., 2017 licensed under CC BY license)

Implications of Studying Local Warming (2)

- **In general, the local warming trends are calculated by using long-term air temperature regimes measured at point-based weather station sites. If both quality and quantity of these required air temperature data are sufficient, then the calculated trends are very accurate.**

- **There are several issues, such as weather stations are:**
  - **usually installed in the populated areas thus often lack spatial distribution;**
  - **having deficiency in maintaining international standards (i.e., World Meteorological Organization guidelines);**
  - **having high installation and maintenance costs in particular to the remote areas; and**
  - **having lack of continuity in data acquisition and its quality; etc.**

- **One of the alternates is to employ satellite-derived remote sensing-based surface temperature data.**

(Adopted from ©Rahaman et al., 2017 licensed under CC BY license)

Quantification of local warming trend: A remote sensing-based approach

(Adopted from ©Rahaman et al., 2017 licensed under CC BY license)

Major Steps

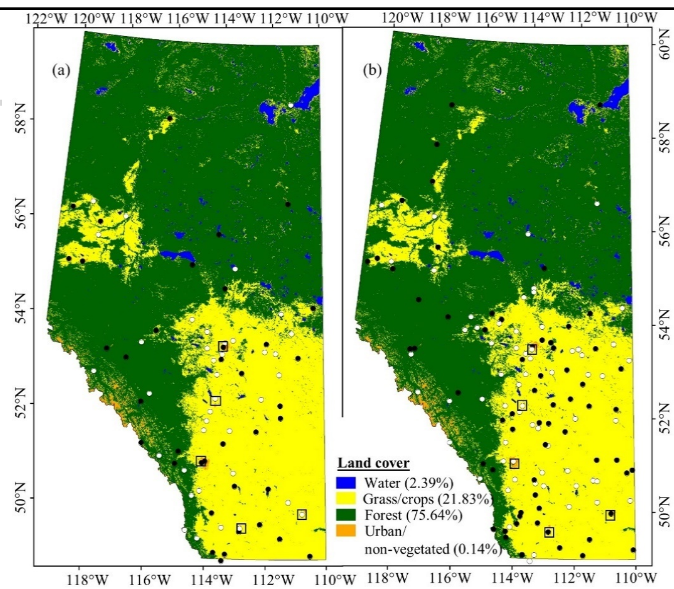
1. **Selection of the MODIS-based surface temperature data available over the 2000-2010 that was harmonized with two different air temperature normal regimes (defined as 30 year averages) over the periods 1961-1990 and 1981-2010 acquired at approximately 100 ground-based weather stations;**

2. **Development of methods for transforming MODIS-based surface temperature data into air temperature normal at 1 km spatial resolution and its validation;**

3. **Comprehension of spatial extent of local changes based on the modelled air temperature normal between 1961-1990 and 1981-2010; and**

4. **Comparison of local warming trends in relation to the regional and global ones.**

Study Area and Data Requirements (1)

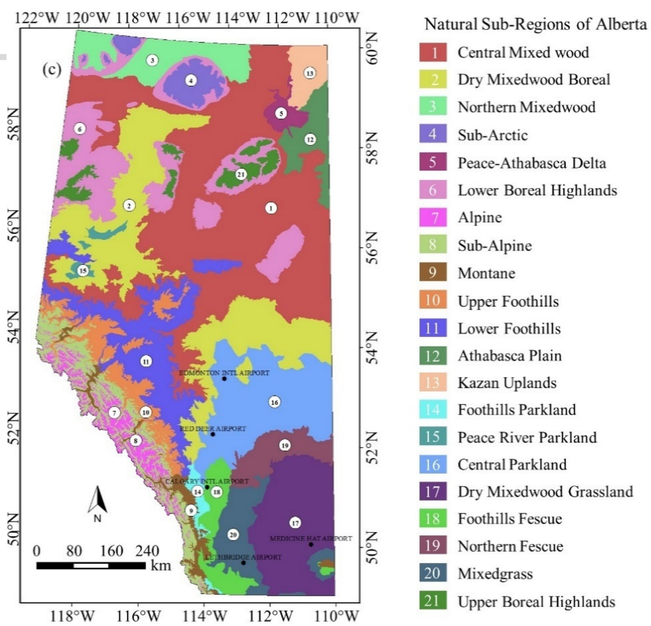


The square boxes indicated major 5 city centers (Calgary, Edmonton, Red Deer, Medicine Hat, and Lethbridge) in Alberta. The background image is a land cover map derived from annual composite of MODIS at 500 m spatial resolution.

Black and white dots are weather stations used for model calibration and validation respectively. The selected stations were based on available ground-based air temperature normal data during 1961-1990 (panel a), and 1981-2010 (panel b).

Suggested citation: Rahaman, K.R., and Hassan, Q.K. 2018. Lecture note on: Local warming modelling, *In Environmental Modelling*, Calgary, AB, Canada.

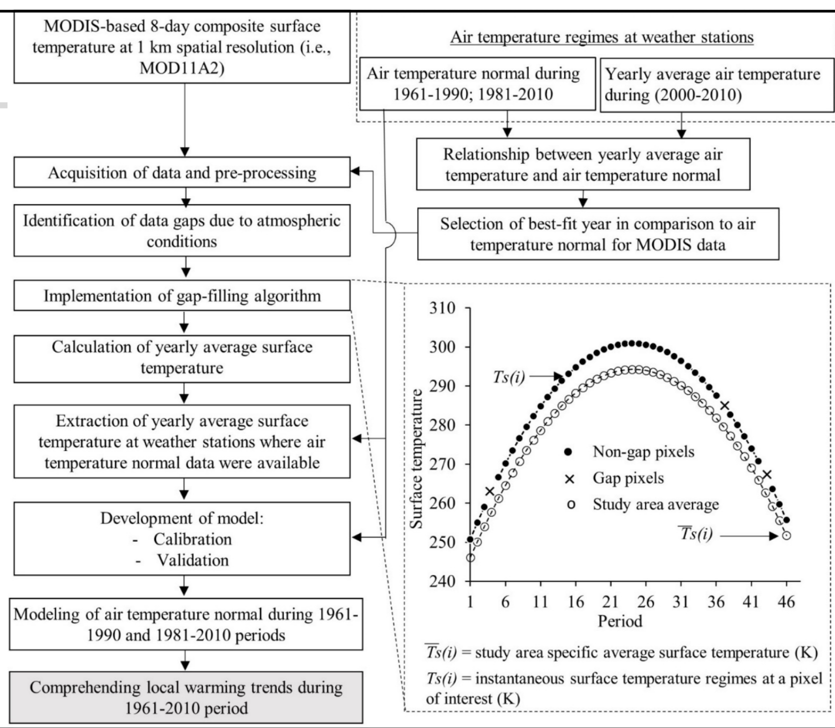
Study Area and Data Requirements (2)



(Adopted from ©Rahaman et al., 2017 licensed under CC BY license)

- **Alberta is divided into 21 natural sub-regions based on climate, soil types, topography, and vegetation types.**
- **Local warming trends are synthesized at these sub-regional levels.**

Schematic Diagram



(Adopted from ©Rahaman et al., 2017 licensed under CC BY license)

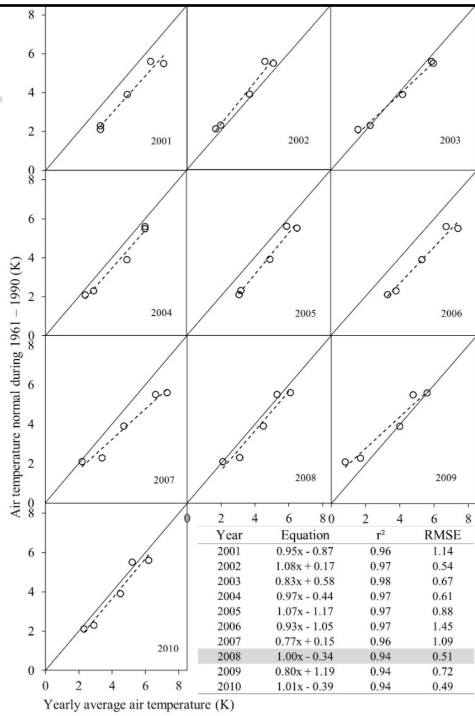
Major Components

1. **Analysing the station-based air temperature data in generating relationships between air temperature normal and yearly average air temperature to aid the selection of year-specific MODIS-based surface temperature data;**
2. **Pre-processing of MODIS data and implementing gap filling algorithm; and**
3. **Modeling of air temperature normal during the periods 1961-1990 and 1981-2010, and generating local warming trends.**

Analysis of Air Temperature Data and Selecting Year-specific MODIS Data (1)

- **Compared the yearly average air temperature for each year over the period 2001-2010 with the air temperature normal during the 1961-1990 and 1981-2010 periods acquired at the 5 major cities.**
- **Accomplished by analysing:**
  - i. **co-efficient of determination (r^2), and**
  - ii. **root mean square error (RMSE).**
- **Upon identifying the best-correlated years in relation to the air temperature normal periods, those year-specific MODIS-based surface temperature images were considered the best representing the air temperature normal over the period of interest.**

Analysis of Air Temperature Data and Selecting Year-specific MODIS Data (2)



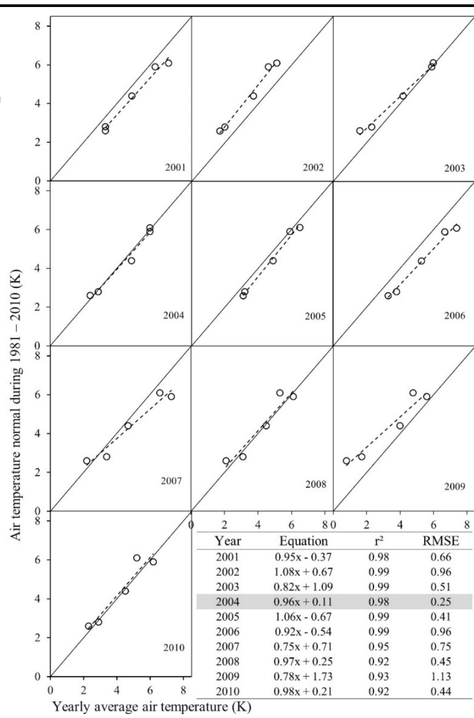
Year	Equation	r^2	RMSE
2001	0.95x - 0.87	0.96	1.14
2002	1.08x + 0.17	0.97	0.54
2003	0.83x + 0.58	0.98	0.67
2004	0.97x - 0.44	0.97	0.61
2005	1.07x - 1.17	0.97	0.88
2006	0.93x - 1.05	0.97	1.45
2007	0.77x + 0.15	0.96	1.09
2008	1.00x - 0.34	0.94	0.51
2009	0.80x + 1.19	0.94	0.72
2010	1.01x - 0.39	0.94	0.49

Relationship between yearly average air temperature and air temperature normal 1961-1990;

- **the solid black line represents 1:1, and**
- **black dotted lines represent regression lines.**

(Adopted from ©Rahaman et al., 2017 licensed under CC BY license)

Analysis of Air Temperature Data and Selecting Year-specific MODIS Data (3)



Year	Equation	r^2	RMSE
2001	0.95x - 0.37	0.98	0.66
2002	1.08x + 0.67	0.99	0.96
2003	0.82x + 1.09	0.99	0.51
2004	0.96x + 0.11	0.98	0.25
2005	1.06x - 0.67	0.99	0.41
2006	0.92x - 0.54	0.99	0.96
2007	0.75x + 0.71	0.95	0.75
2008	0.97x + 0.25	0.92	0.45
2009	0.78x + 1.73	0.93	1.13
2010	0.98x + 0.21	0.92	0.44

Relationship between yearly average air temperature and air temperature normal 1981-2010;

- **the solid black line represents 1:1, and**
- **black dotted lines represent regression lines.**

(Adopted from ©Rahaman et al., 2017 licensed under CC BY license)

Pre-processing of MODIS Data and Implementing Gap-filling Algorithm (1)

- **Four panels of data (i.e., four individual images to represent the whole area) were required in order to capture the entire study area representing the air temperature normal during the period 1961-1990 and 1981-2010.**

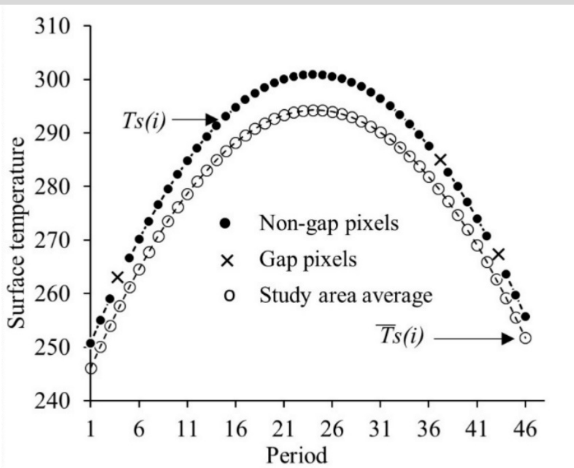
- **Generated two datasets each consisting of 46 layers of 8-day composite images.**

- **Evaluated the quality of each pixels using quality control information in order to determine the null/gap pixels, which were most likely occurred due to atmospheric conditions like cloud and aerosol loading in particular.**

- **To eliminate null pixels, an algorithm developed by Hassan et al. (2007) was adopted so that the surface temperature data in the images could be consistent as a missing data (i.e., gap pixel) might affect the yearly average temperature to a great extent.**

(Adopted from ©Rahaman et al., 2017 licensed under CC BY license)

Pre-processing of MODIS Data and Implementing Gap-filling Algorithm (2)



$\overline{Ts}(i)$ = study area specific average surface temperature (K)
$Ts(i)$ = instantaneous surface temperature regimes at a pixel of interest (K)

$$A = \frac{\sum_{i=1}^{i=n}[\overline{T}_S(i) - T_S(i)]}{m}$$

$$B_n = \overline{T}_S(n) - A$$

(Adopted from ©Rahaman et al., 2017 licensed under CC BY license)

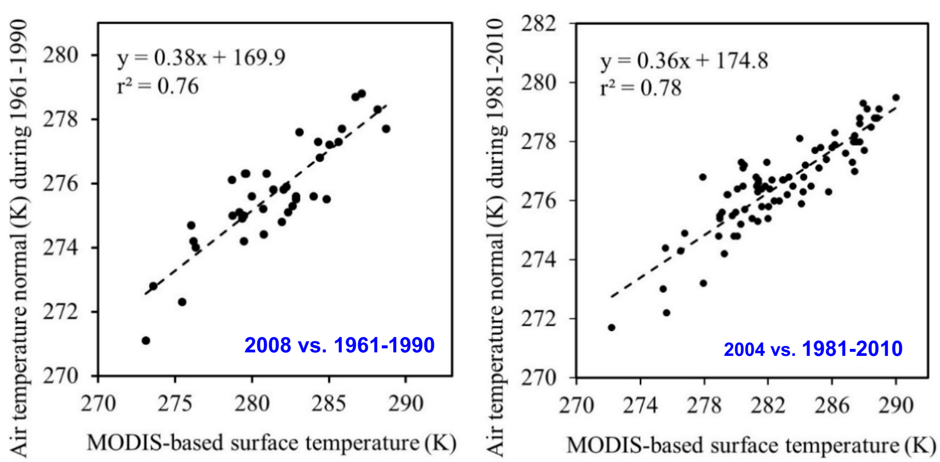
Suggested citation: Rahaman, K.R., and Hassan, Q.K. 2018. Lecture note on: Local warming modelling, *In Environmental Modelling*, Calgary, AB, Canada.

Modelling Air Temperature Normal and Generating Local Warming Trends (1)

- Calculated yearly average surface temperature for each pixel of interest at 1 km spatial resolution.
- Extracted these yearly average surface temperature values at the selected stations, where the ground-based air temperature normal data during the periods 1961-1990 and 1981-2010 were available.
- Divided these data pairs (i.e., yearly average surface temperature vs. air temperature normal) into two sets:
  - i. The first set consisted of 50% of random data points (known as calibration dataset) that were used to establish relationships between the variables of interest.
  - ii. The derived relationship was applied over the remaining 50% of the yearly average surface temperature data points, and then we compared the outcomes against the validation data, i.e., consisting of the unused 50% of the air temperature normal data points.
- Statistical analysis (i.e., r^2 and RMSE) was used to determine the degree of similarities between the modelled and actual air temperature normal values.
- Generated a differential map between the air temperature normal maps from the periods 1961-1990 and 1981-2010; and subsequently used to understand local warming trends.

Modelling Air Temperature Normal and Generating Local Warming Trends (2)

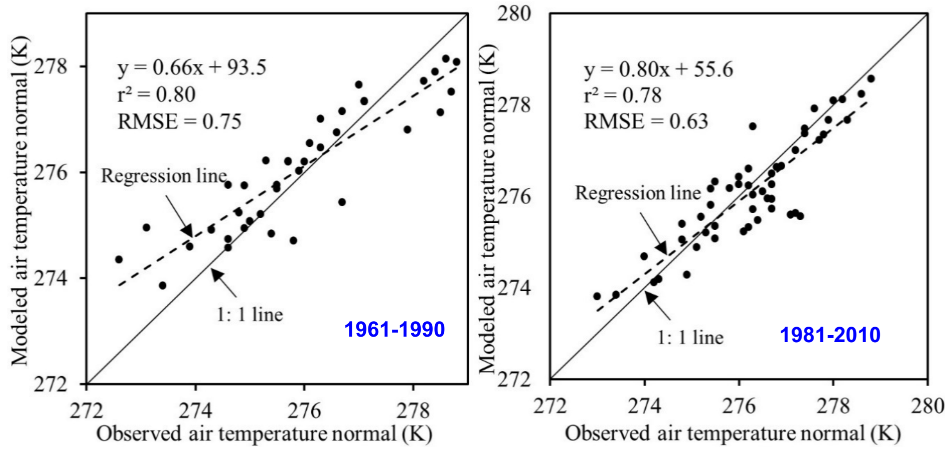
Converting MODIS-based surface temperature into air temperature normal



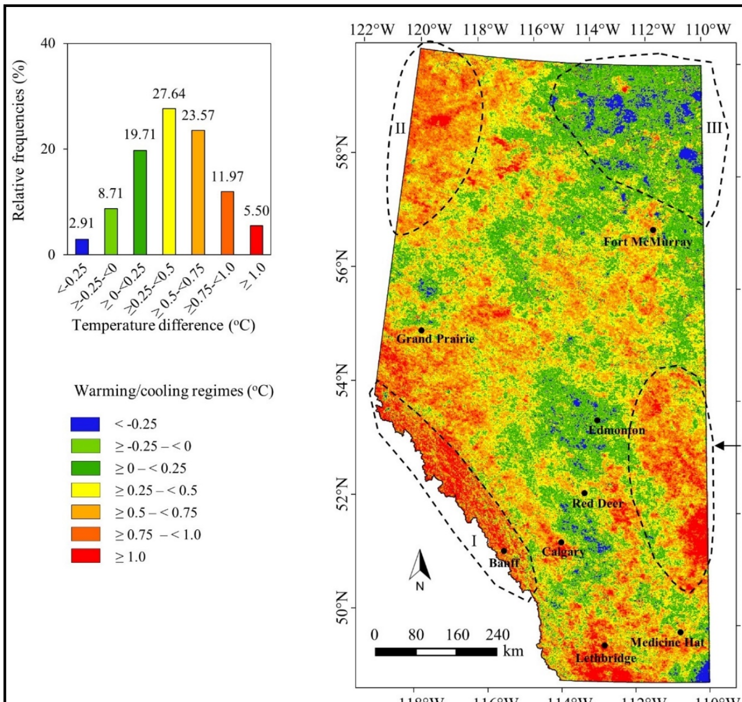
Suggested citation: Rahaman, K.R., and Hassan, Q.K. 2018. Lecture note on: Local warming modelling, *In Environmental Modelling*, Calgary, AB, Canada.

Modelling Air Temperature Normal and Generating Local Warming Trends (3)

Validating MODIS-derived modeled air temperature normal with ground-based air temperature normal



(Adopted from ©Rahaman et al., 2017 licensed under CC BY license)



Spatial extent of local warming during the period 1961-2010 (1)

(Adopted from ©Rahaman et al., 2017 licensed under CC BY license)

Spatial Extent of Local Warming During the Period 1961-2010 (2)

- **The local warming trends were observed in most of the areas of the province/study area (i.e., about 88.39%);**

- **Generic spatial patterns were summarized:**
  - **~68% of the areas experienced local warming trends (i.e., from 0.25 °C to greater than 1.0 °C; see yellow, orange, deep orange, and red color).**
  - **~28% of the areas encountered almost no changes (i.e., in the range -0.25 °C to +0.25 °C; as shown in yellowish green and green color).**
  - **~5% areas underwent higher than 1 °C warming.**
  - **an insignificant percentage (i.e., 2.91% depicted in blue color demonstrated minor cooling trends (i.e., less then - 0.25 °C) are considered as outliers (polygon III)**

- **Warming trends (i.e., in the range 0.75 °C to more than 1.0 °C) were observed in major cities, such as Lethbridge, Medicine Hat, Calgary, Red Deer, Grand Prairie, and Fort McMurray with an exception of Edmonton having relatively moderate warming regimes (i.e., ~ 0.25 °C).**

Spatial Extent of Local Warming During the Period 1961-2010 (3)

- **In Rocky Mountain areas (including Banff National Park, polygon I), warming trends were significantly higher (i.e., 0.75 °C to more than 1.0 °C); which might be due to rapid expansion of infrastructure networks to accelerate tourism industries, and because of the environmental changes due to growing number of visitation of tourists every year.**

- **In the North West part (i.e., polygon II), warming trends were also found to be incremental (i.e., more than 0.75 °C); which might be due to change of landscape composition over the time period and expansion of human activities.**

- **In the South East part (i.e., polygon IV), warming trends were significantly high (i.e., more than 0.75 °C). This area had been characterized as western prairie and had been experiencing the cumulative effects of drought, agriculture-based industrialization.**

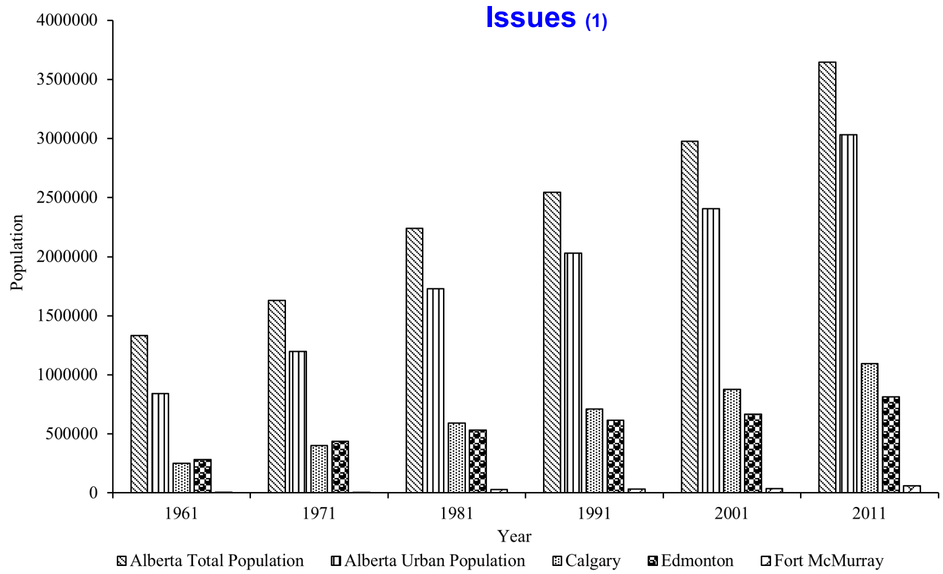
Suggested citation: Rahaman, K.R., and Hassan, Q.K. 2018. Lecture note on: Local warming modelling, *In Environmental Modelling*, Calgary, AB, Canada.

Local Warming Trends over the Natural Region and Sub-regional Levels

Natural Regions	Natural Sub-regions	Average temperature changes (warming trends) °C	Standard deviation ± (°C)
Rocky Mountain	Alpine	0.93	0.42
	Subalpine	0.70	0.39
	Montane	0.50	0.35
Foothills	Upper Foothills	0.61	0.26
	Lower Foothills	0.48	0.25
Grassland	Dry Mixedgrass	0.49	0.37
	Mixedgrass	0.58	0.39
	Northern Fescue	0.54	0.43
	Foothills Fescue	0.54	0.48
Parkland	Foothills Parkland	0.51	0.39
	Central Parkland	0.42	0.38
	Peace River Parkland	0.22	0.29
Boreal Forest	Dry Mixedwood	0.40	0.30
	Central Mixedwood	0.32	0.32
	Lower Boreal Highlands	0.44	0.30
	Upper Boreal Highlands	0.35	0.31
	Athabasca Plain	0.02	0.37
	Peace-Athabasca Delta	0.13	0.33
	Northern Mixedwood	0.39	0.39
	Boreal Subarctic	0.27	0.33
Canada Sheild	Kazan Upland	-1.00	0.30

- **Kazan Upland sub-region doesn't have enough ground-based weather station data. Thus, the recommendation is to use this particular cooling trends with extreme caution.**

Issues (1)



Approximately 83% of Albertans live in urban areas, while the remaining 17% live in rural areas. Thus, the analysis on the basis of major centres are acceptable.

Issues (2)

Despite demonstrating fairly strong relationships between station-based temperature data and MODIS derived surface temperature data to draw local warming maps, two note-worthy issues are:

- **Seasonal variation of temperature: MODIS-derived 8-days composite of surface temperature mostly acquired under clear sky condition. However, temperature varied at different scales at diurnal, seasonal, regional, and annual levels.**

- **Influence of Land use on temperature regimes: Human activity and land use practices are cumulatively a major driver of global environmental (i.e., climate) change. Population growth, urban land use change, and the urban heat island potentials (includes temperature change at local scale) have concurrent relationships for temperature change. It was beyond scope of this study to incorporate land use component as a matter of temperature change.**

References

- **Fritzsche, J. (2013) Temperature trends in Canada. Govt. of Canada (Statistics Canada). http://www.statcan.gc.ca/pub/16-002-x/2011001/part-partie2-eng.htm last accessed 13 September, 2015 at 17.05 MST.**
- **Mahlstein, I., Hegerl, G., Solomon, S. (2012) Emerging local warming signals in observational data. *Geo. Res. Let.* 39 (L21711): 1 – 5.**
- **Menne, M. J., Williams, C. N., Palecki, MA. (2010) On the reliability of the U.S. surface temperature record. *J. of Geo. Res*. 115: 1 – 9.**
- **Rahaman, et al., (2017). Quantification of Local Warming Trend: A Remote Sensing-Based Approach. *PLOS ONE 12(1)*: e0169423. doi: 10.1371/journal.pone.0169423**
- **Vanderbei, R. (2012) Local warming. *SIAM Review.* 54(3): 597 – 606.**

Suggested citation: Rahaman, K.R., and Hassan, Q.K. 2018. Lecture note on: Local warming modelling, *In Environmental Modelling*, Calgary, AB, Canada.

Sample Questions

- **Define local warming and why it is important to study.**
- **What are global and regional (Canadian) warming trends?**
- **Draw a schematic diagram to quantify local warming trends upon identifying available data and challenges.**
- **Describe the major steps in modelling local warming.**
- **Propose a data gap-filling algorithm in order to eliminate gaps in remote sensing-derived surface temperature.**
- **Describe the mechanism of converting remote sensing-based surface temperature into equivalent air temperature.**