

Knowledge Transfer Workshop Agenda

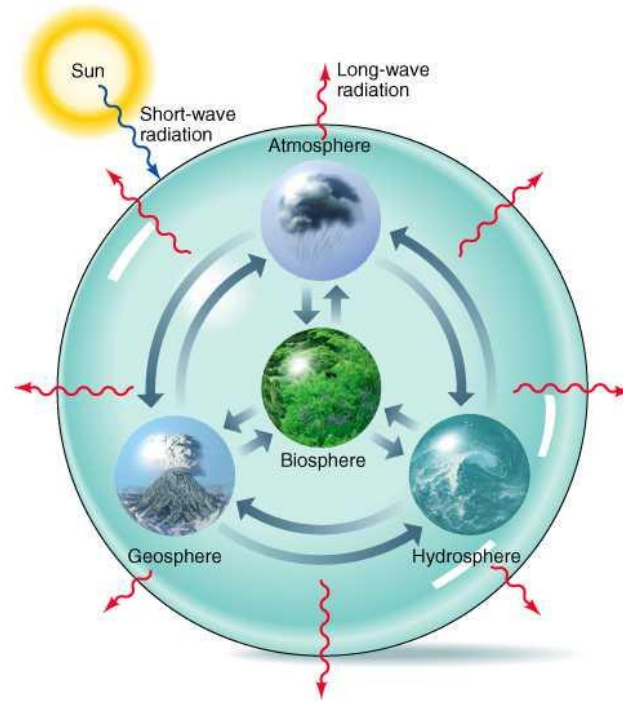
| Time | Section | Person |
|-----------|----------------------------------------|---------------------|
| 1:00 1:10 | Welcome and Opening Remarks | Niagara Region |
| 1:10 1:20 | Brief Introduction to Climate Modeling | TRCA |
| 1:20 1:50 | Climate Projections: Methods/Results | TRCA |
| 1:50 2:50 | Discussion/Questions | All |
| 2:50 | Closing Remarks | TRCA/Niagara Region |

Knowledge Transfer Workshop: Climate Change Modelling for Niagara Region

Presented by: Yuestas David and Lubna Seal

February 16, 2022

Introduction to Climate Modeling



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Introduction to Climate Modeling

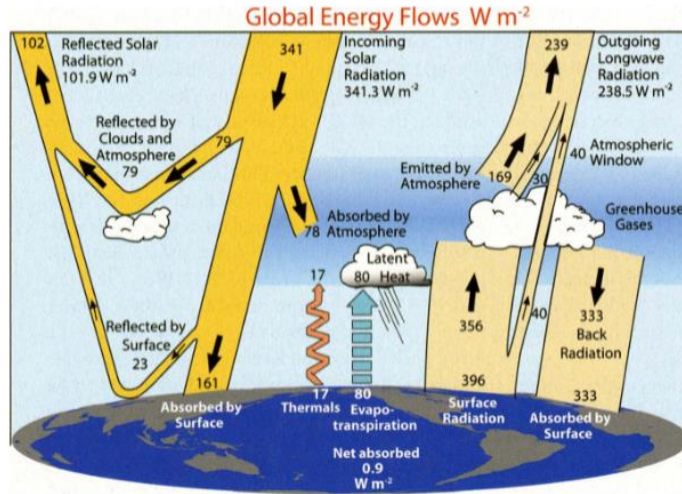
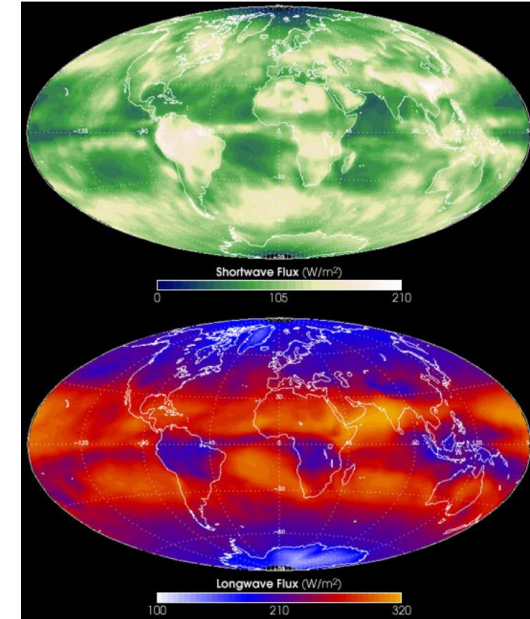


FIG. 1. The global annual mean Earth's energy budget for the Mar 2000 to May 2004 period (W m^{-2}). The broad arrows indicate the schematic flow of energy in proportion to their importance.



Imagery of reflected short wave and emitted long wave radiation acquired by NASA's Clouds and the Earth's radiant Energy System, or CERES, sensors during March 2000

Introduction to Climate Modeling

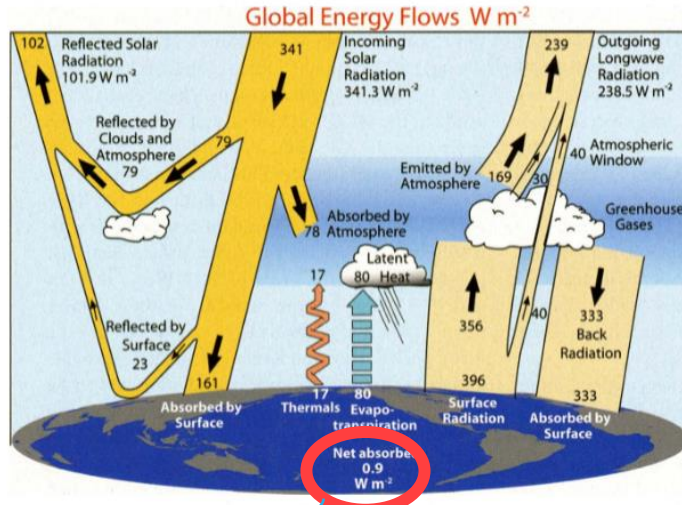
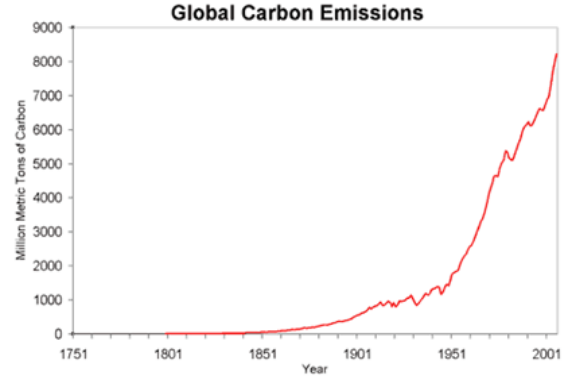


FIG. 1. The global annual mean Earth's energy budget for the Mar 2000 to May 2004 period (W m^{-2}). The broad arrows indicate the schematic flow of energy in proportion to their importance.

Representative Concentration Pathways (RCP):
2.6, 4.5, 6.0, 8.5 W/m^2



Global atmospheric CO₂ concentrations from 1700 to 2021. Credit: Met Office.

Introduction to Climate Modeling



Mathematical Equations
+
Parameterization
(e.g., topography)

```

**** DIAGNOSTIC VARIABLES
HCB( 0:1H*2,0:1H,0:4), &
HAB( 0:1H*2,0:1H,0:4), HBA( 0:1H*2,0:1H,0:4), &
VAB(3,0:1H*2,0:1H,0:4), &
VBB(3,0:1H*2,0:1H,0:4), &
dHCBADV( 0:1H*2,0:1H,0:4), &
dHABADV(3,0:1H*2,0:1H,0:4), dHBAADV(3,0:1H*2,0:1H,0:4), &
dVABTROP(3,0:1H*2,0:1H,0:4), dVBBTROP(3,0:1H*2,0:1H,0:4), &
HSC(0:1000), HVC(0:1000), HVC(0:1000), EP(0:1000), EK(0:1000), PENS(0:1000), &
HLL(1000), HLL(1000), VLL(1000), VLL(1000), VLL(1000), AKZAP(1000,2), EKAP(1000,2)
EndModule SCOS

Program MAIN
Use SCOS
Implicit None
Integer :: I,J,K, NARGS
Real*8 :: DTFS,DTLF, VABH, &
HCB(0:1H*2,0:1H,0:4), HAB(0:1H*2,0:1H,0:4), HBA(0:1H*2,0:1H,0:4), VAB(3,0:1H*2,0:1H,0:4), VBB(3,0:1H*2,0:1H,0:4), &
HCO(0:1H*2,0:1H,0:4), HAO(0:1H*2,0:1H,0:4), HBD(0:1H*2,0:1H,0:4), VAD(3,0:1H*2,0:1H,0:4), VBD(3,0:1H*2,0:1H,0:4)
Real*8 :: S
dHCB(0:1H*2,0:1H,0:4), dVA(3,0:1H*2,0:1H,0:4), dVB(3,0:1H*2,0:1H,0:4) ! acceleration
Character*80 :: ARG,FILOUT

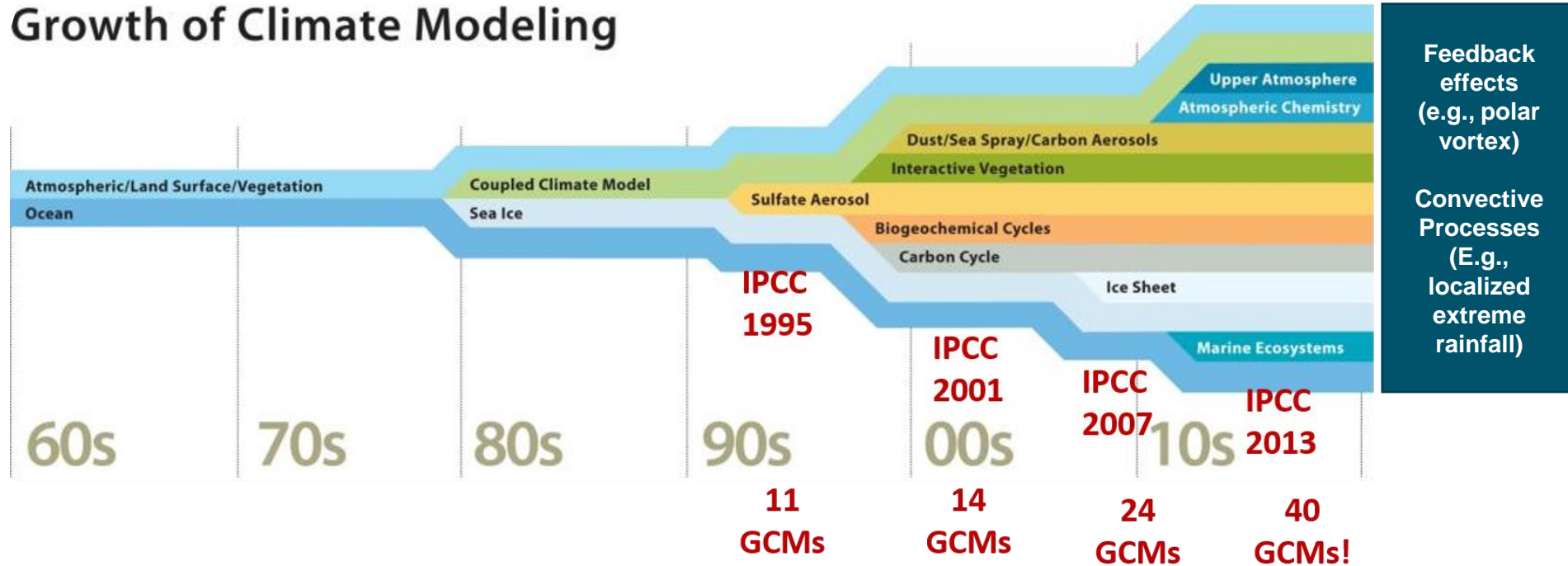
**** Collect command line argument
NARGS = Iargc()
If (NARGS == 0) GoTo 800
Call Getarg(1,ARG) ; Read (ARG,*) NDAYS
Write (6,*) "2H,DTFSRC,SDAY=",2H,DT,DT*NDAYS,DT*NDAYS*HSCS

**** Initialize variables
Call GEOMETRY
Call INPUT
Call HCBHAB (HCB,HAB,HBA)
HCB( 1:1,1) = HCB( 1:1,1) ; HAB( 1:1,1) = HAB( 1:1,1) ; HBA( 1:1,1) = HBA( 1:1,1)
VAB( 1:1,1) = VAB( 1:1,1) ; VBB( 1:1,1) = VBB( 1:1,1)

ZTC(1:1,1) = SPVOL*HCB(1:1,1) * ZSC(1:1,1)
Call WRITEC (ZTC(1:1,1),M,165,1) ; ZTC(1:1,1) = M * 165 ! Initial altitude of fluid top at grid cell centers'
VAB(3,1:1,1) = VAB(3,1:1,1) * ZCOS(3,1:1,1)
VBB(3,1:1,1) = VBB(3,1:1,1) * ZCOS(3,1:1,1)
VAB(1:1,1,1) = (VAB(1:1,1,1)*PRAC(2,1:1,1) - VAB(2,1:1,1))*PRAC(1,1:1,1) * ZCOS(3,1:1,1)
VBB(1:1,1,1) = (VBB(1:1,1,1)*PRAC(2,1:1,1) - VBB(2,1:1,1))*PRAC(1,1:1,1) * ZCOS(3,1:1,1)
Call WRITEAB (VAB(3,0,0),VBB(3,0,0),165,165) ! Initial eastward velocity at points A and B'
Call WRITEAB (VAB(1,0,0),VBB(1,0,0),165,165) ! Initial northward velocity at points A and B'
Call DIARC (0)
Write (6,99H) 0, HSC(0), HVC(0), HVC(0), HVC(EP(0,0),0), HVC(EK(0,0),0), HVC(ET(0,0),0), HVC(1000*PENS(0))
NDAY = 0 ; HSC = 0 ; HVC = 0 ; HVC = 0
DTLF = DT*2 ; If (NDAYS == 0) GoTo 500 ! compare Initial differential results with numerical scheme
    
```

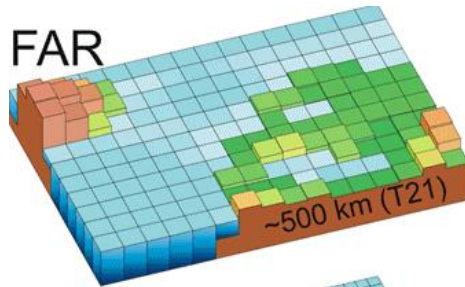
A Brief History of Climate Modeling

Growth of Climate Modeling

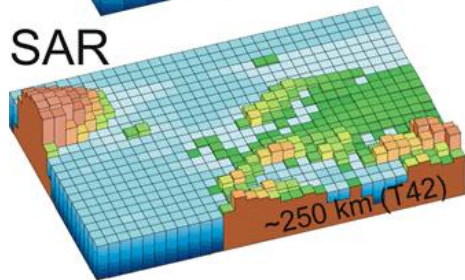
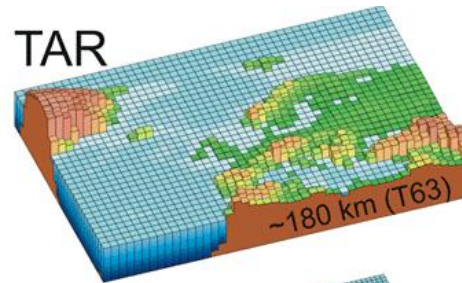


As Global Climate Models have Advanced, so has their Spatial Resolution...

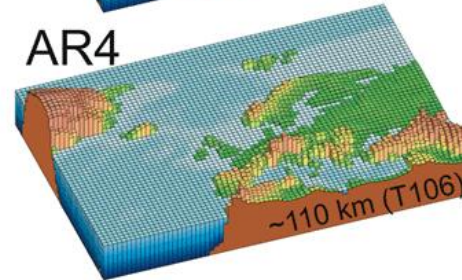
IPCC (1990)



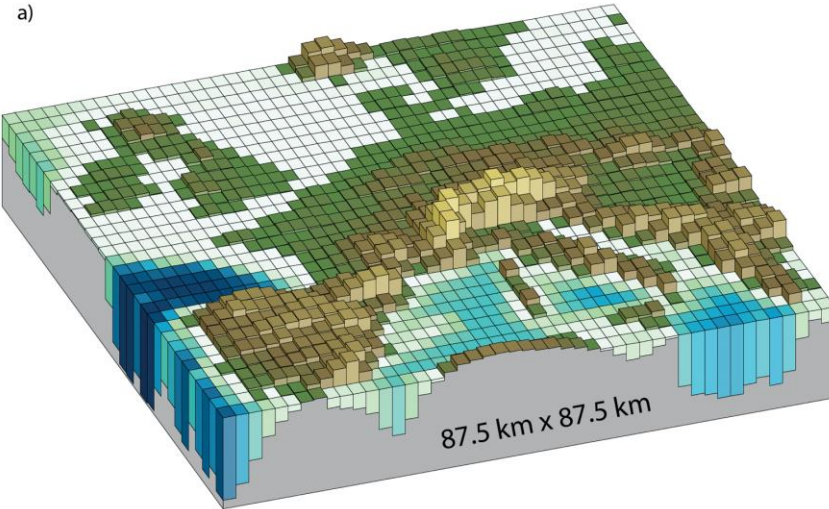
IPCC (2001)



IPCC (1995)

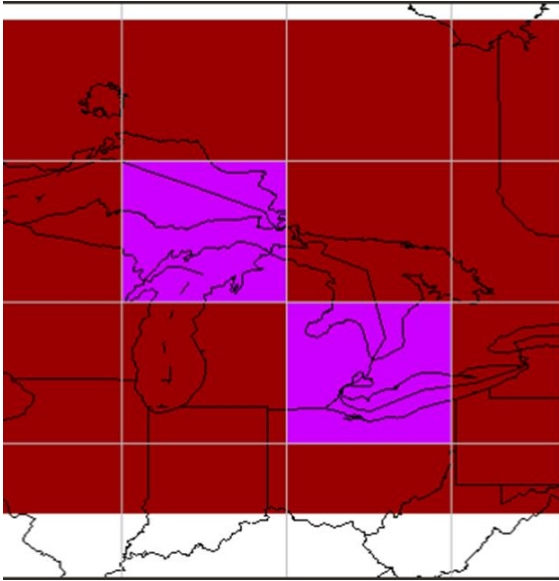


IPCC (2007)

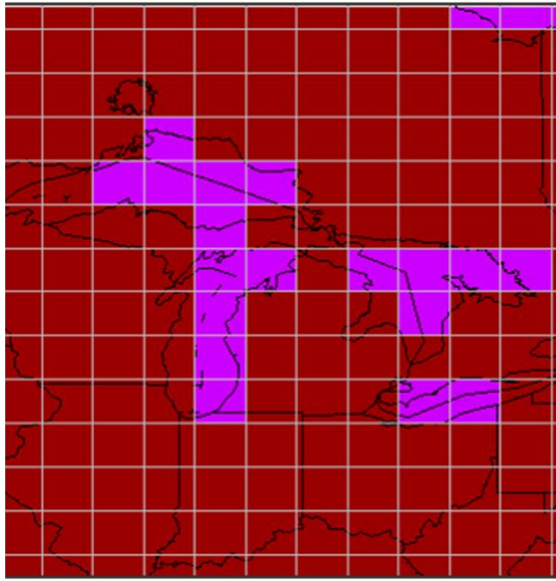


IPCC (2013) – AR5

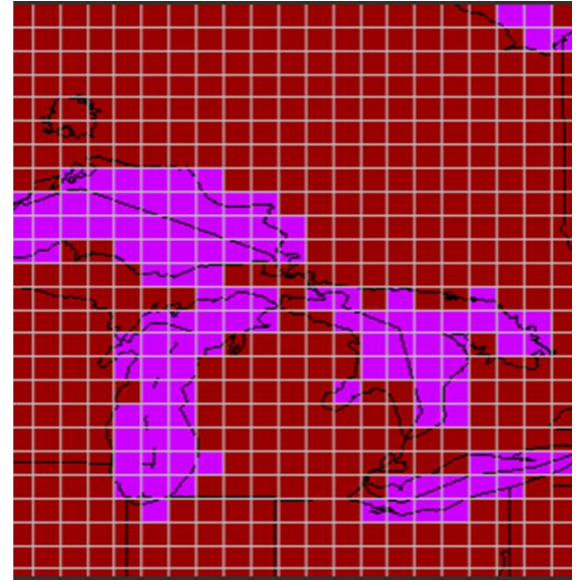
Spatial Resolution Matters particularly in the Great Lakes Basin...



IPCC 2013 GCM

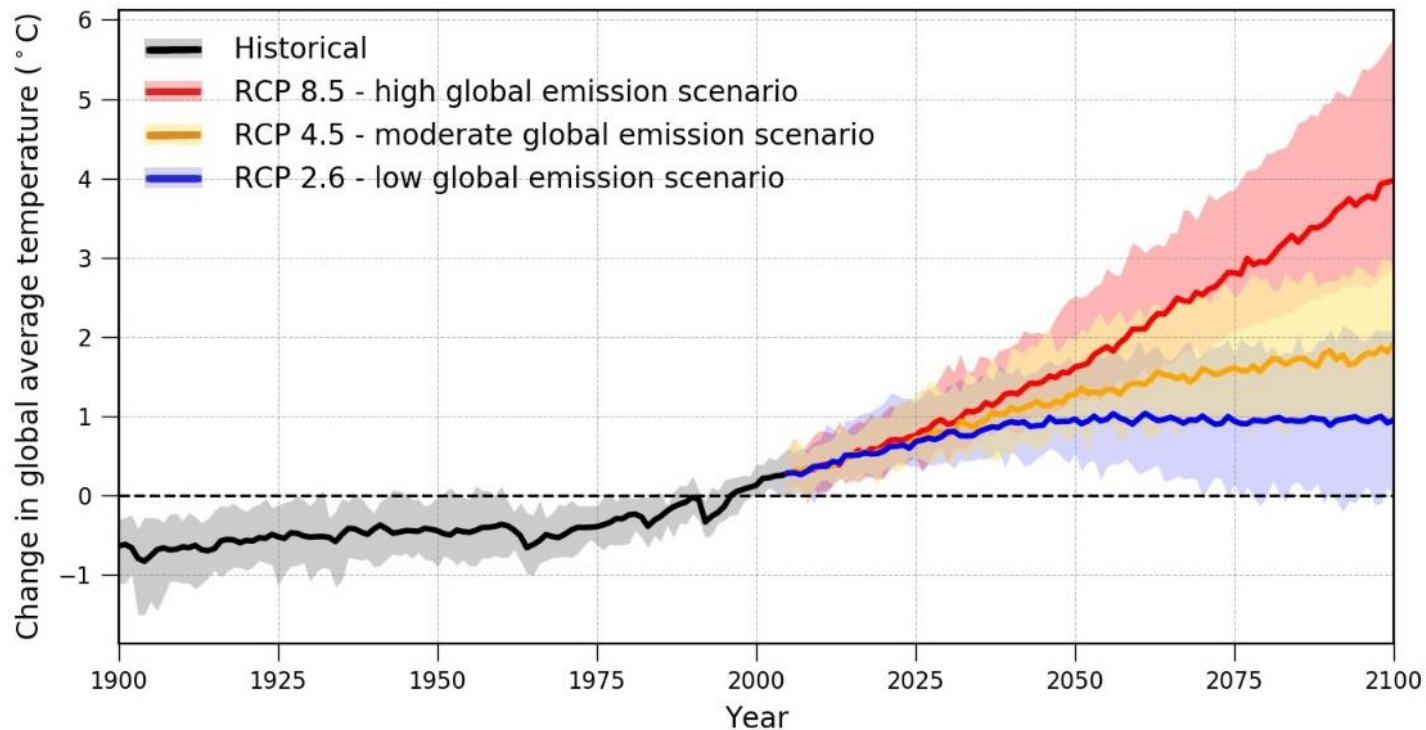


**Regional Climate Model
(50 x 50km)**



**Regional Climate Model
(25 x 25km)**

Climate Change Scenarios



Approach



Obtain Data

Collect Historical Data
Future time-series for each grid cell
Quality Control & Infilling Gaps



Historical Characterization

Use baseline (1971-2000)
Spatial, seasonal, long term
temporal trend analyses



Future Analysis

Bias Correction
Determine anomalies
Spatial, seasonal, long term
temporal trend analyses

Historical Data Accessed for Niagara Region

https://climate.weather.gc.ca/climate_normals/index_e.html

To view a list of locations for which Climate Normals have been calculated, please download [Normals Station Inventory](#), or select and submit one of the following searches:

- Search by Station Name
- Search by Province or Territory
- ▼ Search by Proximity

Select a distance, city or National Park, or enter location coordinates and click "Go".

50 kilometres away from:

☐ a city,

☐ a National Park,

☐ location coordinates:

Latitude (e.g., 48°49'27.010" N): North

Longitude (e.g., 123°43'08.009" W): West

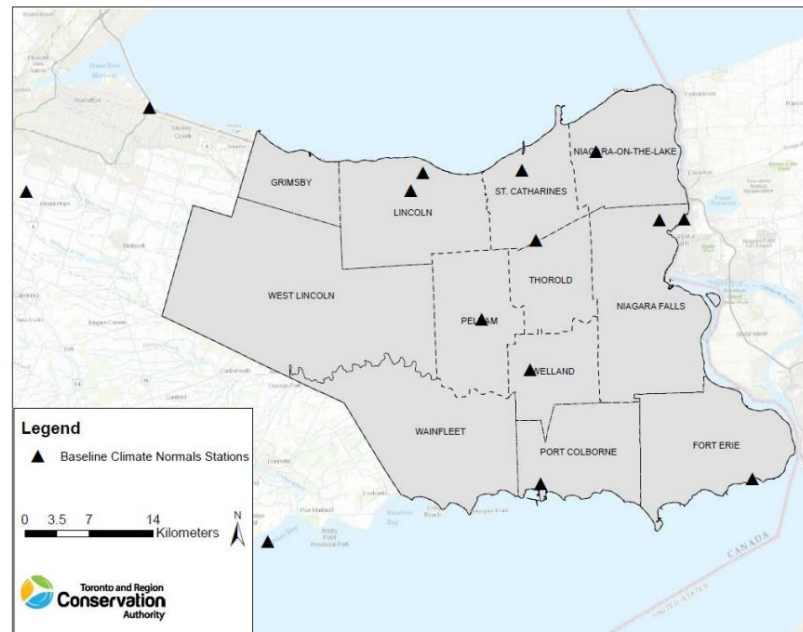
* location coordinates in Decimal Degrees:

latitude (e.g., 61.3701°):

longitude (e.g., -139.0317°):

| Station No. | Station Name | Longitude | Latitude |
|-------------|--------------------------|-----------|----------|
| 1 | FORT ERIE | 78.97° W | 42.88° N |
| 2 | NIAGARA FALLS NPCSH | 79.05 ° W | 43.13° N |
| 3 | NIAGARA FALLS | 79.08 ° W | 43.13° N |
| 4 | PORT COLBORNE | 79.25 ° W | 42.88° N |
| 5 | PORT DALHOUSIE | 79.27 ° W | 43.18° N |
| 6 | RIDGEVILLE | 79.33 ° W | 43.04° N |
| 7 | ST CATHARINES A | 79.17 ° W | 43.20° N |
| 8 | ST CATHARINES POWER GLEN | 79.25 ° W | 43.12° N |
| 9 | VINELAND RITTENHOUSE | 79.42 ° W | 43.17° N |
| 10 | VINELAND STATION | 79.40 ° W | 43.18° N |
| 11 | WELLAND | 79.26 ° W | 42.99° N |
| 12 | HAMILTON A | 79.93 ° W | 43.17° N |

Baseline Climate Data from Environment Canada Meteorological Stations



Extracting Future Climate Data



Downloaded daily temperature and precipitation data for:

- RCP 4.5 and RCP 8.5 Scenarios
- Up until 2080

16 Regional Climate Models which are:

- Dynamically-downscaled (physics-based) models run by differing boundary conditions (to account for uncertainties)
- “Raw” climate model output at 25 x 25 km grid cells

NA-CORDEX Search

NA-CORDEX Documentation: Explanation of Dataset Facets

| | | | | | | |
|------------------------------------------|-------------------------------------------|---------------------------------------|-------------------------------------|-----------------------------------------|---------------------------------------------|-----------------------------------------|
| Variable | Experiment | Driver | Model | Frequency | Grid | Bias Correction |
| <input checked="" type="checkbox"/> prec | <input type="checkbox"/> eval | <input type="checkbox"/> ERA-Int | <input type="checkbox"/> CanRCM4 | <input type="checkbox"/> fixed | <input type="checkbox"/> NAM-11 | <input checked="" type="checkbox"/> raw |
| <input type="checkbox"/> temp | <input type="checkbox"/> hist | <input type="checkbox"/> CNRM-CM5 | <input type="checkbox"/> CRCM5-OUR | <input type="checkbox"/> 1hr | <input type="checkbox"/> NAM-22 | <input type="checkbox"/> mbon-gridMET |
| <input type="checkbox"/> tmax | <input type="checkbox"/> rcp26 | <input type="checkbox"/> CanESM2 | <input type="checkbox"/> CRCM5-UQAM | <input type="checkbox"/> 3hr | <input type="checkbox"/> NAM-44 | <input type="checkbox"/> mbon-Daymet |
| <input type="checkbox"/> tmin | <input type="checkbox"/> rcp45 | <input type="checkbox"/> EC-EARTH | <input type="checkbox"/> HIRHAM5 | <input type="checkbox"/> 6hr | <input checked="" type="checkbox"/> NAM-22i | |
| <input type="checkbox"/> hurs | <input checked="" type="checkbox"/> rcp85 | <input type="checkbox"/> GEMstatm-Can | <input type="checkbox"/> RCA4 | <input checked="" type="checkbox"/> day | <input type="checkbox"/> NAM-44i | |
| <input type="checkbox"/> pe | | <input type="checkbox"/> GEMstatm-HP1 | <input type="checkbox"/> RegCM4 | <input type="checkbox"/> mon | | |
| <input type="checkbox"/> rsds | | <input type="checkbox"/> GFDL-ESM2M | <input type="checkbox"/> WRF | <input type="checkbox"/> seas | | |
| <input type="checkbox"/> vas | | <input type="checkbox"/> HadGEM2-ES | | <input type="checkbox"/> ann | | |
| <input type="checkbox"/> vas | | <input type="checkbox"/> MPI-ESM-LR | | <input type="checkbox"/> ymon | | |
| <input type="checkbox"/> hurs | | <input type="checkbox"/> MPI-ESM-MR | | <input type="checkbox"/> years | | |

Search Clear Search

16 files

Download Options For Selection

| <input type="checkbox"/> file | Size | Subset File | NetCDF Header |
|---------------------------------------------------------------------------|-------|-------------|---------------|
| <input type="checkbox"/> prec.rcp85.CanESM2.CanRCM4.day.NAM-22i.raw.nc | 20 GB | Subset | View |
| <input type="checkbox"/> prec.rcp85.CanESM2.CRCM5-UQAM.day.NAM-22i.raw.nc | 20 GB | Subset | View |

Horizontal subset:

Lat/lon box

BOUNDING BOX (IN DECIMAL DEGREES)

North

West East

South

Horizontal stride:

Time subset:

Time range **Single time**

Start:

End:

Stride:

Vertical subset:

Single level **Vertical stride**

Level:

Stride:

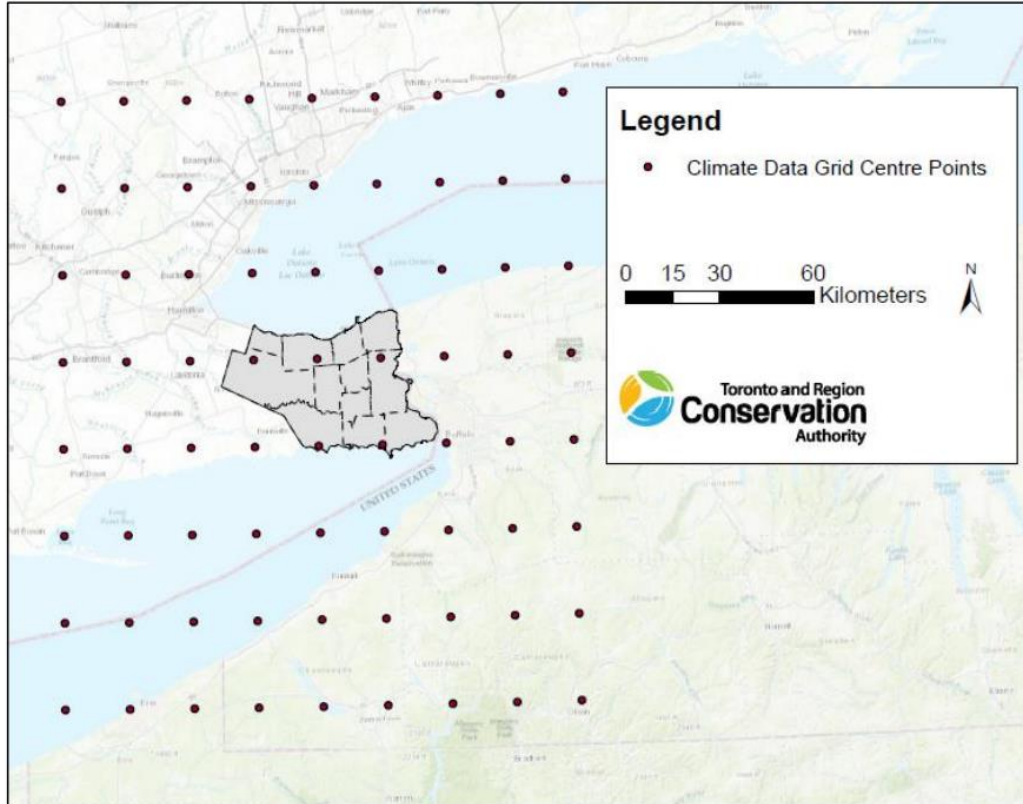
Output format:

Format:

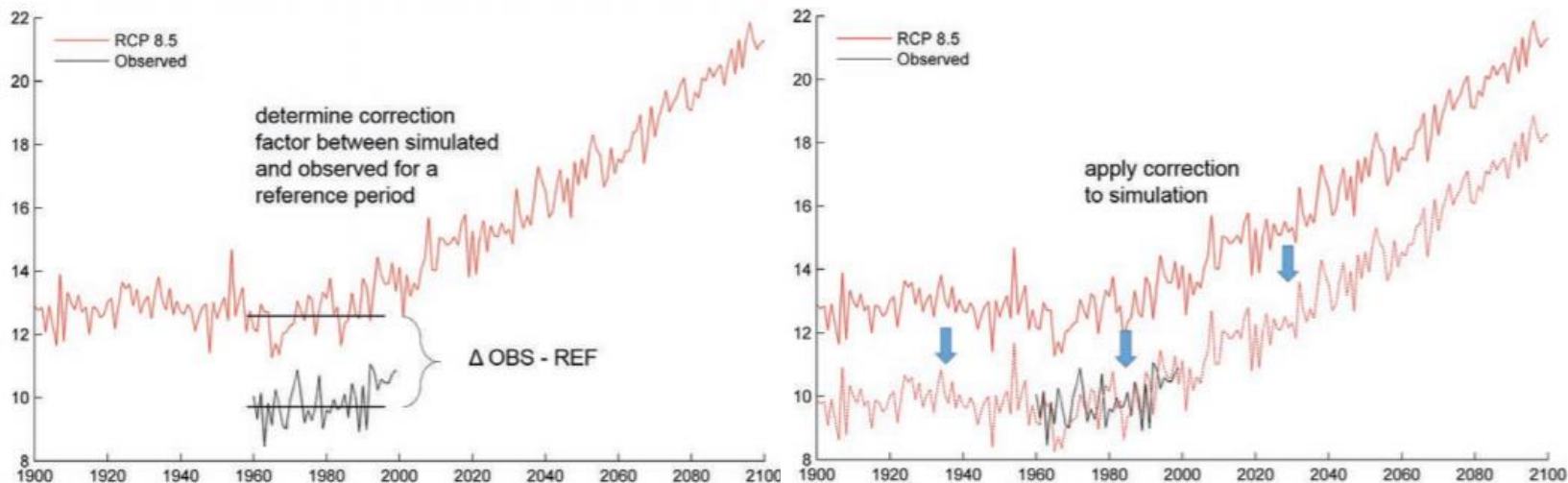
CF compliance:

☐ Add 2D Lat/Lon to file

NA-CORDEX Data



Conducting Bias Correction



Climate Parameters

Direct Model Output (4)

- Mean Air Temperature
- Max Air Temperature
- Min Air Temperature
- Total Precipitation

Inferred or Calculated (52)

- All Threshold-based Parameters
- Extreme Precipitation
- Growing Season
- Dry Conditions
- Freeze-Thaw
- Ice Potential

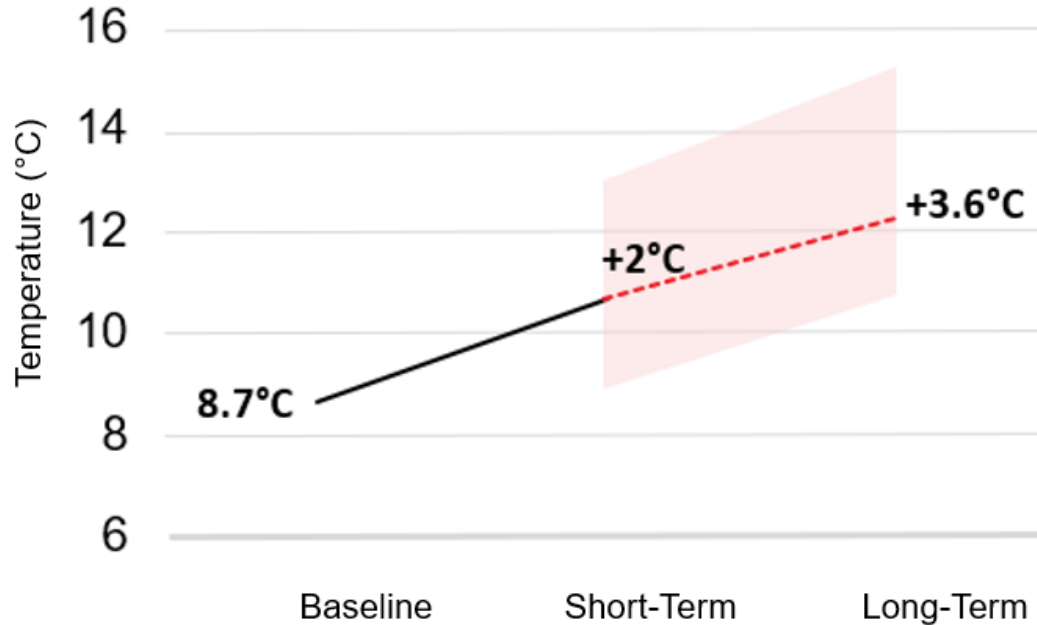
Model Confidence Level

To assess the robustness of the future projections, the agreement in change direction between models and the strength of the change signal from the baseline values are assessed

- **The change direction agreement** evaluates how many models agree on the direction of change for each parameter from baseline to future periods
- **Change signal** compares the magnitude of change between baseline and future climate periods to the variability of means between models in the future period

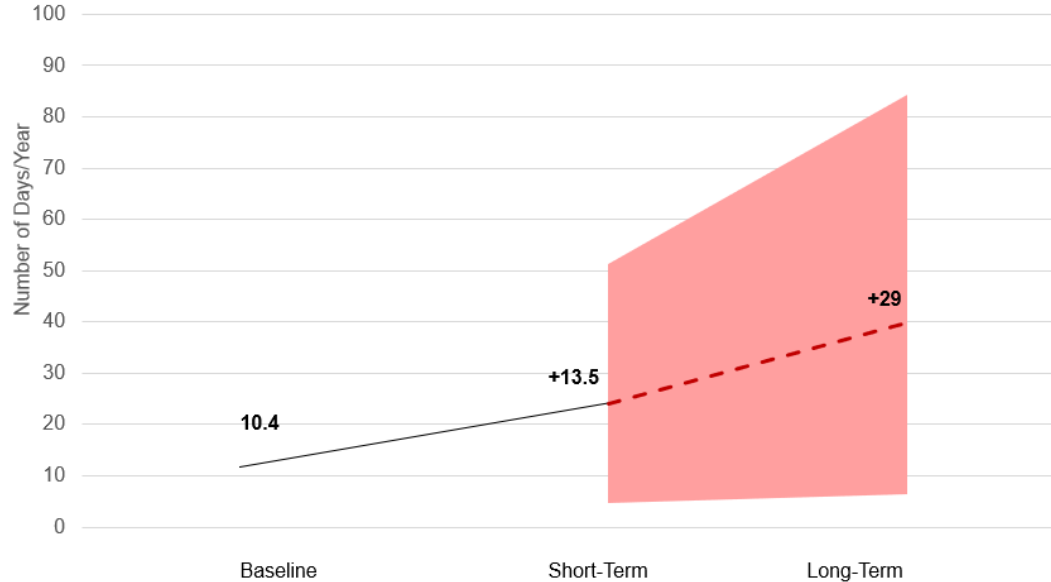
Regional Climate Projections Under RCP8.5 Scenario

Mean Annual Daily Air Temperature



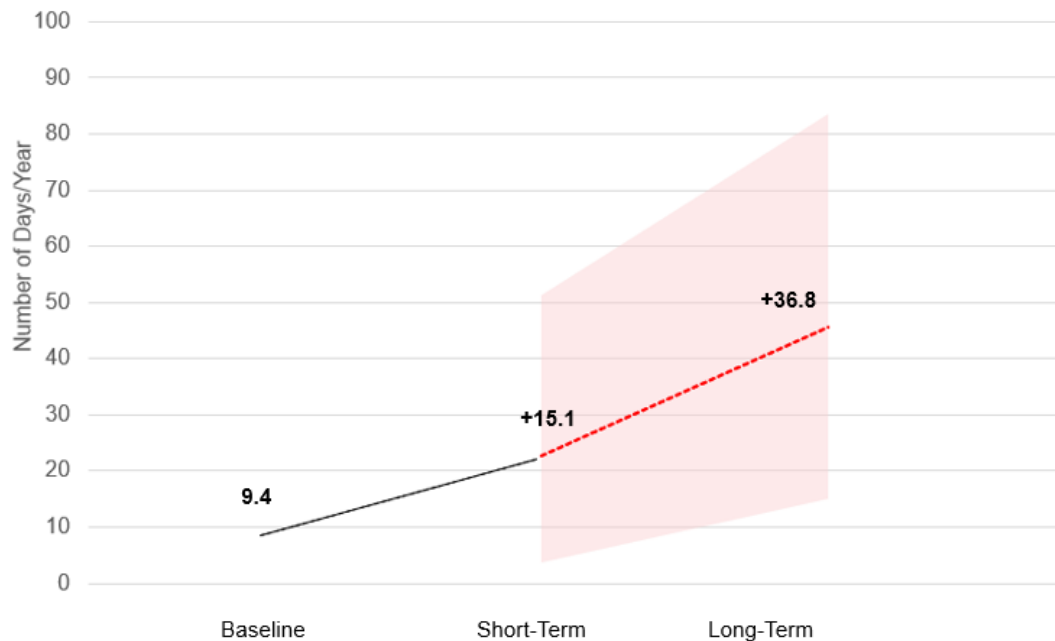
| Change Direction Agreement | Change Signal |
|----------------------------|---------------|
| High | High |

Extreme Heat Days: Daily Max Temperature > 30°C



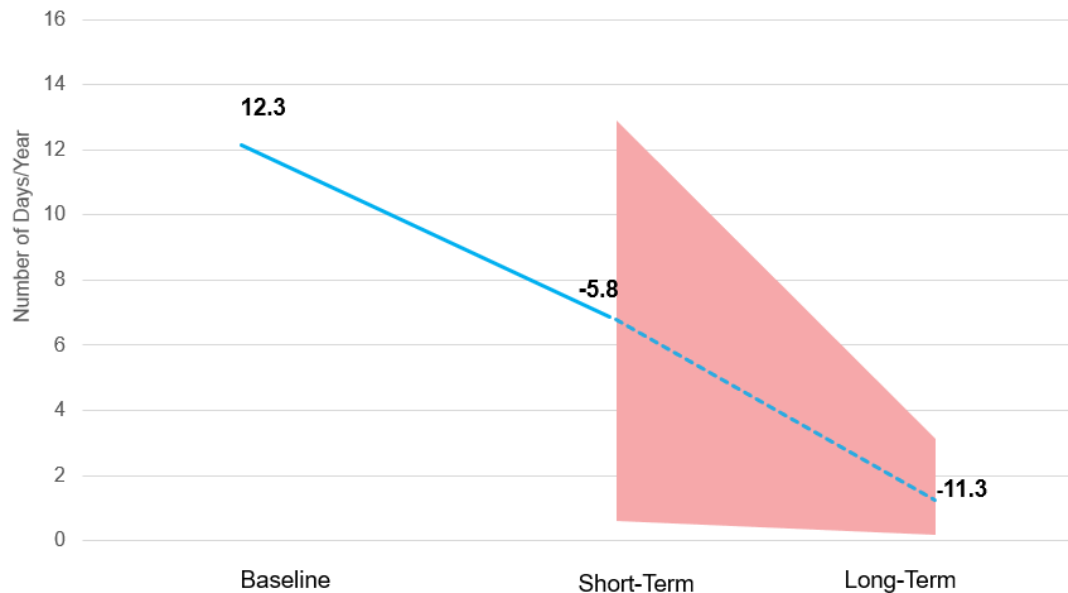
| Change Direction Agreement | Change Signal |
|----------------------------|---------------|
| Medium | Medium |

Tropical Nights: Daily Minimum Temp > 20 °C



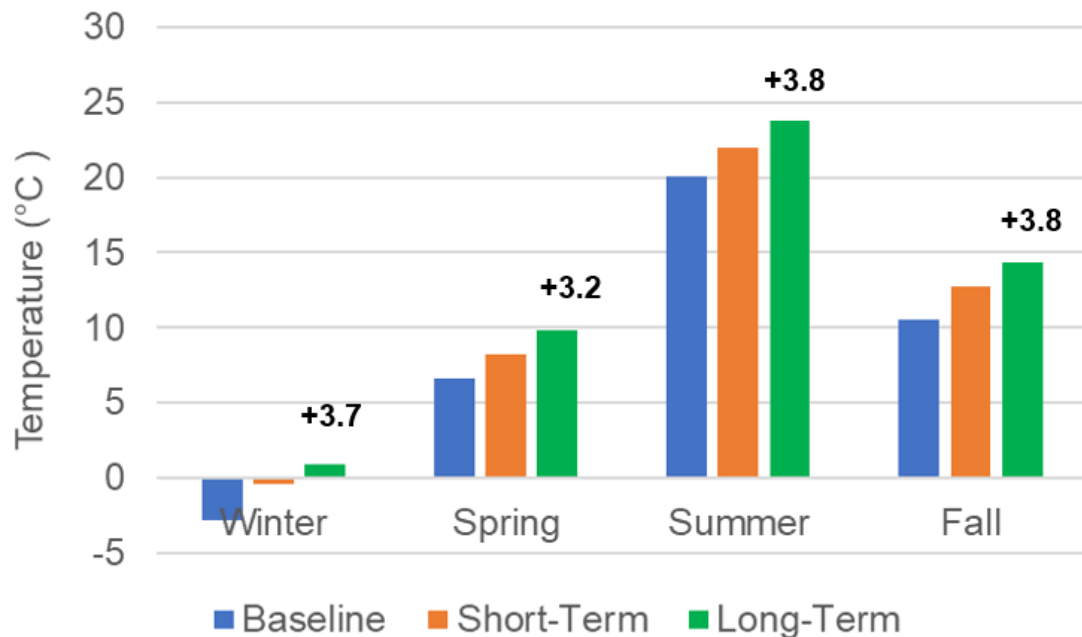
| Change Direction Agreement | Change Signal |
|----------------------------|---------------|
| High | Medium |

Extreme Cold Days: Daily Minimum Temp < -15°C



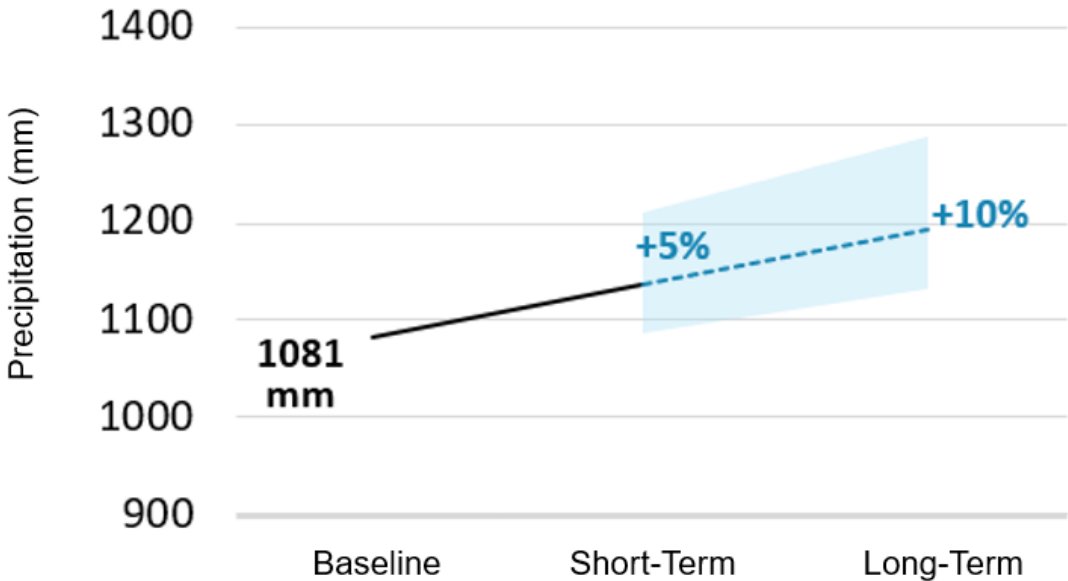
| Change Direction Agreement | Change Signal |
|----------------------------|---------------|
| High | High |

Mean Seasonal Air Temperature



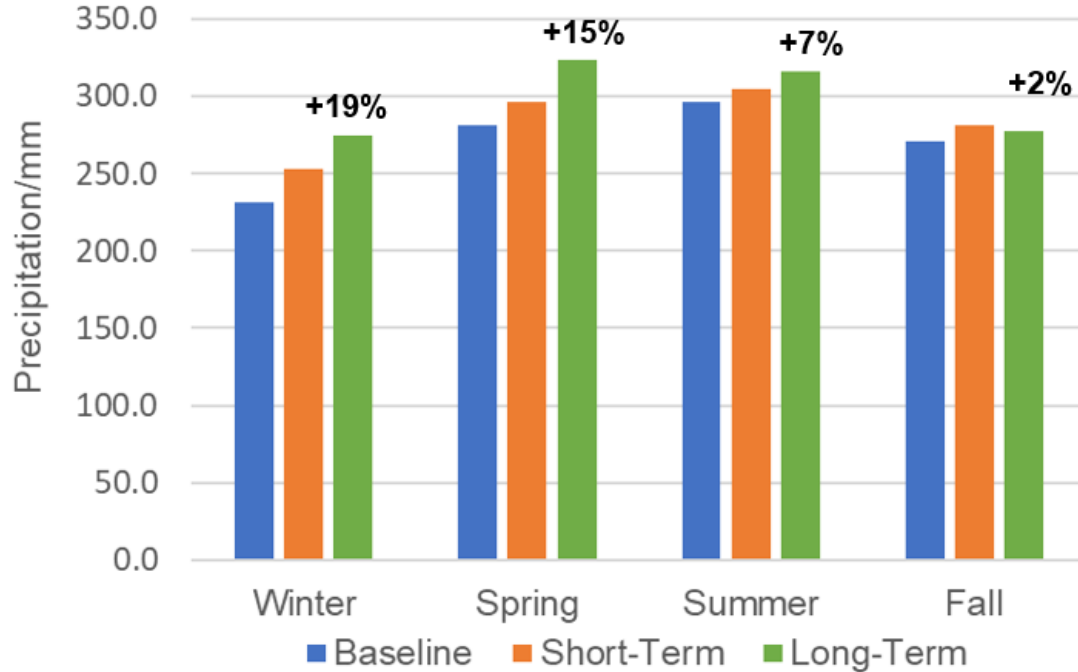
| Season | Change Direction Agreement | Change Signal |
|--------|----------------------------|---------------|
| Winter | High | Medium |
| Spring | High | Medium |
| Summer | High | Medium |
| Fall | High | Medium |

Mean Annual Total Precipitation



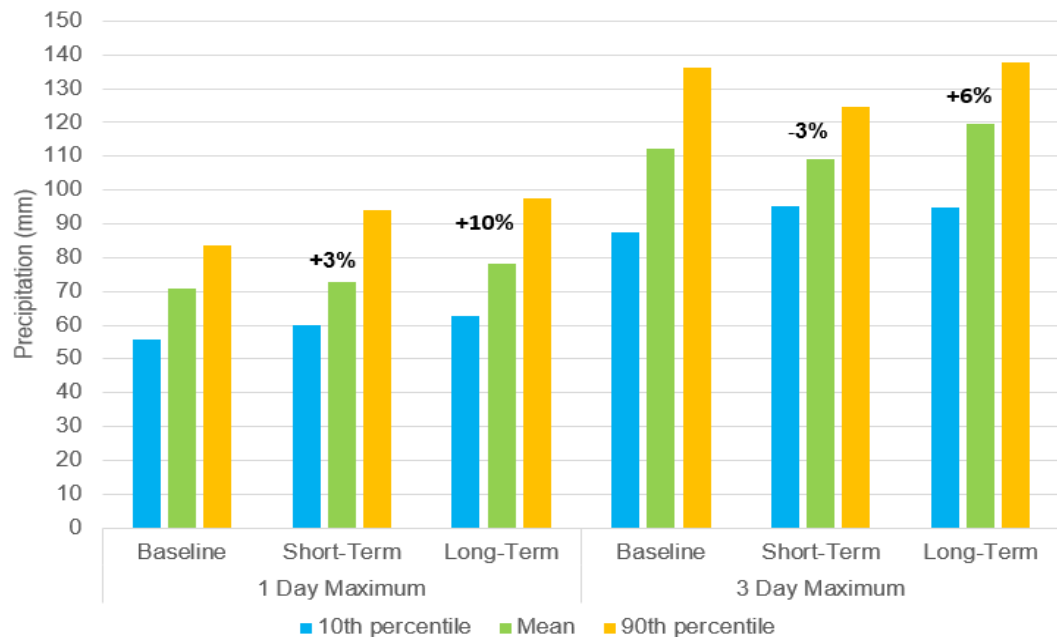
| Change Direction Agreement | Change Signal |
|----------------------------|---------------|
| High | Medium |

Mean Seasonal Total Precipitation



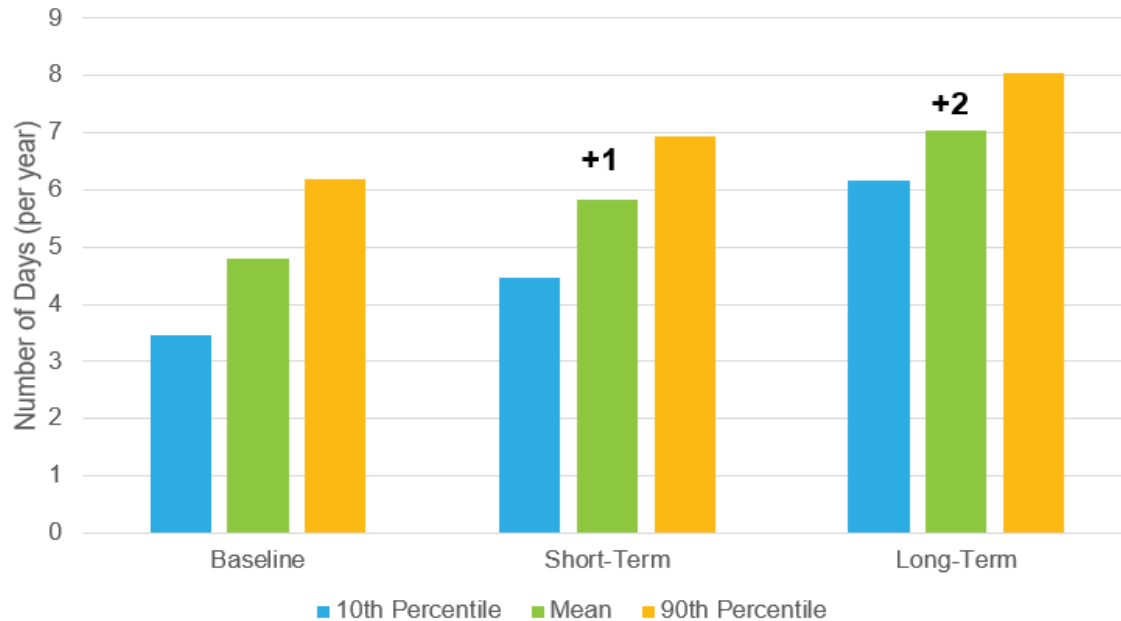
| Season | Change Direction Agreement | Change Signal |
|--------|----------------------------|---------------|
| Winter | Medium | Medium |
| Spring | High | Medium |
| Summer | Low | Low |
| Fall | Low | Low |

Extreme Precipitation: 1-Day and 3-Day Maximum Precipitation



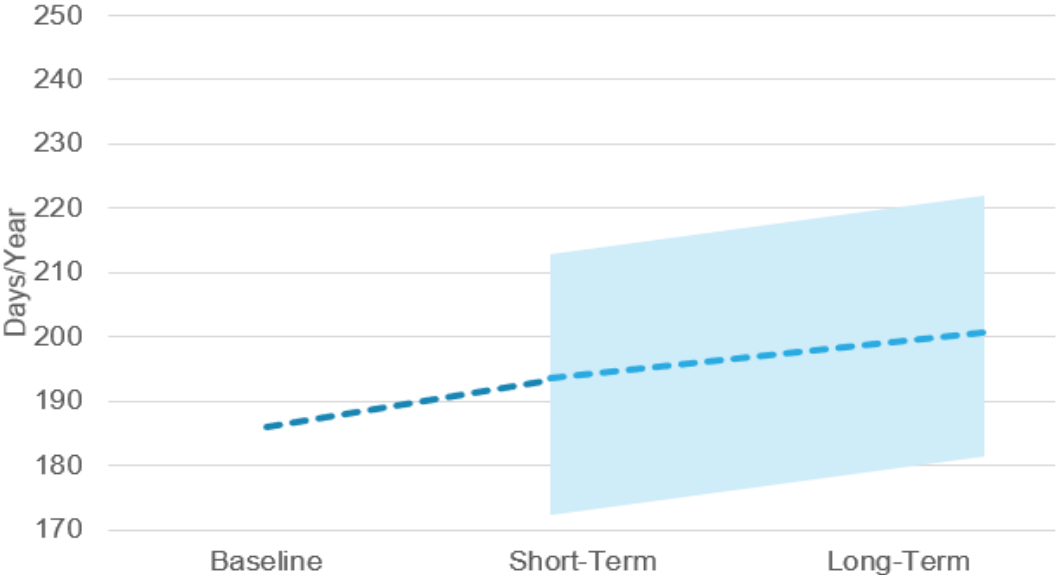
| Change Direction Agreement | Change Signal |
|----------------------------|---------------|
| Low | Low |

Extreme Precipitation: Daily Precipitation > 25mm



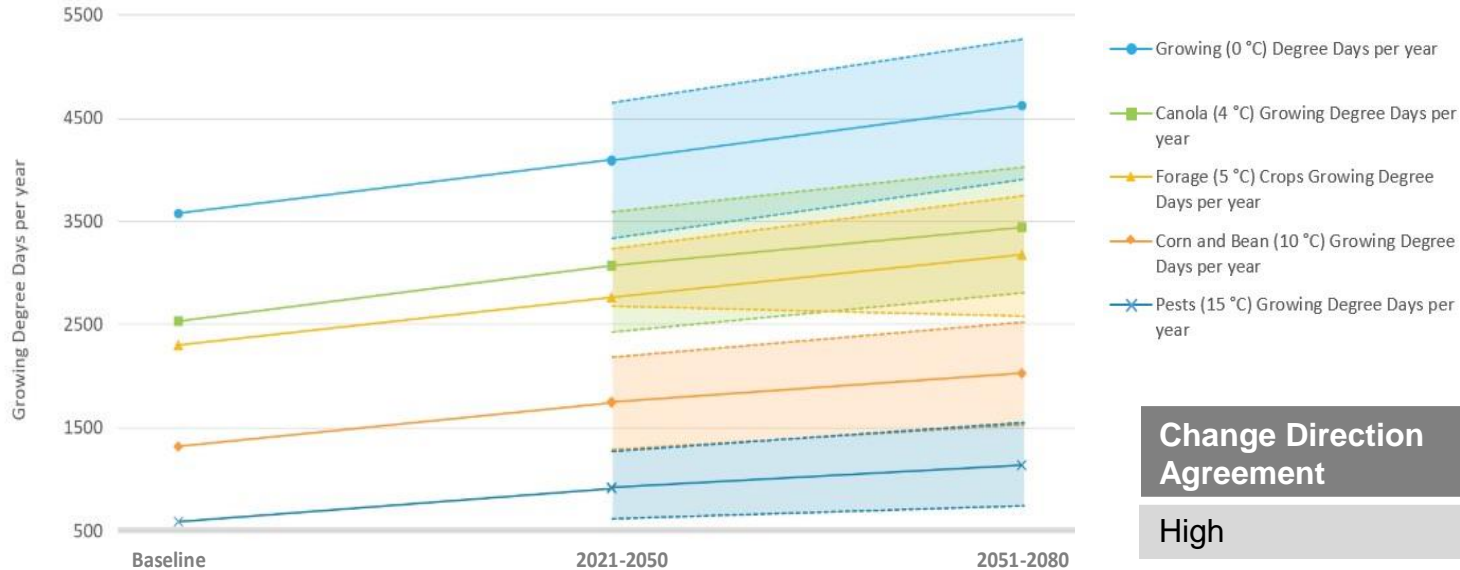
| Change Direction Agreement | Change Signal |
|----------------------------|---------------|
| High | High |

Growing Season Length



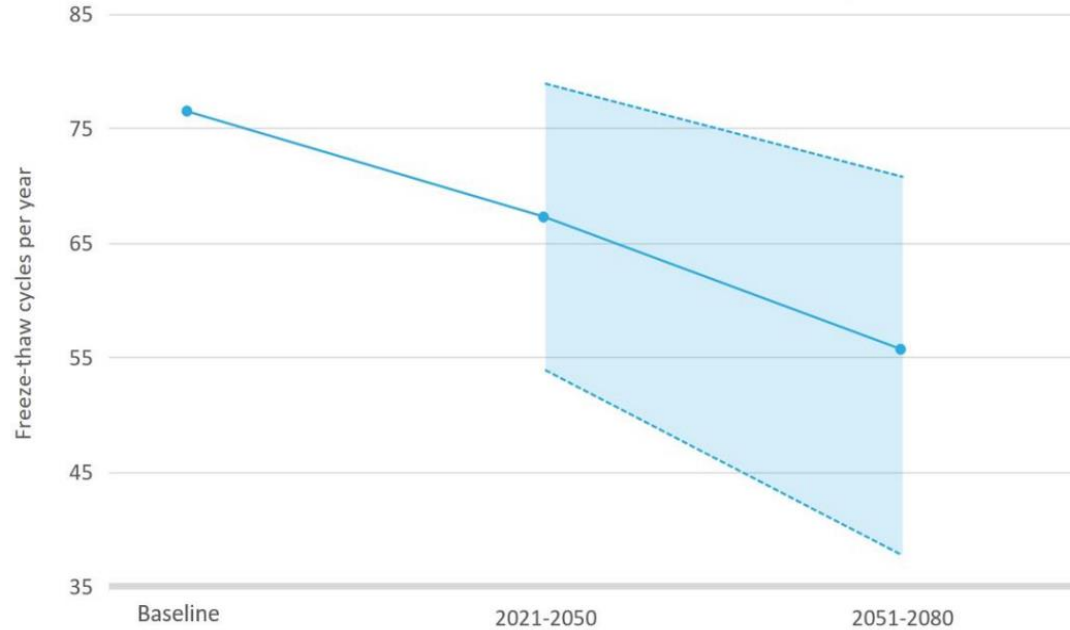
| Change Direction Agreement | Change Signal |
|----------------------------|---------------|
| Medium | High |

Annual Growing Degree Days



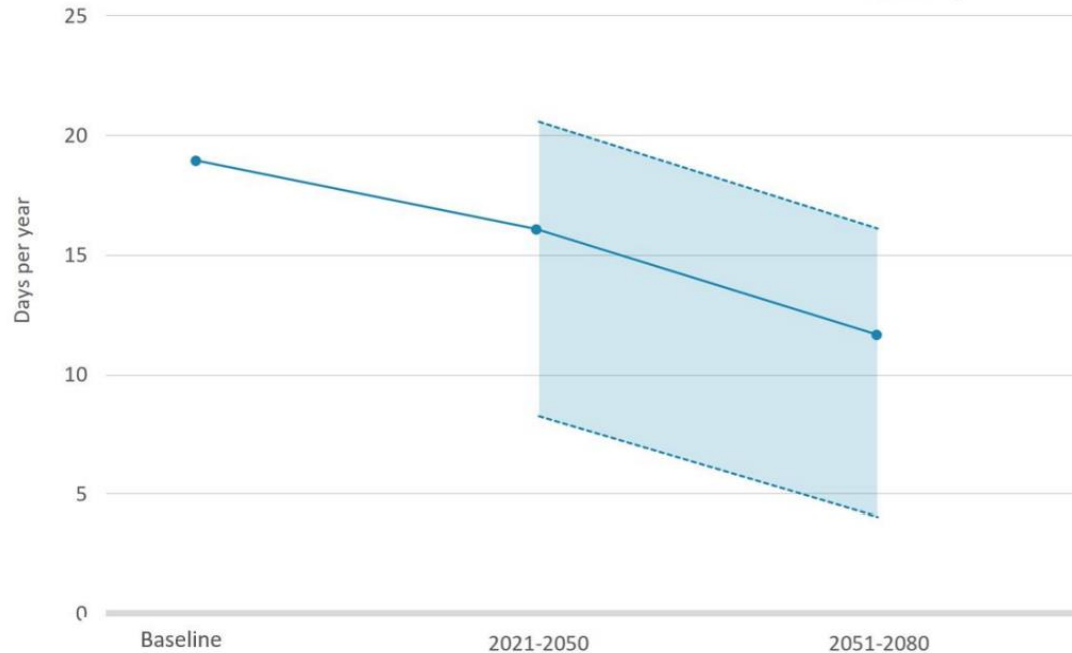
| Change Direction Agreement | Change Signal |
|----------------------------|---------------|
| High | Medium |

Freeze-Thaw Cycles: Daily Min Temperature Below -1°C and Max Temperature Above 0°C



| Change Direction Agreement | Change Signal |
|----------------------------|---------------|
| High | Medium |

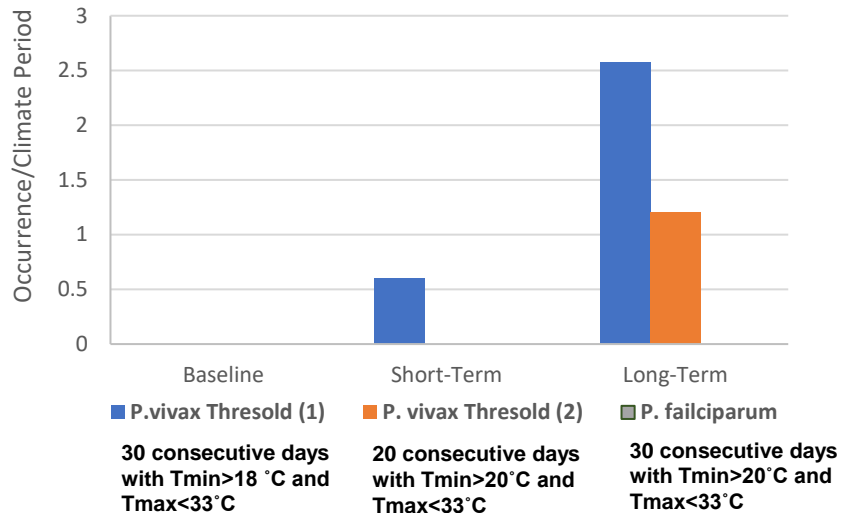
Ice Potentials: Daily Min Temperature $< -2^{\circ}\text{C}$, Max Temperature $< 2^{\circ}\text{C}$, and Precipitation $> 1\text{ mm}$



| Change Direction Agreement | Change Signal |
|----------------------------|---------------|
| High | Medium |

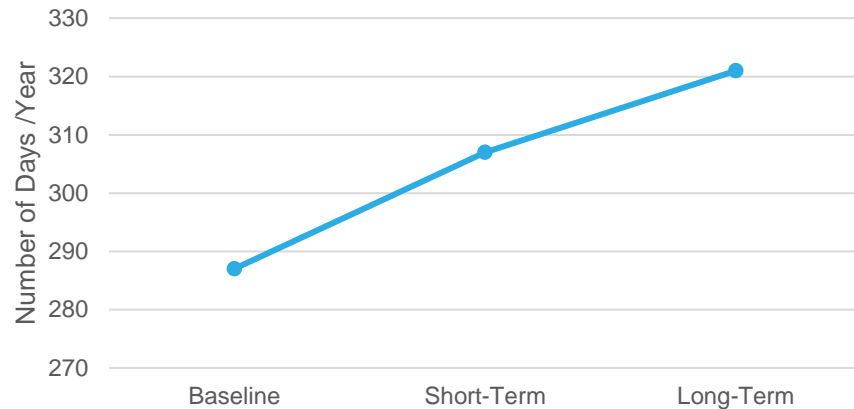
Public Health Variables

Temperature Suitability for Malaria Parasites



| Change Direction Agreement | Change Signal |
|----------------------------|---------------|
| Low | Low |

Daily Temperature Suitable for Ticks

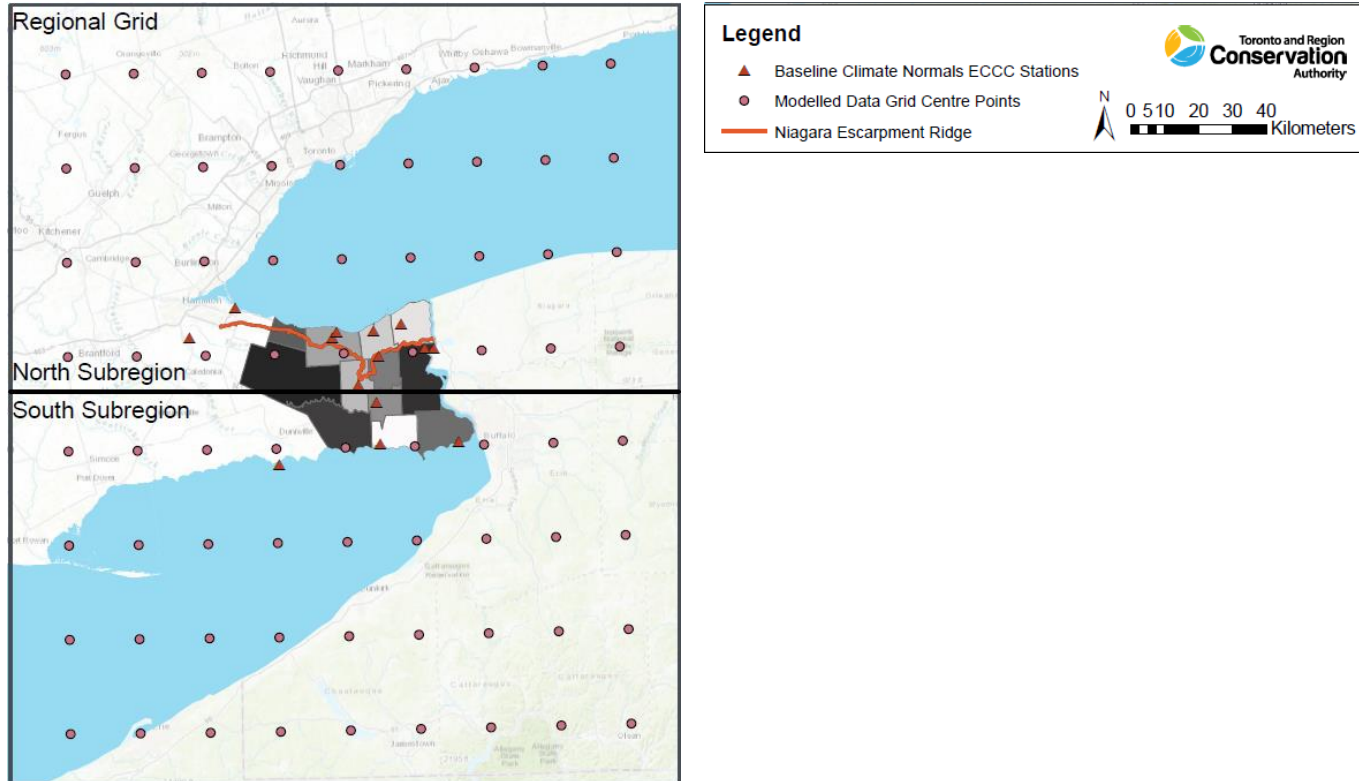


Daily Mean Temperature > 0 °C

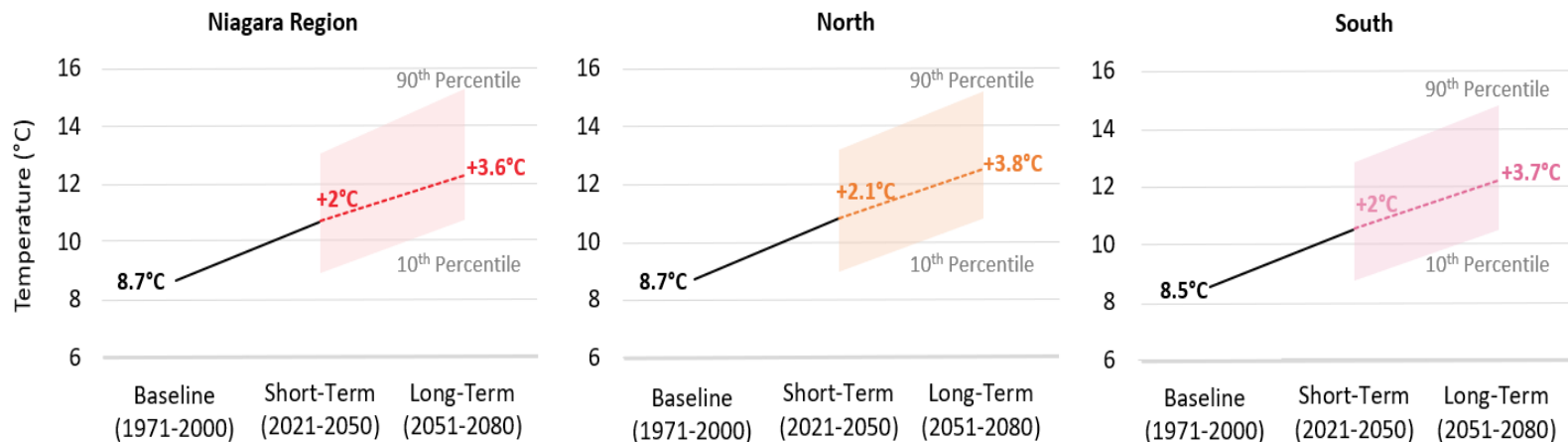
| Change Direction Agreement | Change Signal |
|----------------------------|---------------|
| High | Medium |

Comparison Between Regional and Subregional Climate Projections Under RCP 8.5 Scenario

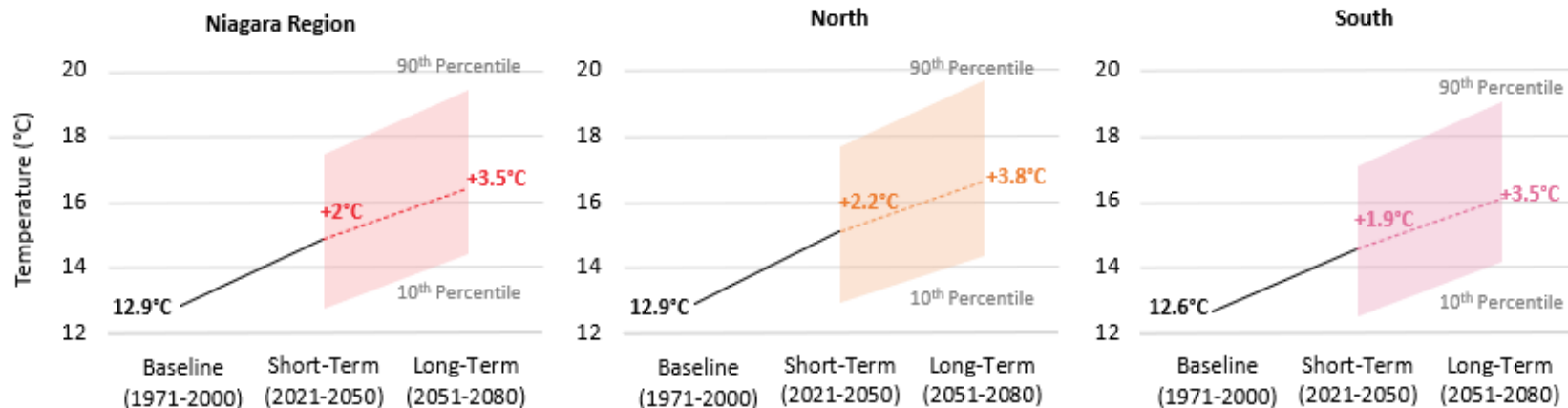
Subregional Grid Cells



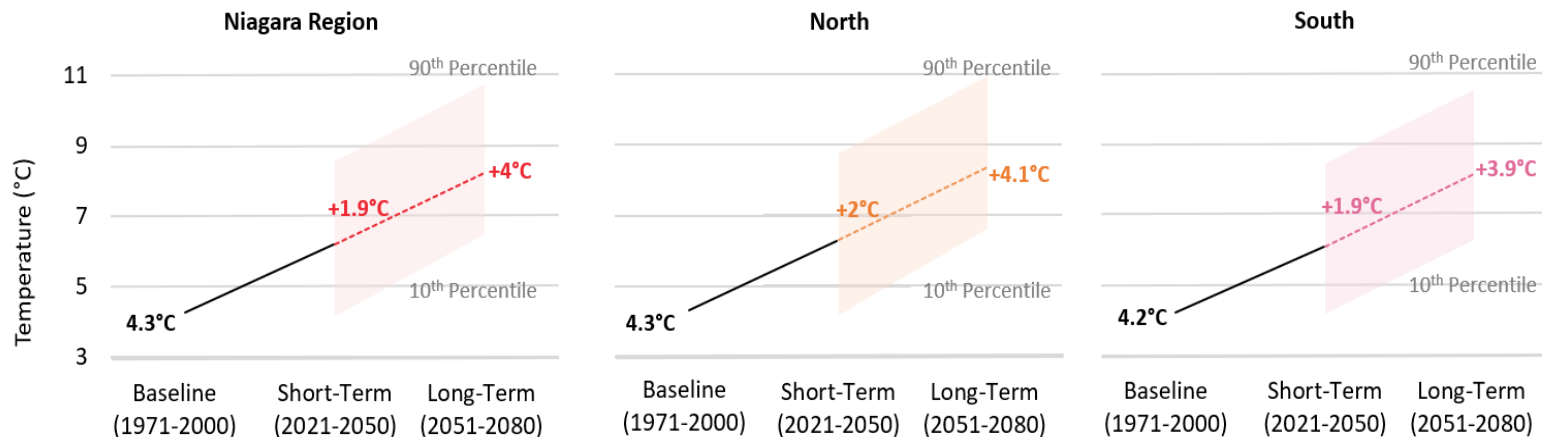
Mean Annual Daily Temperature Between Regional And Subregional Analysis



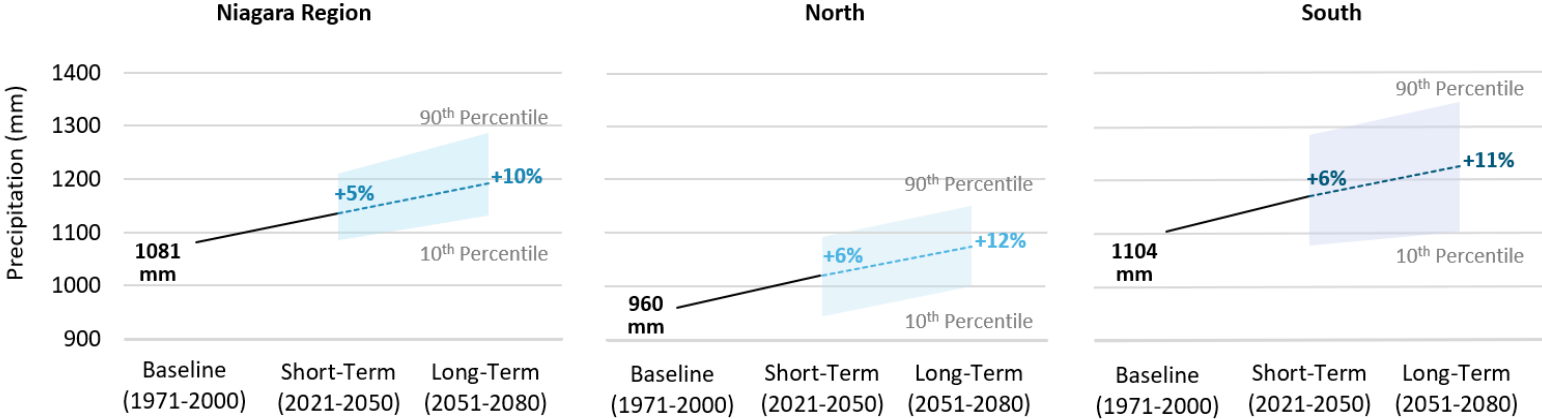
Mean Maximum Daily Temperature Between Regional And Subregional Analysis



Mean Minimum Daily Temperature Between Regional And Subregional Analysis



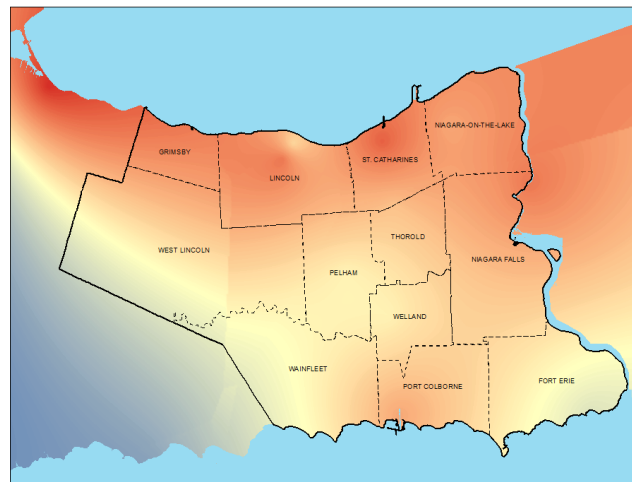
Mean Annual Precipitation Between Regional And Subregional Analysis



Spatial Analysis Under RCP 8.5 Climate Scenario

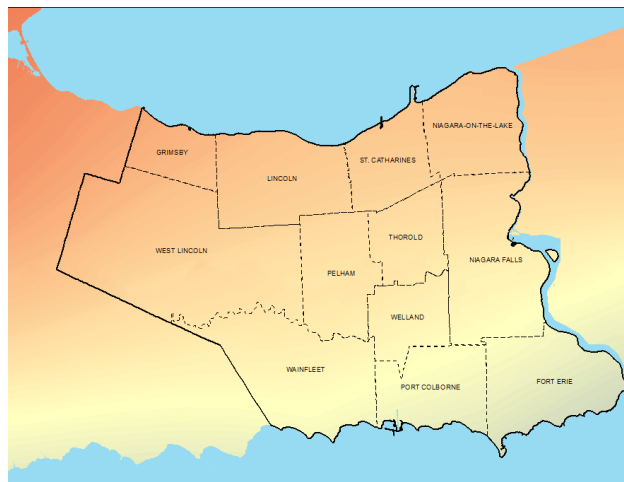
Average Annual Daily Mean Temperature (°C)

a) 1971-2000



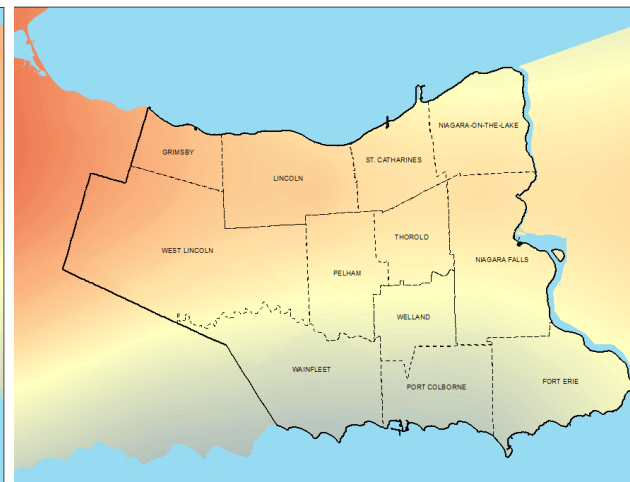
High : 9.3
Low : 7.6

b) 2021-2050



High : 10.9
Low : 10.5

c) 2051-2080



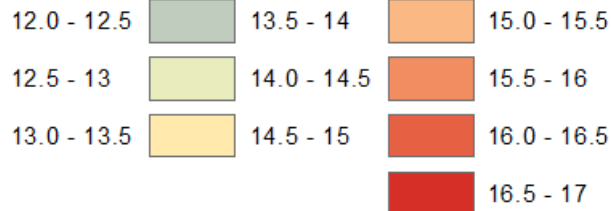
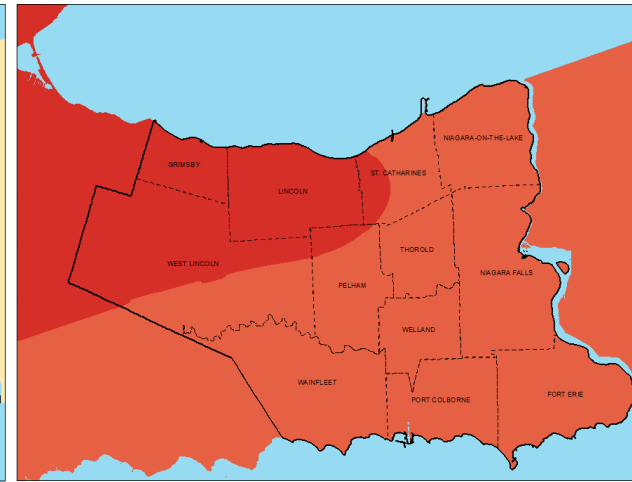
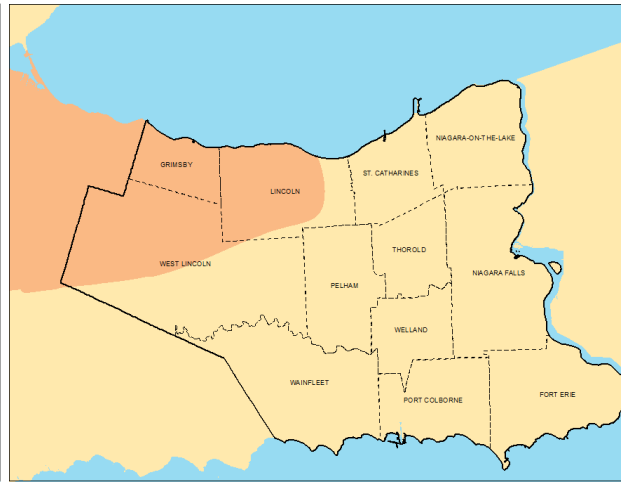
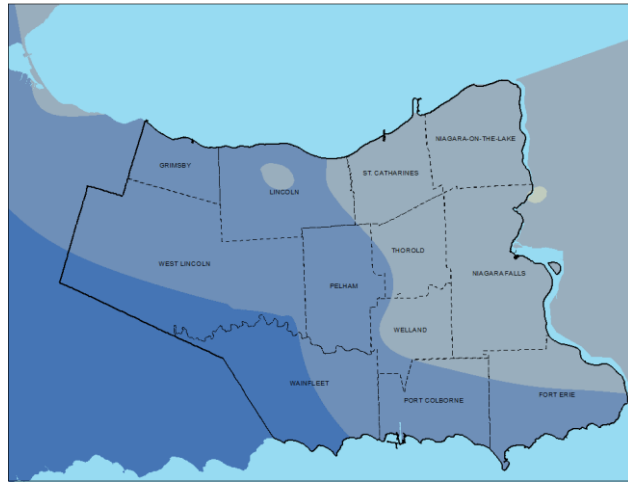
High : 12.5
Low : 12.0

Average Annual Daily Max Temperature (°C)

a) 1971-2000 (12-13.5 °C)

b) 2021-2050 (14.5 – 15.5 °C)

c) 2051-2080 (16 -17 °C)



1971-2000 to 2021-2050: 1 - 3.5°C increase

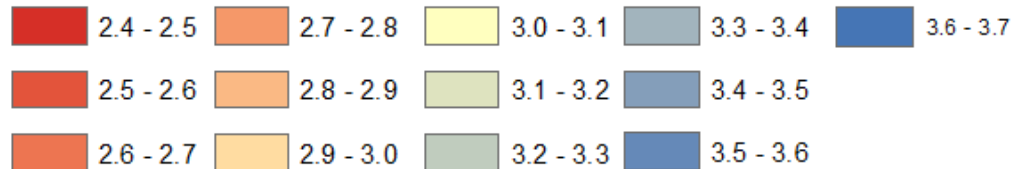
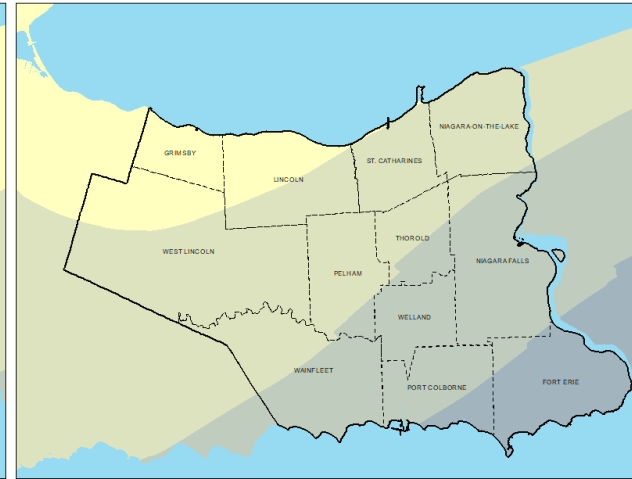
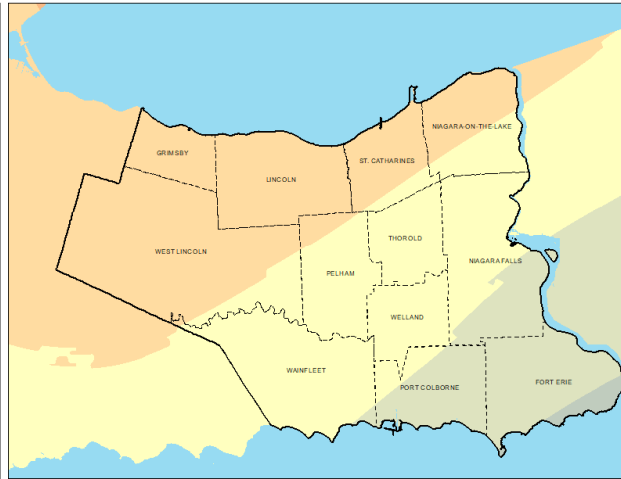
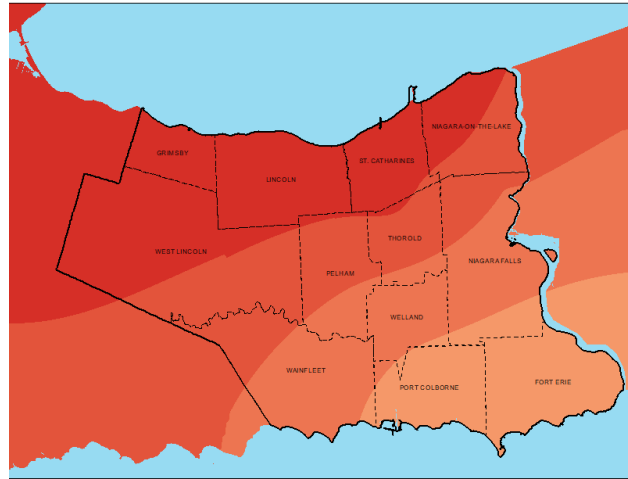
1971-2000 to 2051-2080: 2.5 - 5°C increase

Average Annual Daily Mean Precipitation (mm)

a) 1971-2000

b) 2021-2050

c) 2051-2080



1971-2000: 2.4 - 2.8 mm

2021-2050: 2.9 - 3.3 mm

2051-2080: 3.0 - 3.4 mm

A Rapid Comparison Between TRCA and Niagara Adapts Regional Climate Projections

| | TRCA | SCCCAP |
|----------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------|
| Data Source(s) | NA-CORDEX (the North American component of the Coordinated al Downscaling Experiment) | Climatedata.ca |
| Baseline Period | 1971-2000 | 1976-2005 |
| Future Periods | 2021-2050 and 2051-2080 | 2050 and 2100 (one year only) |
| Climate Stations | 12 Climate Stations | It is unclear which stations or how many contributed to St. Catharines projections |
| GCMs or RCMs? | Ensemble of RCMs | Ensemble of GCMs from CMIP5 (the Coupled Model Intercomparison Project) |
| Number of Climate Models | 16 climate models | 24 climate models |
| Climate Scenarios | RCP 4.5 and 8.5 | RCP 8.5 |
| Bias Correction Method | Delta approach where delta = difference between observed and modelled baseline values; one delta is produced for each model for all climate variables | Statistical downscaling (Bias Correction with Constructed Analogues and Quantile mapping, Version 2; BCCAQv2) |
| Output Scale | ~25 km x 25 km | ~10 km x 6 km |
| Consideration for the influence of the Great Lakes | Part of the model selection criteria so all models include some representation of the Great Lakes | n/a |

A Rapid Comparison Between TRCA and Niagara Adapts Regional Climate Projections

| Variable | TRCA (2021 2050) | | | SCCAP (2050) |
|-------------------------------------------|-----------------------------|--------|-----------------------------|--------------|
| | 10 th Percentile | Mean | 90 th Percentile | Mean |
| Mean Annual Air Temperature | 8.9 | 10.7 | 13.0 | 9 |
| Mean Winter Temperature | -3.5 | -0.4 | 1.9 | 0 |
| Mean Spring Temperature | 6.4 | 8.2 | 10.4 | 9 |
| Mean Summer Temperature | 20.2 | 22.0 | 24.2 | 23 |
| Mean Fall Temperature | 10.9 | 12.7 | 15.4 | 14 |
| Mean Annual Maximum Daily Air Temperature | 12.7 | 14.9 | 17.4 | 17 |
| Mean Annual Minimum Daily Air Temperature | 4.2 | 6.2 | 8.5 | 8 |
| Mean Annual Total Precipitation | 1086.0 | 1135.0 | 1209.1 | 1018 |
| Mean Winter Total Precipitation | 214.7 | 253.0 | 288.1 | 208 |
| Mean Spring Total Precipitation | 256.0 | 296.2 | 324.2 | 233 |
| Mean Summer Total Precipitation | 246.8 | 305.0 | 340.8 | 210 |
| Mean Fall Total Precipitation | 244.5 | 280.8 | 317.5 | 223 |

Conclusions

It can be expected that by the 2080s under RCP 8.5 Niagara Region will be:

- Warmer ($\sim 3.5^{\circ}\text{C}$ increase)
- Wetter ($\sim 10\%$ increase)
- More intense storms ($\sim 10\%$ increase in 1-day maximum precipitation)
- Opportunities for agricultural crops to thrive (increase in growing degree days by 10% to 20%), however, risk of pests will be higher by $\sim 30\%$

Limitations of the Study

- There are more suitable bias correction methods for precipitation datasets (quantile mapping)
- Baseline results are derived from modeled data
- Areal extents of the study area and number of grid cells used have an impact on the results

Discussion Questions

1. What are your impressions of the data?
2. How is climate data being used now?
3. How can climate data be integrated into future projects?
4. Are there additional climate parameters/products of interest?

Thank You!

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