Environment and Climate Change Canada | Environnement et Changement climatique Canada

THE FASCINATING ALBEIT UNPAVED ROAD FOR SUBKILOMETER NWP SYSTEMS

A CANADIAN PERSPECTIVE

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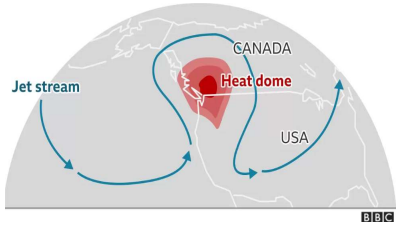
Aknowledgements to ECCC individuals for contributions and useful discussions
Thanks to S. Bélair, M. Verville

L(2

HIGH EXPECTATIONS ON HECTOMETRIC NWP

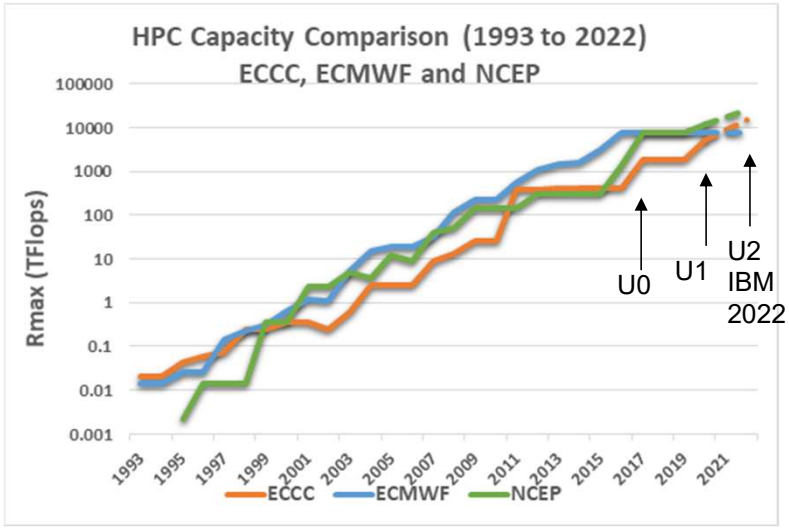
- Recurrent Extreme Weather Impacts
  - Localized heavy Rainfalls
  - Heat waves
- Urban Heat Island, Heterogeneity
  - Services for urban dwellers
- Valleys / mountains

June 2021
British Columbia



- More recently
  - Air quality
  - Hydrology
  - Climate change adaptation
  - Outdoor and indoor

- Increase of High Performance Computing resources



J-P Gauthier

Diapositive 2

L(2 Leroyer,Sylvie (ECCC); 2022-09-24

CURRENT BALANCE BETWEEN COUPLING AND AFFORDABILITY

- *new at 2.5 km*
- *radar (latent heat nudging)*

Soil Moisture
(CaLDAS screen & Sat)

** Meteorological Service of Canada*
***Global Environmental Multiscale model*

Data assimilation: surface

Atmospheric forcing from MSC*

Data assimilation: atmosphere

Water** surface **temperature** & **Ice** cover **(Great lakes…)

2D
Aka **SPS** or GEM-SURF

3D
interactions

Contractual
Or
Scenarios

Canopy Representation

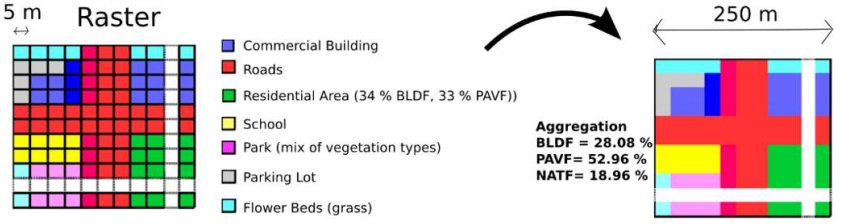
Surface models, **TEB**$^{\Delta}$ **ISBA** $^{\beta}$ or **SVS** $^{\lambda}$

GEM** Atmospheric model

5th Generation

(a)

Databases
vectorial data
Raster data
Population density
2.5 D building heights



$^{\Delta}$ *Town Energy Balance*
$^{\beta}$*Interaction between the Soil and Biosphere and the Atmosphere*
$^{\lambda}$ *Soil Vegetation and Snow*

MAIN GEM-3D 250 M PROJECTS AT ECCC

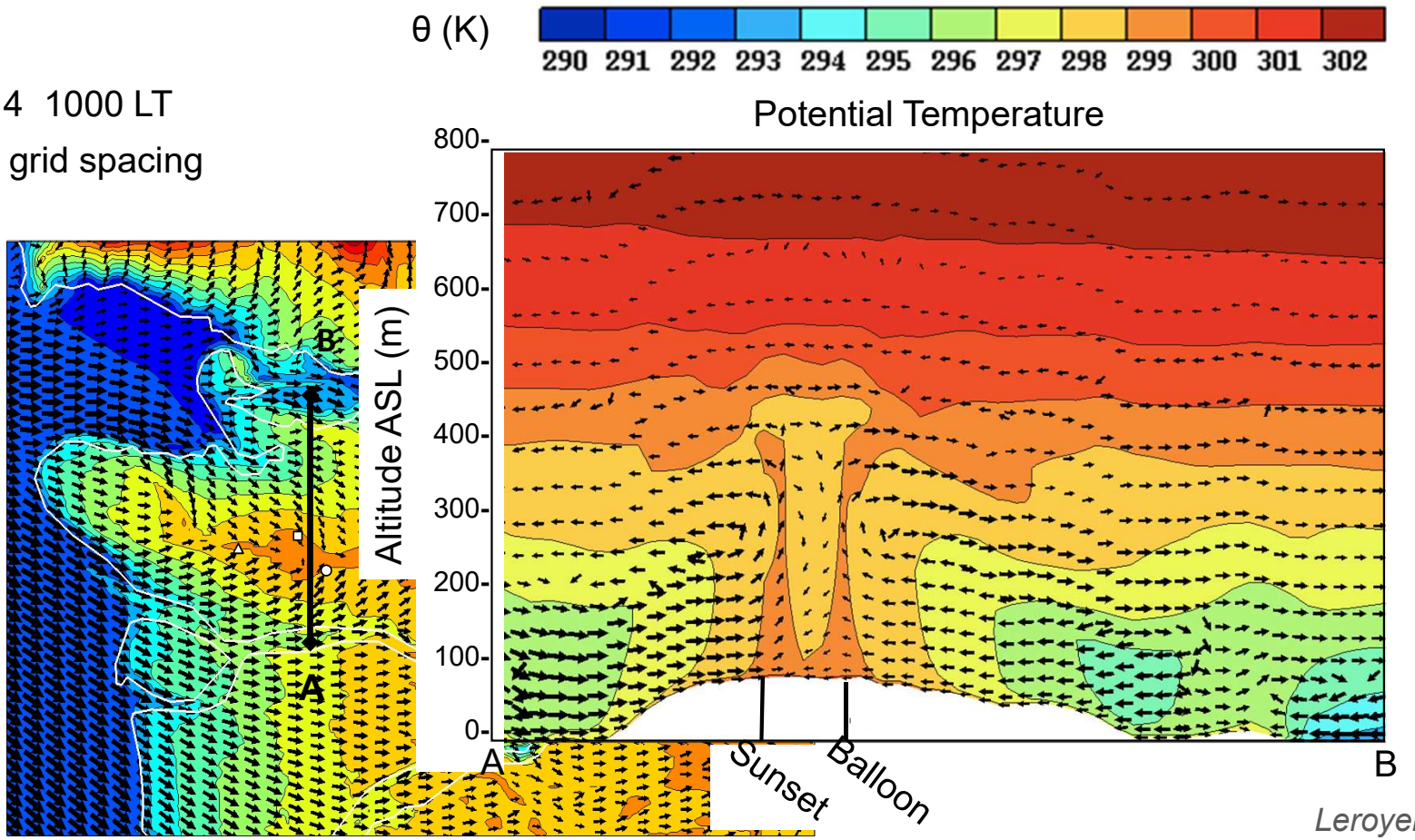
R(research) D(development) O(Operations)

Region	Context	Scientific Target	Grid points	1st vertical level (U)	Reference
Oklahoma City (US)	R- Joint Urban 2003	US plains Low-level jet and UHI	400 x 200	40 m (GEM3)	Lemonsu et al (2009)
Vancouver (CA)	R- EPiCC	Sea-Breeze and UHI	300 x 300	10 m (GEM4)	Leroyer et al. (2014)
Rocky Mountains (CA)	R-	Mountains and snow prediction	648 x 450	10 m (GEM4)	Vionnet el al (2015)
Sochi (RU)	R&D- JO2014 games (RDP) → REALTIME	Mountains and wintertime prediction,		40 m (GEM4)	Kiktev et al. (2017)
Toronto (CA)	R&D- PanAm Games 2015 → REALTIME (1 year)	Urban-scale integrated prediction (NWP, UHI, thermal comfort)	1024 x 1024	10 m (GEM4)	Leroyer et al. (2018) Joe et al. (2018) Leroyer et al. (2022)
Toronto (CA)	R&D&O- ECCC 2017 flooding → REALTIME (3 months)	Great-lakes water-level assessments, waves height, 2017 floods	1024 x 1024	10 m (GEM4)	
Tokyo (JP)	R- TOMACS	Heavy Rainfall, Sea-Breeze and UHI	1024 x 1024	10 m (GEM4)	Bélair et al. (2018)
French Guiana (Fr)	R- HAIC-HIWC	Clouds and microphysics	640 x 640	10 m (GEM4) 20 m (GEM5)	Barker et al. (2018) Qu et al (2018) Qu et al. (2022)
Toronto, Montreal (CA)	R- Quebec Health Institute	Heat mitigation strategies	1024 x 1024	10 m (GEM4)	Leroyer et al. (2019) – report ongoing
Toronto, Montreal (CA)	R&D- ECCC 2019-2020 →realtime, on pause	NWP	1024 x 1024	10 m (GEM5)	
Alberta (CA)	D&O- ECCC summer 2021	NWP, thunderstorms (temporary assistance during a radar loss)	2011 x 2292	10 m (GEM5)	ECCC report
Paris (FR)	R&D- JO2014 Games (RDP), PANAME2022	Urban-scale NWP, Heat Waves, UHI, convection; testing 100 m	1024 x 1024	10 m (GEM4) (GEM5)	Forster, A., et al (2020)-report Ongoing
Montreal (CA)	R- Master study	UHI, thunderstorms and mitigation	1024 x 1024	10 m (GEM5)	ongoing
Detroit (US/CA)	R&D- MOOSE	Air quality	1024 x 1024	10 m (GEM5)	ongoing

VANCOUVER FOR THE FIRST EXPERIENCE WITH CANADIAN CITIES

Aug 14 1000 LT

250 m grid spacing

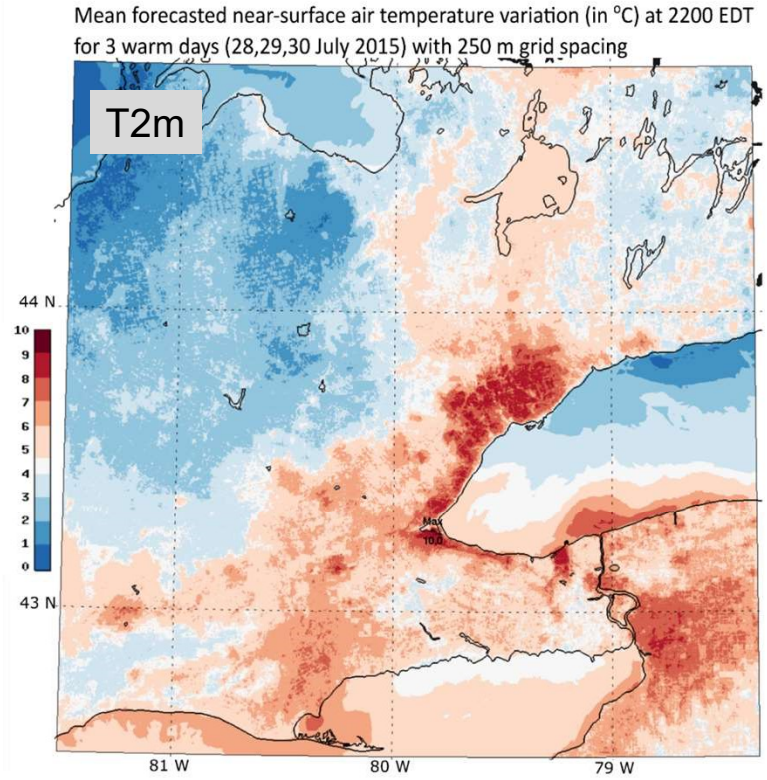


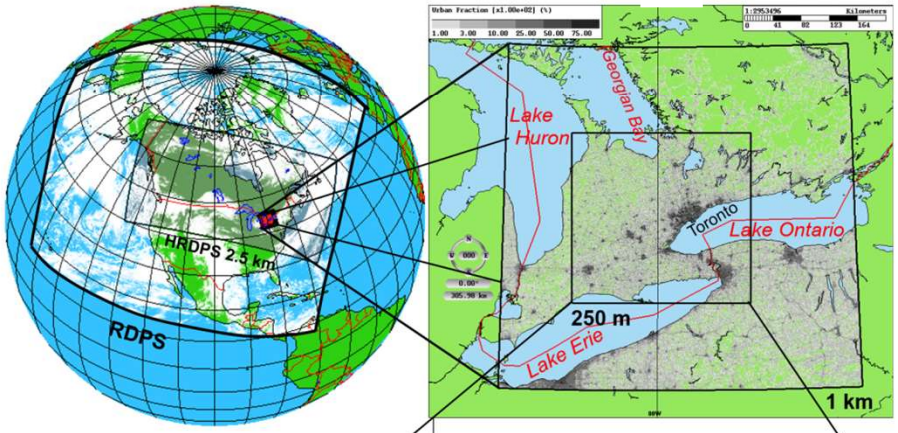
Leroyer et al. 2014

- Such resolution permits the representation of oscilating convergence line above residential districts
- Grid point comparison in the convergence area : not obvious improvment for hectometric

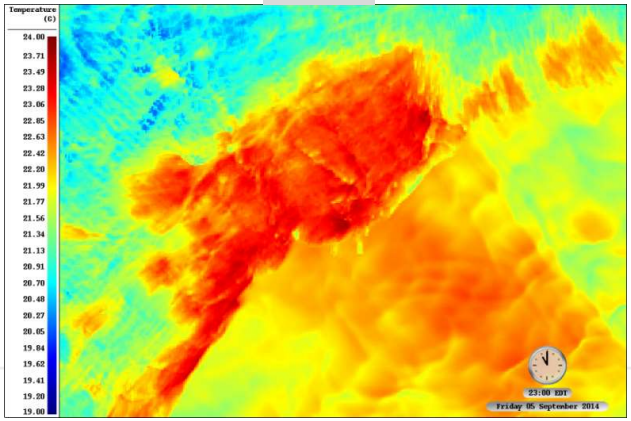
TORONTO FOR THE FIRST URBAN-SCALE REALTIME 250 M FORECASTS: PANAM

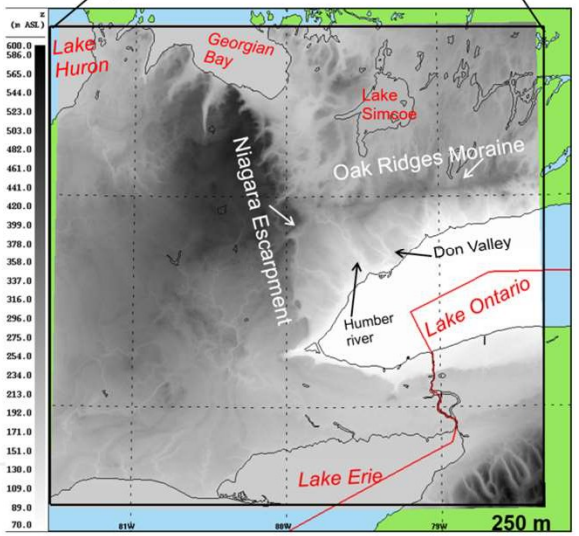
PanAm Games in Toronto 2015
Experimental realtime, in R&D mode but with products disseminated
ECCC science project *(Joe et al. 2018)*





T5m

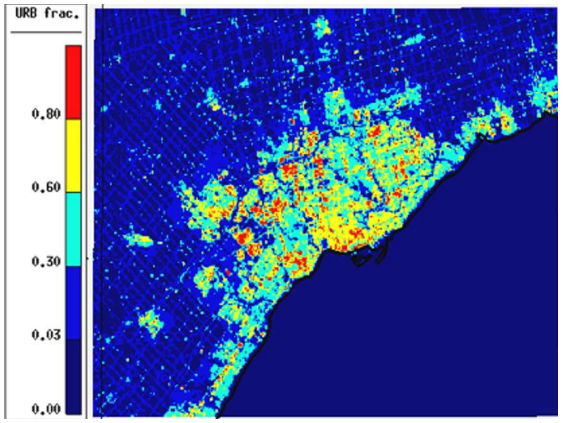




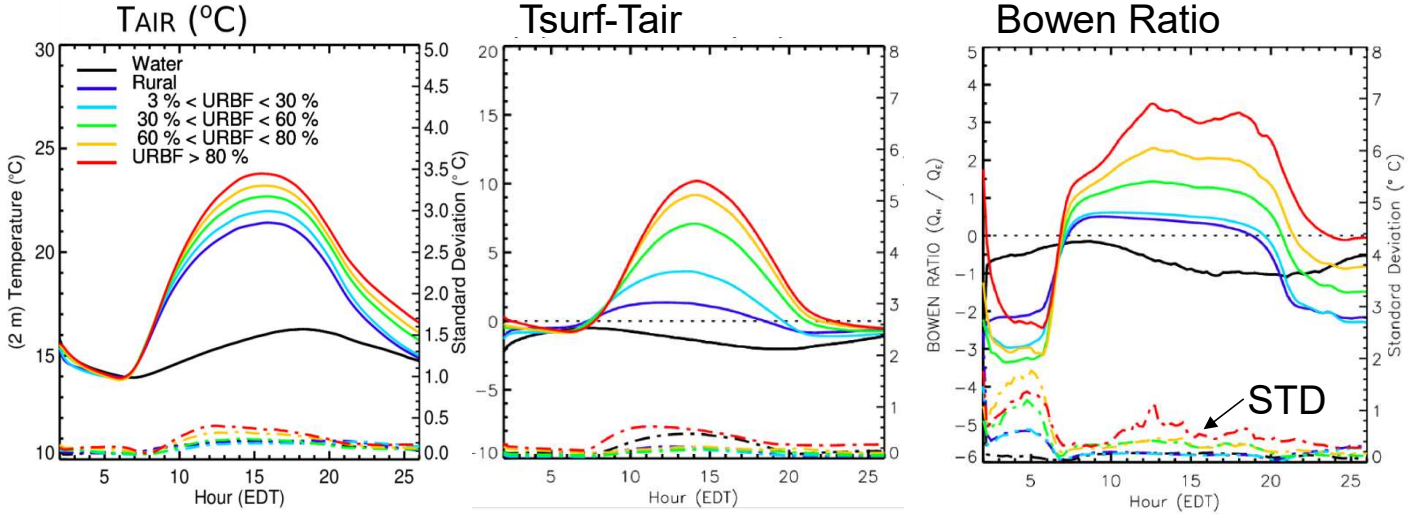
URBAN HETEROGENEITY PREDICTION

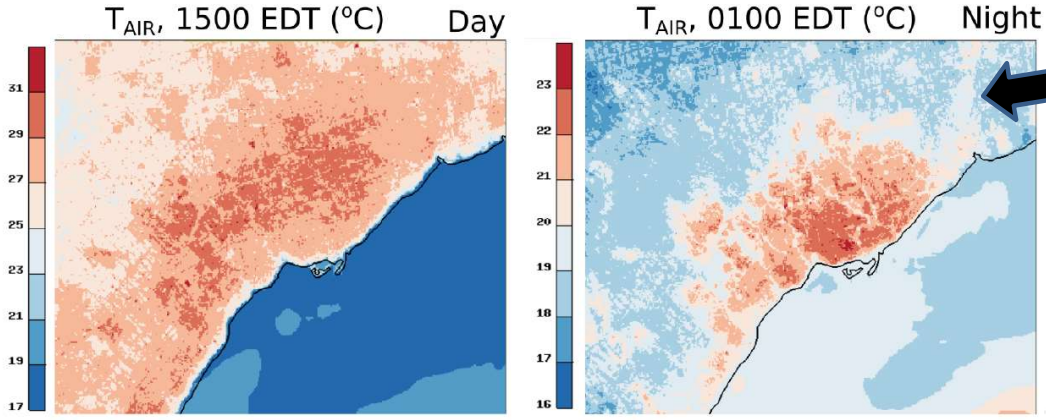
TOR-GEM250

= GEM model with 250m grid spacing for Toronto



Detailed urban microclimate forecasts (Toronto PanAm period, 15 May-31 Aug. 2015)





Days with lake-breeze (low-deformation)

- Sub-km urban-scale forecasts allows for the refined urban microclimate forecasts
- Interactions with the local/mesoscale weather patterns

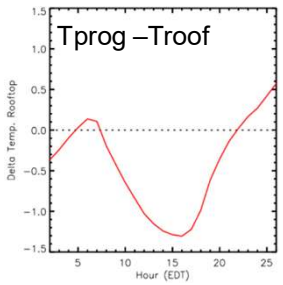
GAPS :

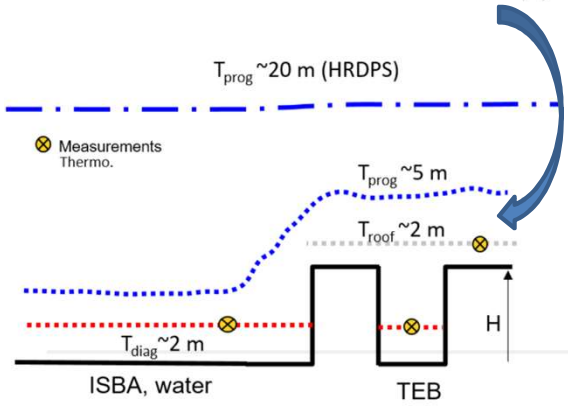
- Initialization might be improved

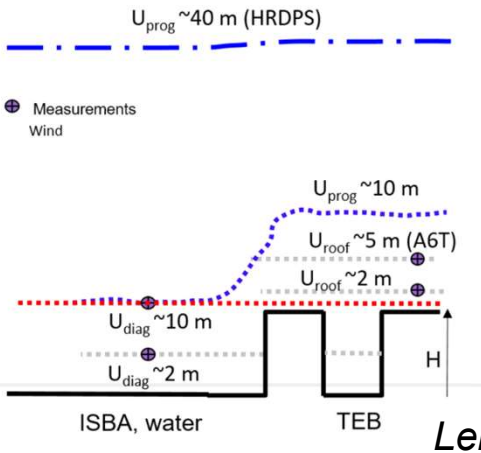
Leroyer et al. 2022

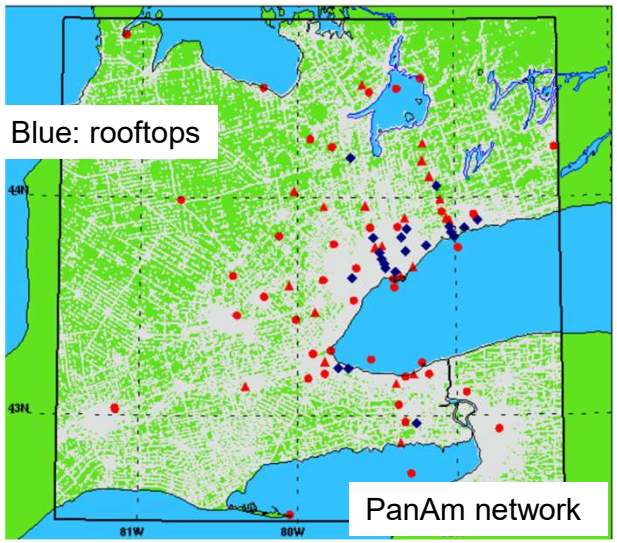
OBJECTIVE EVALUATION WITH A DENSE OBSERVATIONAL NETWORK

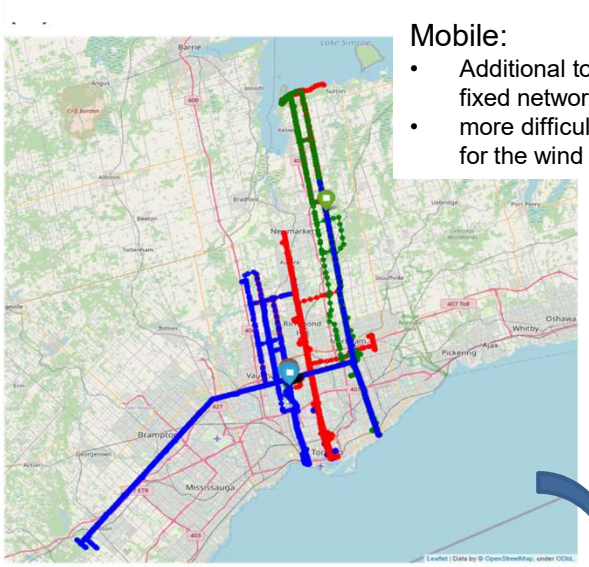
- Efforts to consider variables that are fairly comparable between sensors and prediction assumptions
- Importance of metadata in databases
- Eg: modelled difference of temperature above the roof



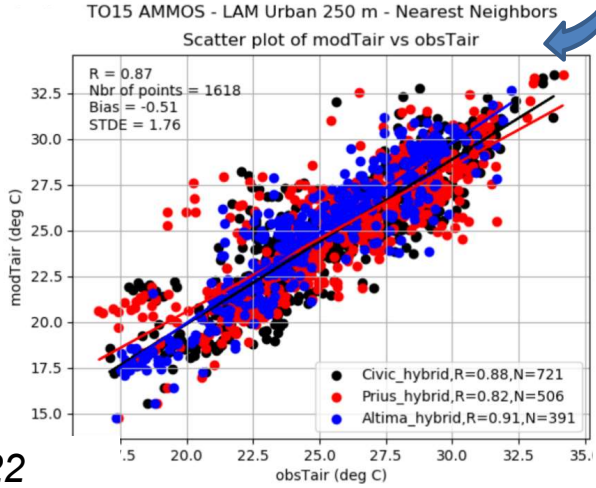






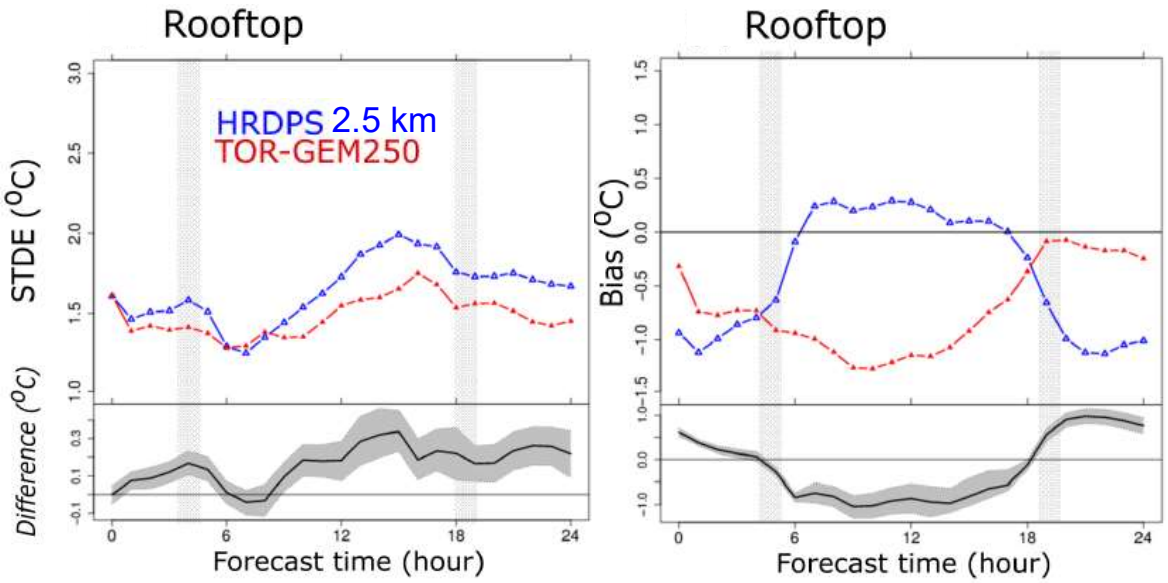


Mobile:
- Additional to fixed network
- more difficult for the wind



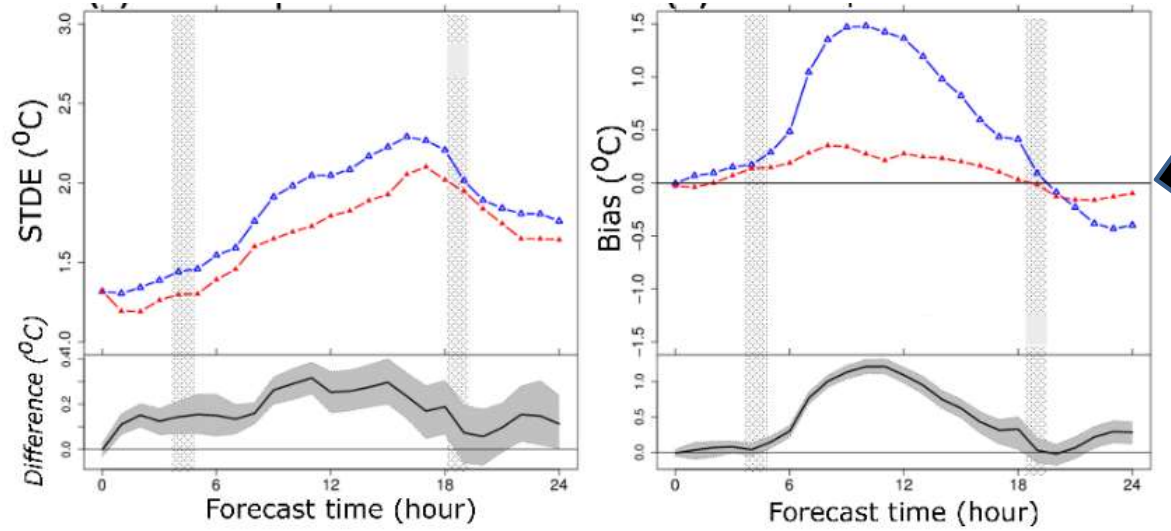
Leroyer et al. 2022

SUMMERTIME MAY-AUG



TEMPERATURE

- Improvement in the STandard Deviation Errors STDE indicate a better spatial variability in the city, which is one of the target



DEW POINT TEMPERATURE

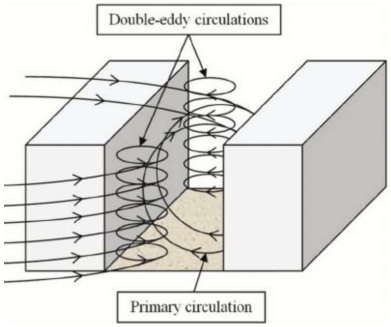
Leroyer et al. 2022

SUMMERTIME MAY-AUG

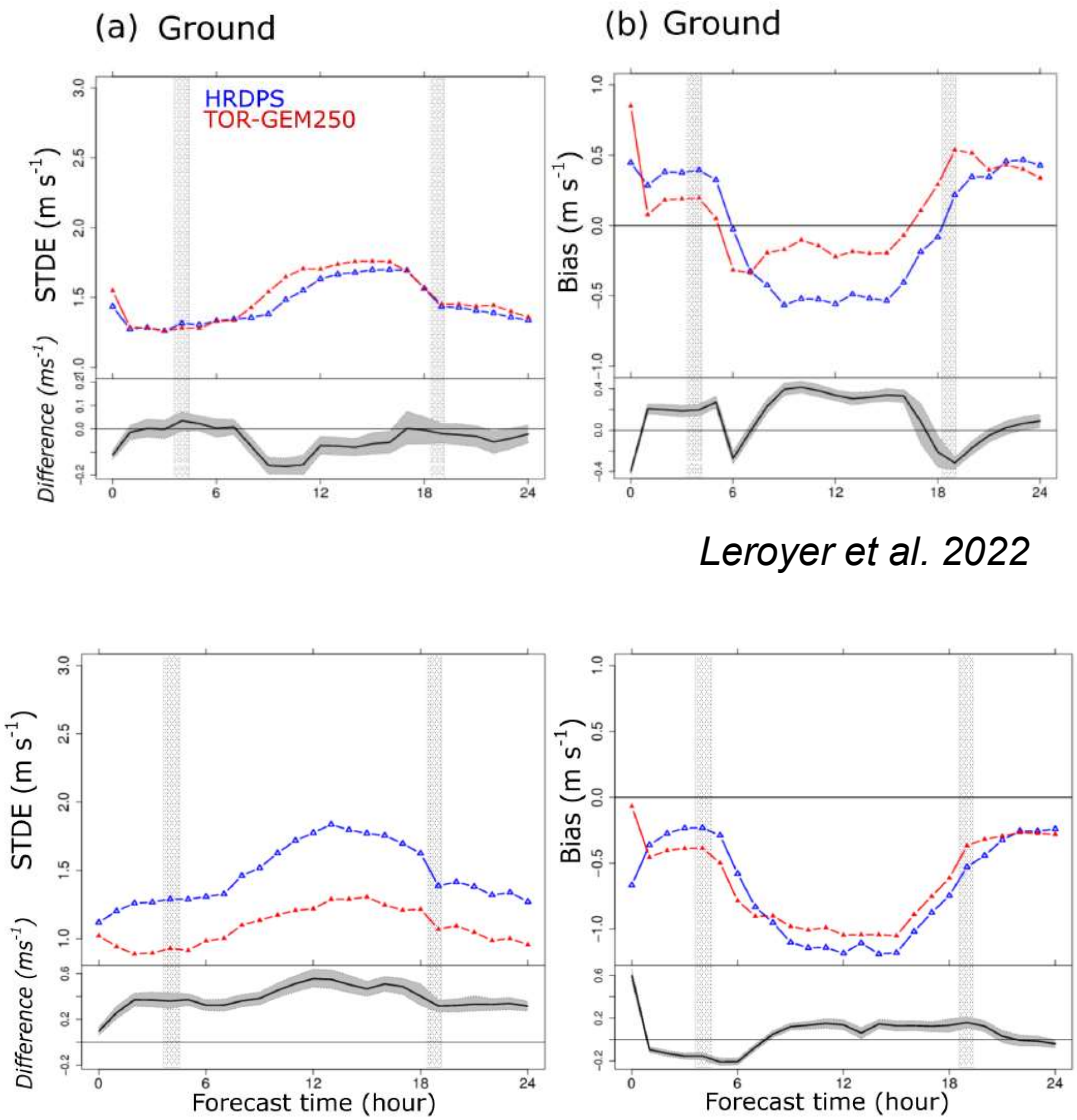
WIND **(10 m height, Ground stations)**

- Sub-km not always outperforms lower-resolution model (STDE)
- Need more research and wind data at different heights (2 m)
- Such system cannot represent all complex wind features

Yazid, M., et al (2014)



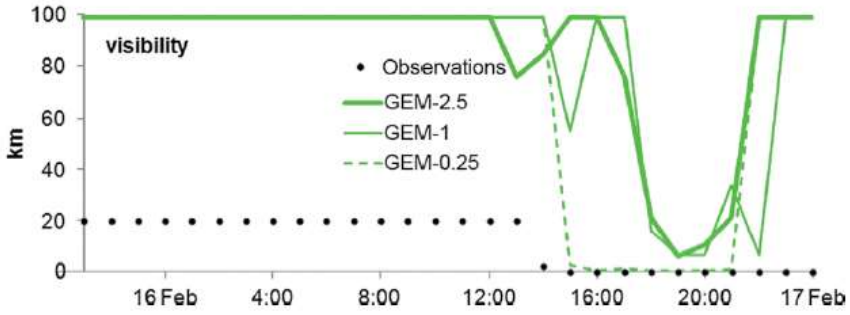
2.5 m Rooftop, height correction



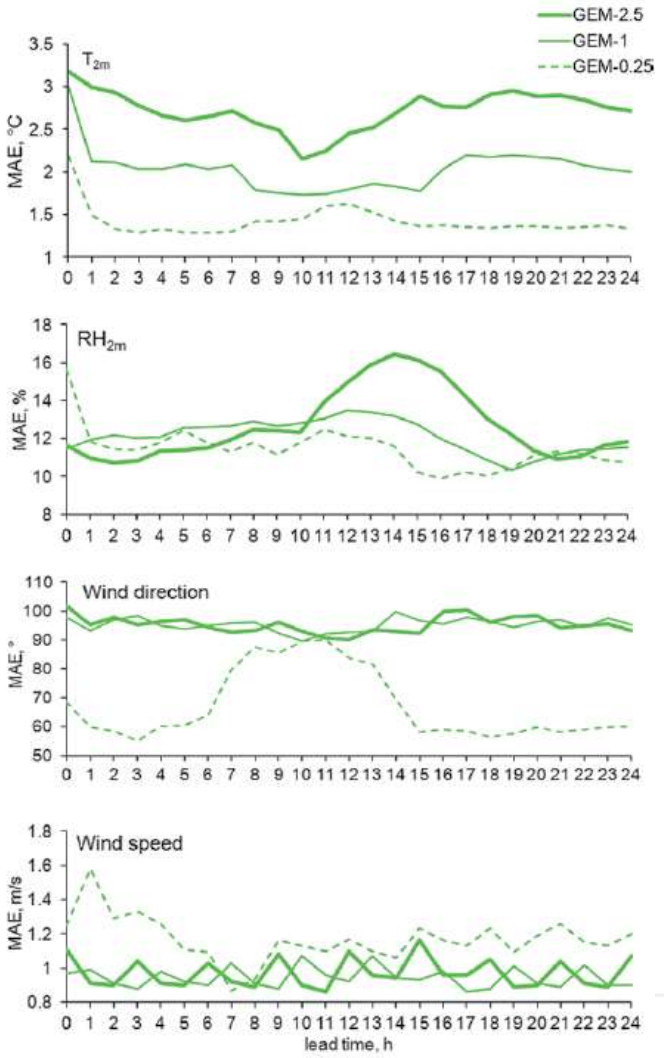
Leroyer et al. 2022

WINTERTIME AND MOUNTAINS

Sochi
Frost



Kiktev et al. (2017)

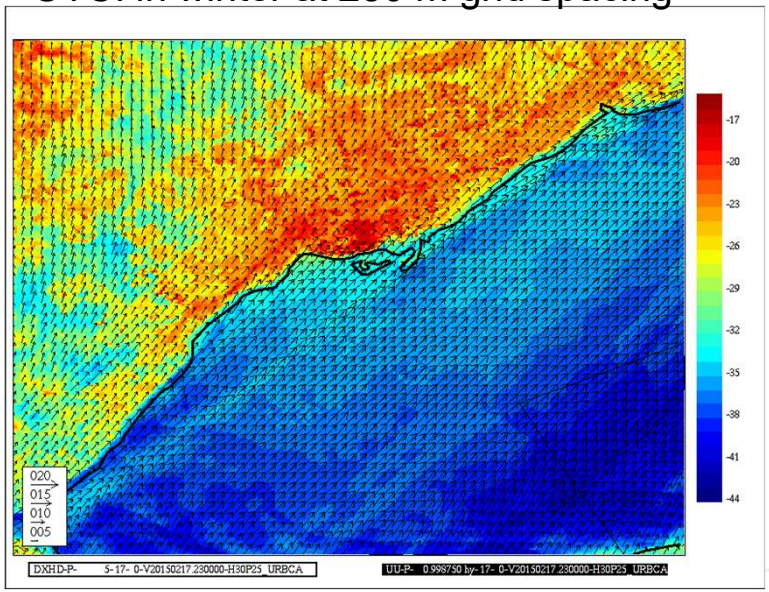


- In general improvement with hectometric scale but not always, not everywhere.
- For the wind, several studies agree that statistical score are not better at 250 m than 1km.

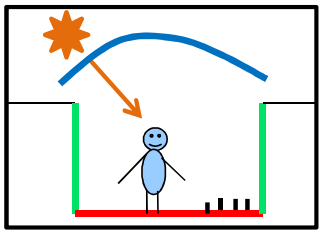
NEW ERA FOR THE THERMAL COMFORT FORECASTING

- In Canada : **Humidex** (T, Hu) and **wind Chill** (T, U) as operationnal references
- In recent years : dissemination of **UTCI** and **WBGT** (T, Hu, U, rad)
- and **MRT** (Rad) in short-range forecasts
  - Now in WMO grib tables
- High-res : surrounding surfaces contributions

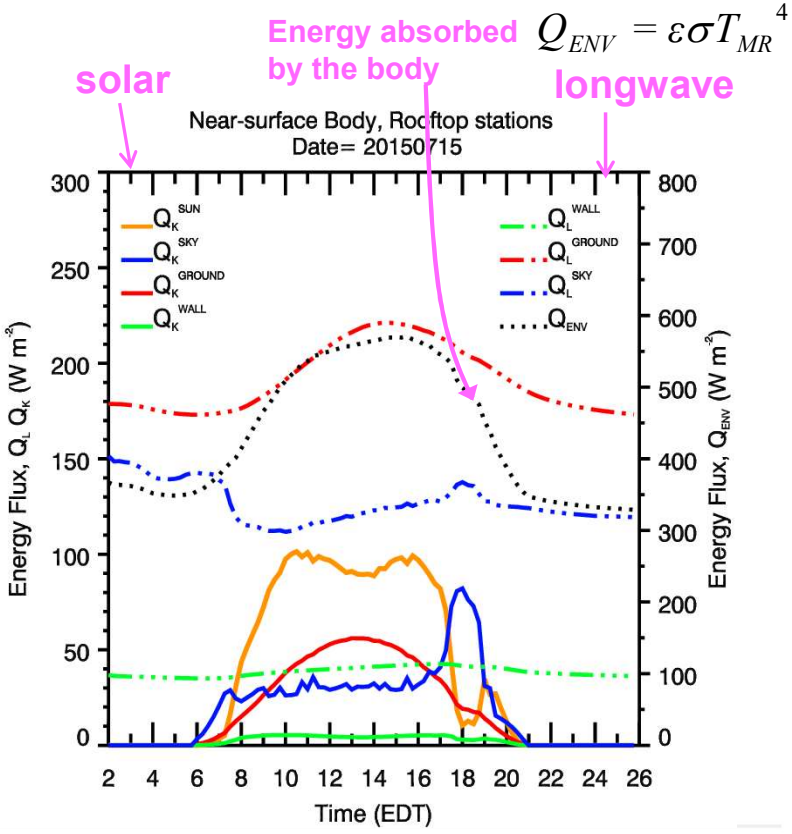
UTCI in winter at 250 m grid spacing



Radiation Budget for a standing human

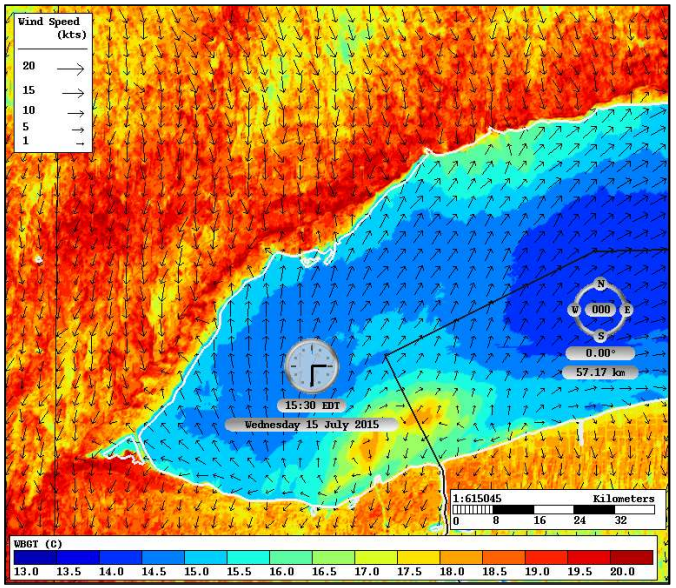


$Q_{ENV} = \varepsilon\sigma T_{MR}^{4}$

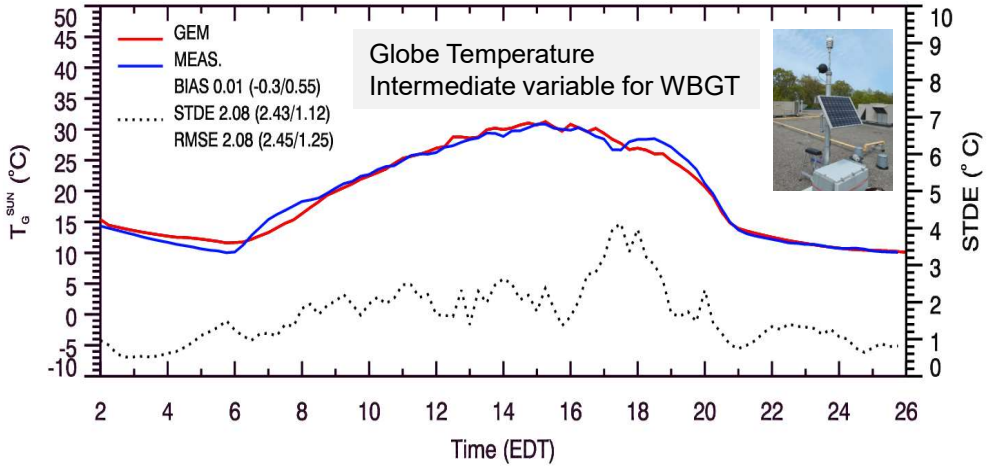


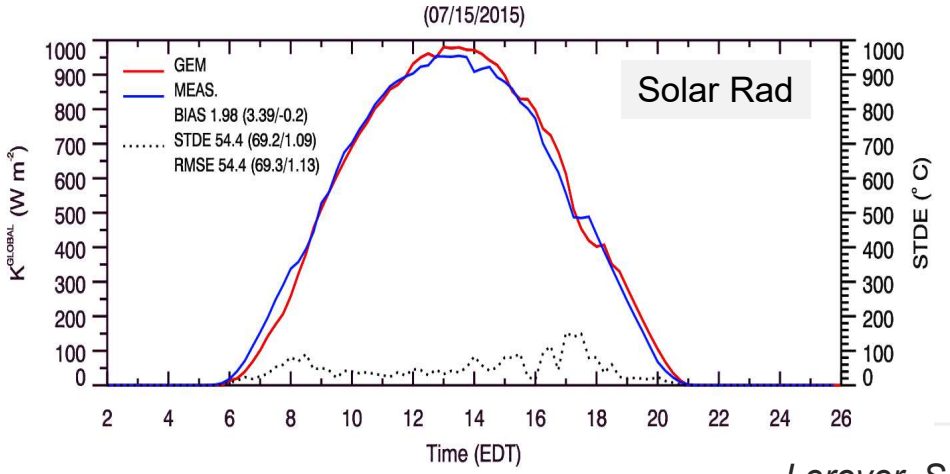
Leroyer, S., et al (2018)

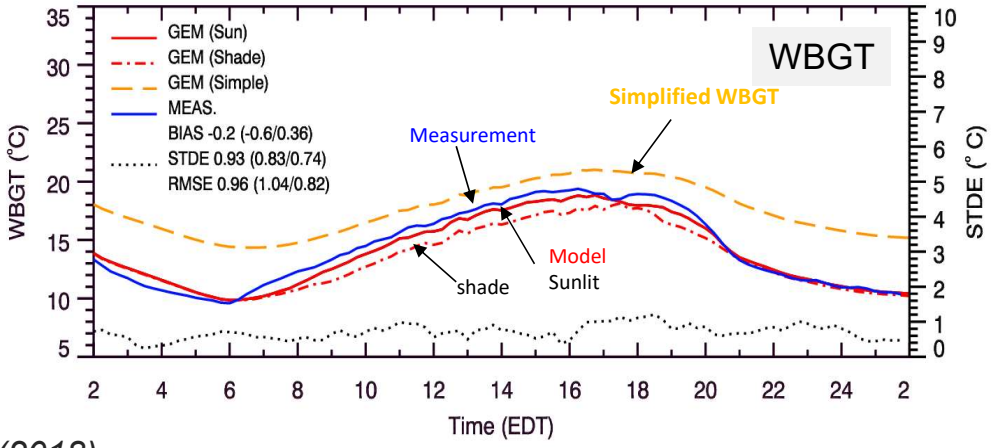
EVALUATION OF WBGT WITH THE PANAM NETWORK (TORONTO)



-15 July 2015
-Clear-sky and mild
- 7 stations with solar rad mesurements
-Convergence above the city



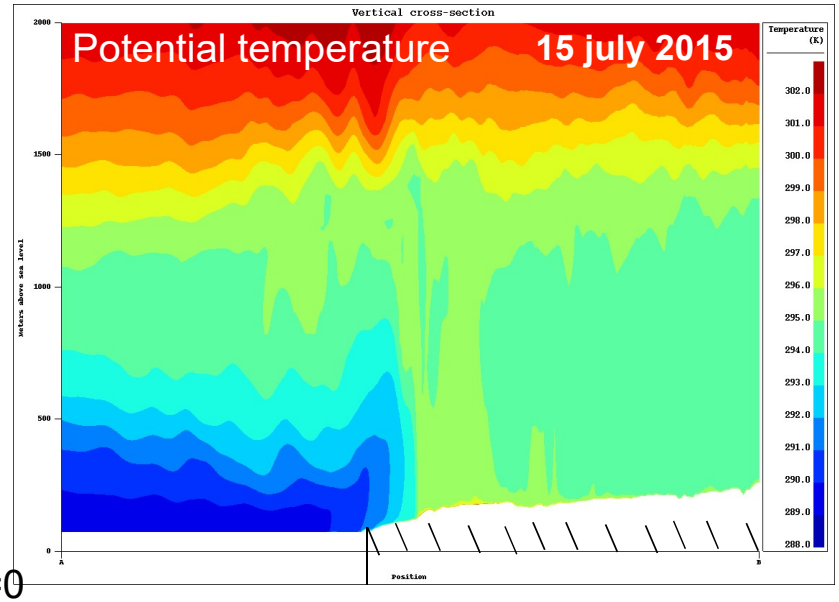




Leroyer, S., et al (2018)

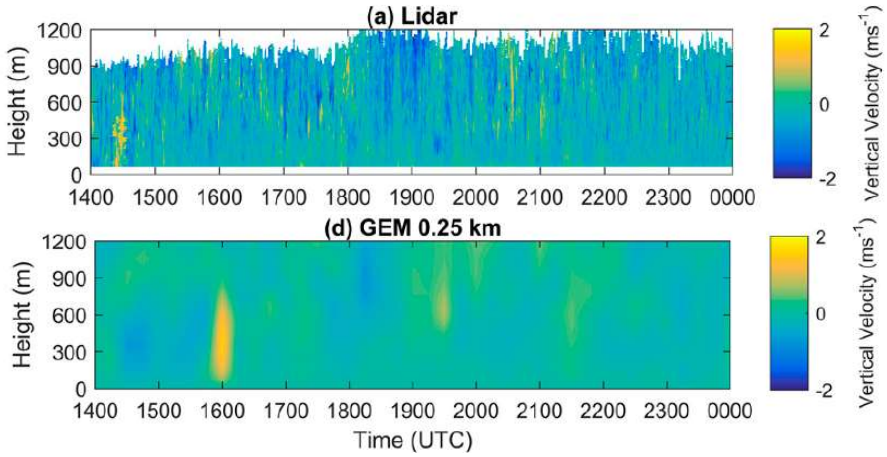
MESOSCALE CIRCULATIONS FORECASTING (LAKE-BREEZE)

z=2000m

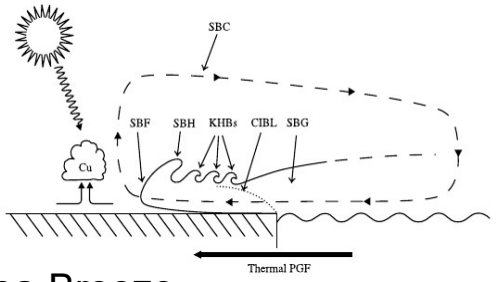


Z=0

- Lidar :vertical velocities

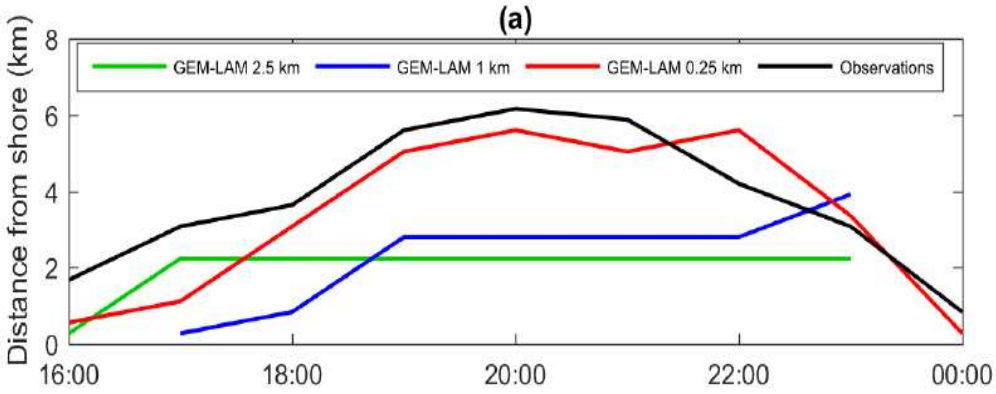


Dehghan, A., et al 2018



Sea-Breeze System, Miller, 2003

- Evaluation with Lidar/mesonet analysis



CLOUD FORECASTING DURING A PURE LAKE-BREEZE EVENT

MODIS (Terra)

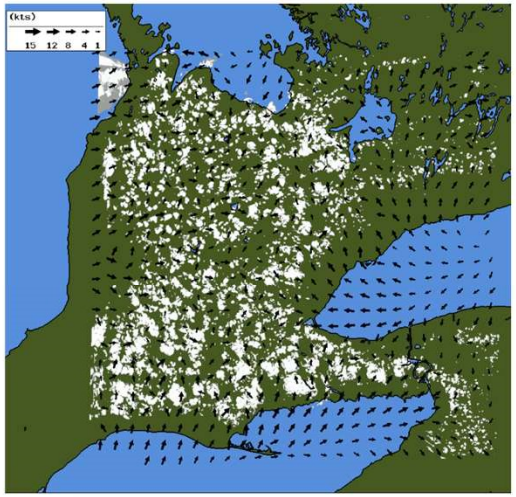
MODIS
AQUA
Visible : 250m

iCast
Analysis

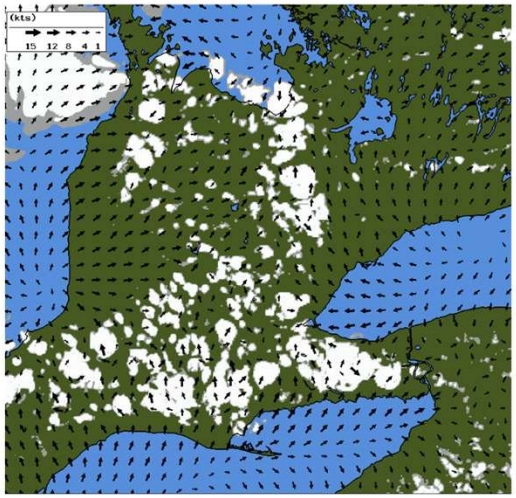
•18 July 2014

Leroyer et al. 2022

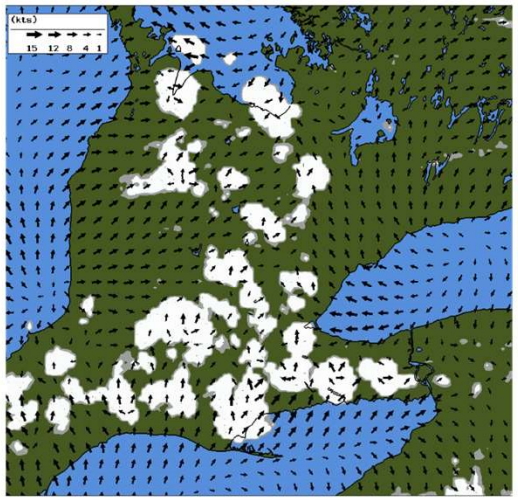
Models



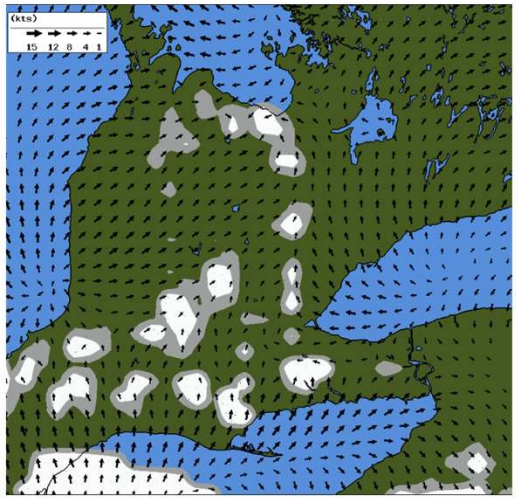
250 m



1 km



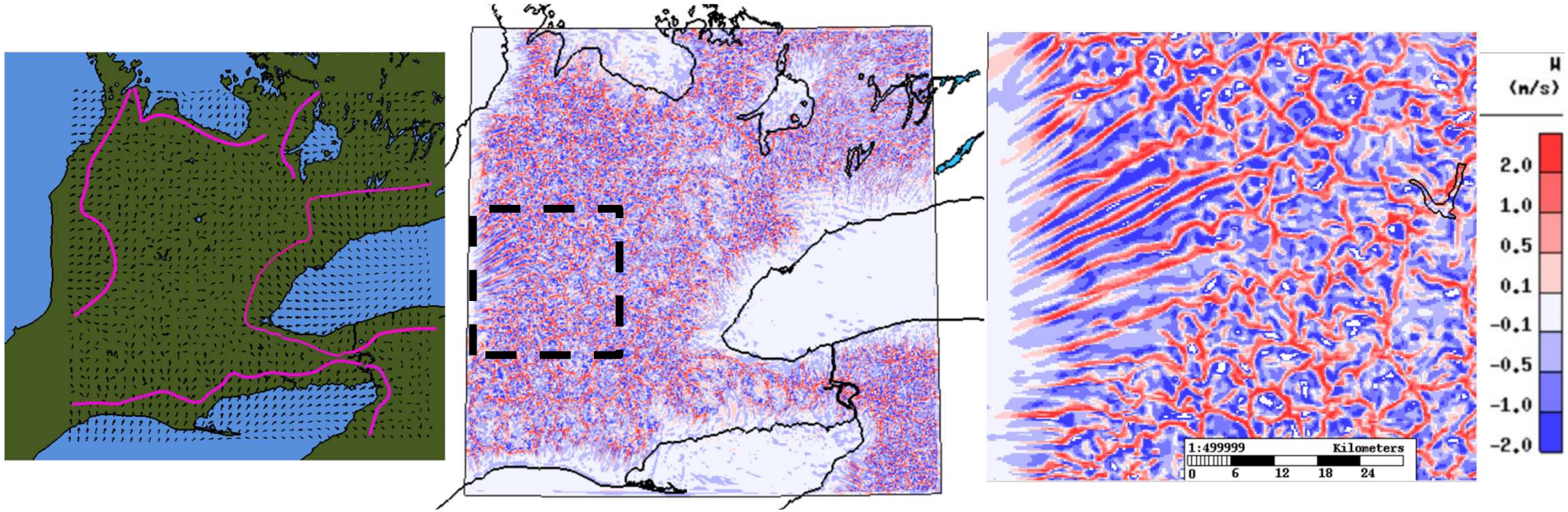
2.5 km



10 km

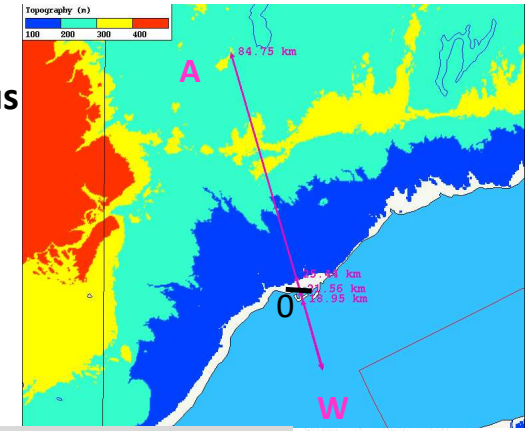
ASSOCIATED INLAND CELLULAR CONVECTION

•18 July 2014

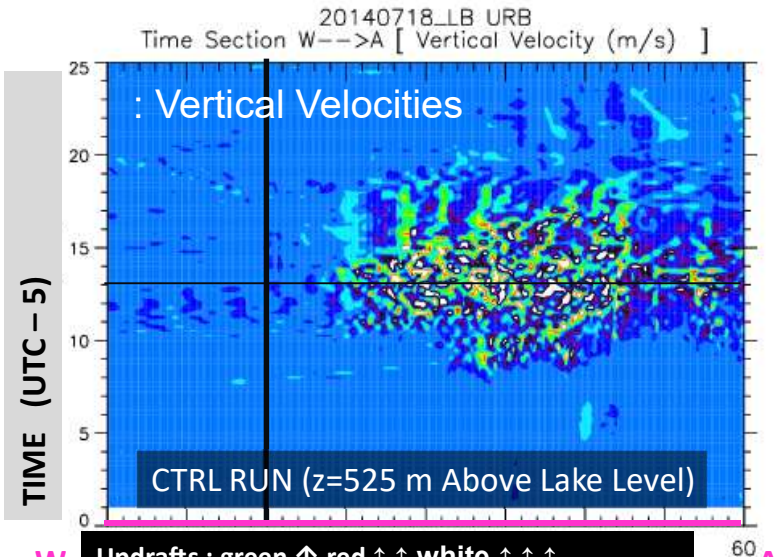


Influence of the urban area on the lake-breeze propagation and turbulence

•cumulus inland
• ideal Lake-breeze

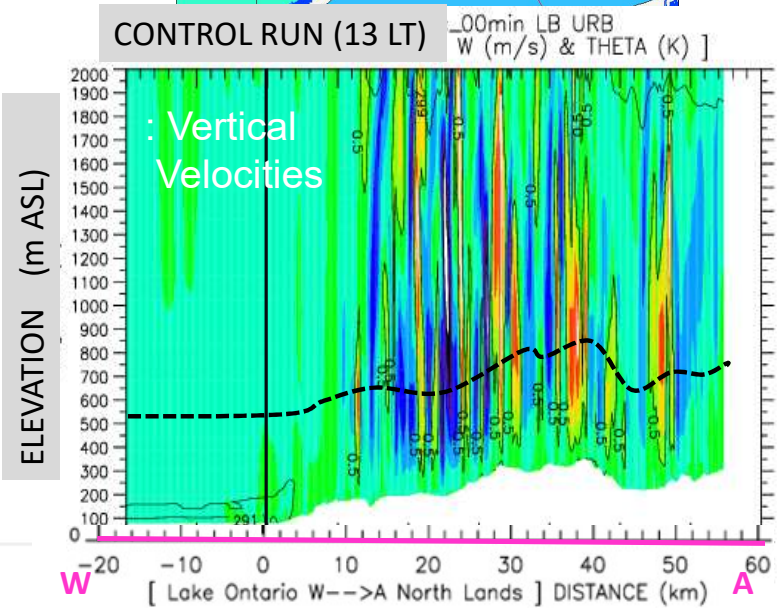


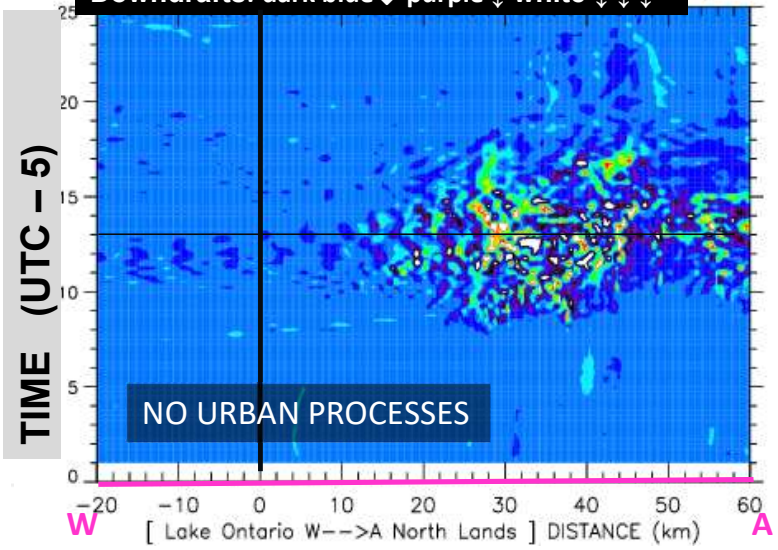
•18 July 2014



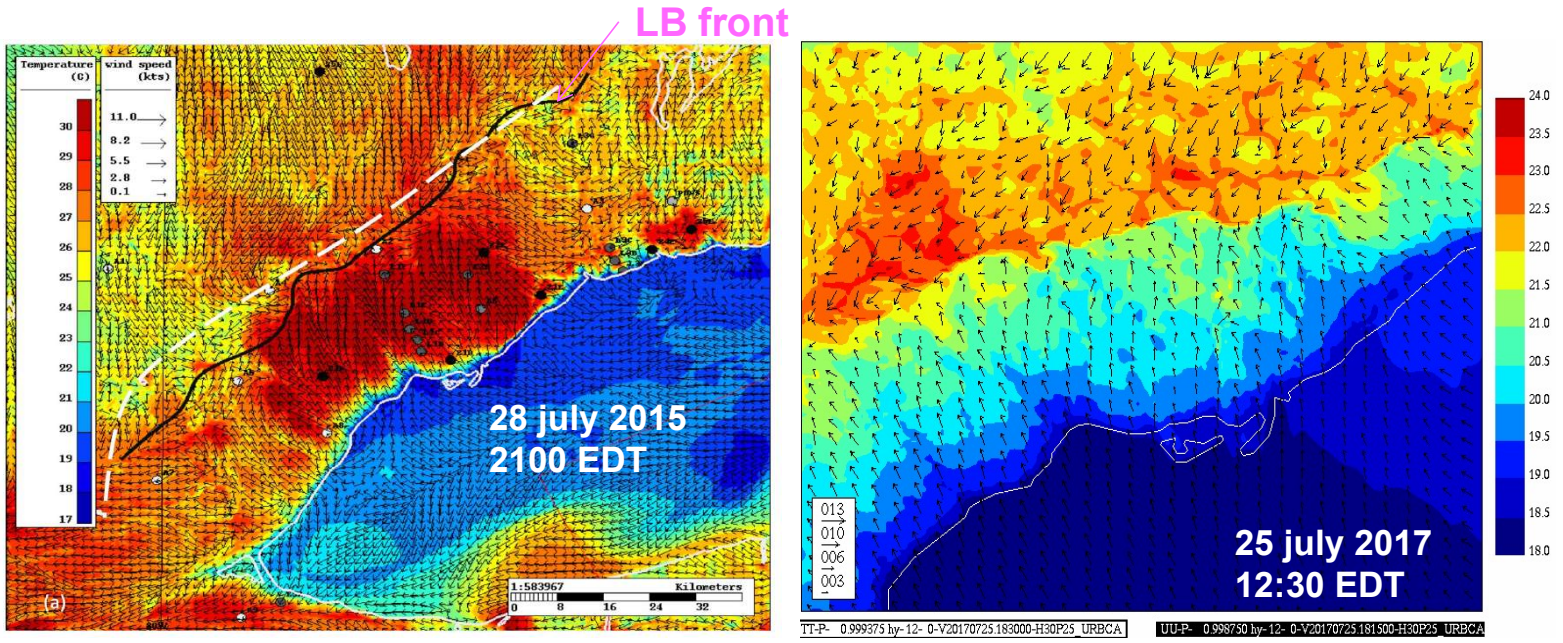
CONTROL RUN (13 LT)

Updrafts : green ↑ red ↑ ↑ white ↑ ↑ ↑
Downdrafts: dark blue↓ purple ↓ white ↓ ↓ ↓





A FEW EXAMPLES OF FEATURES

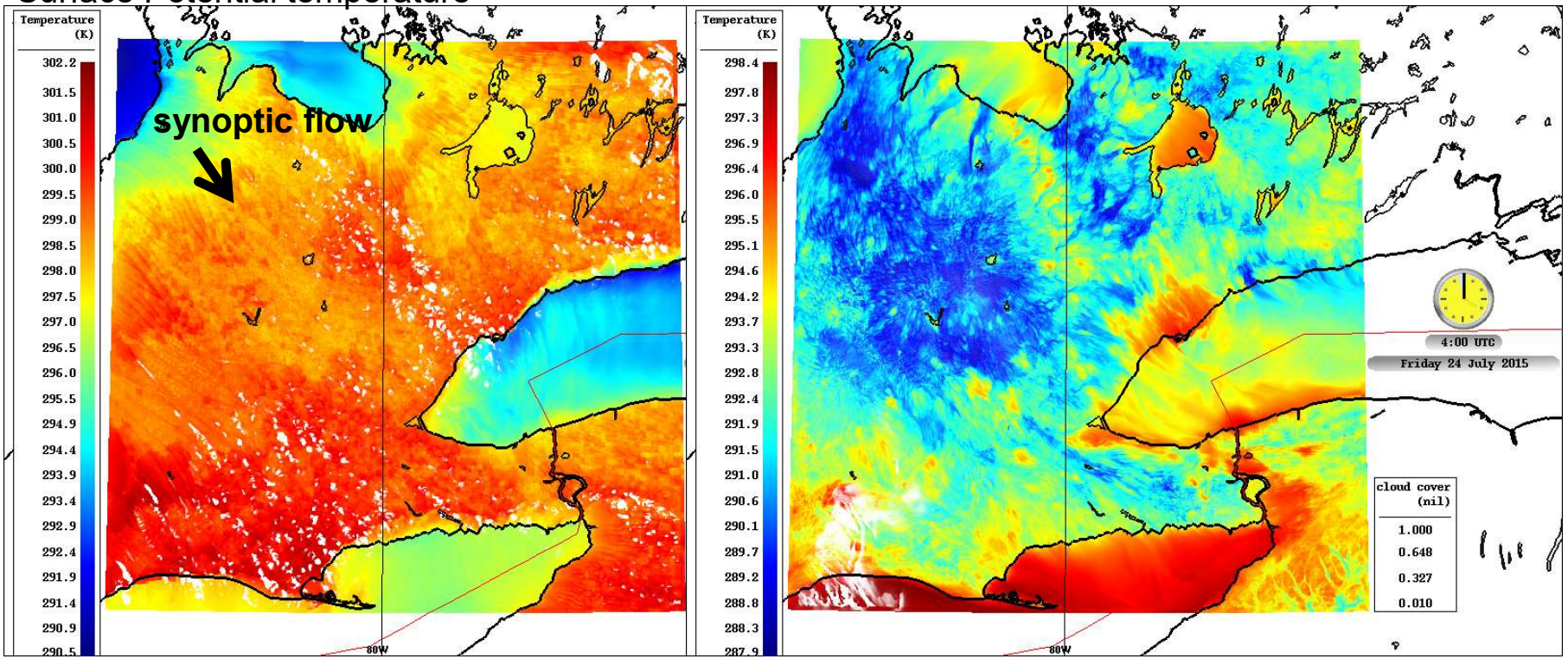


In Joe et al. (2018)

A FEW EXAMPLES OF FEATURES

Surface Potential temperature

23 July 2015 (offshore lake-breeze front)



1600 EDT

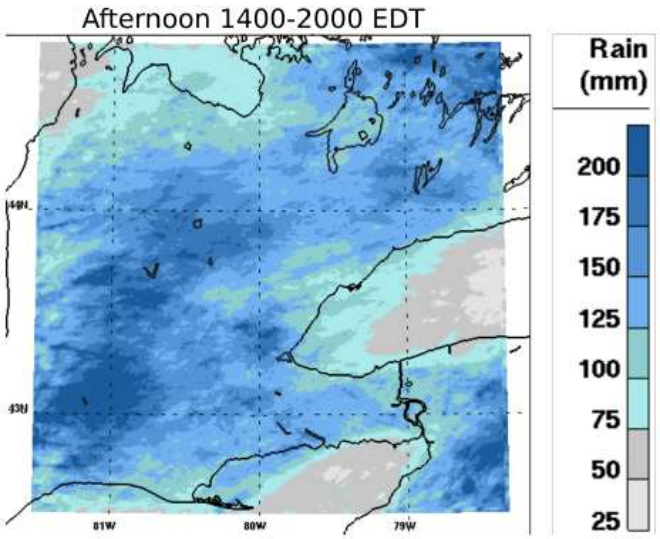
2400 EDT

Clouds formation at convergence zones (realism - GOES)

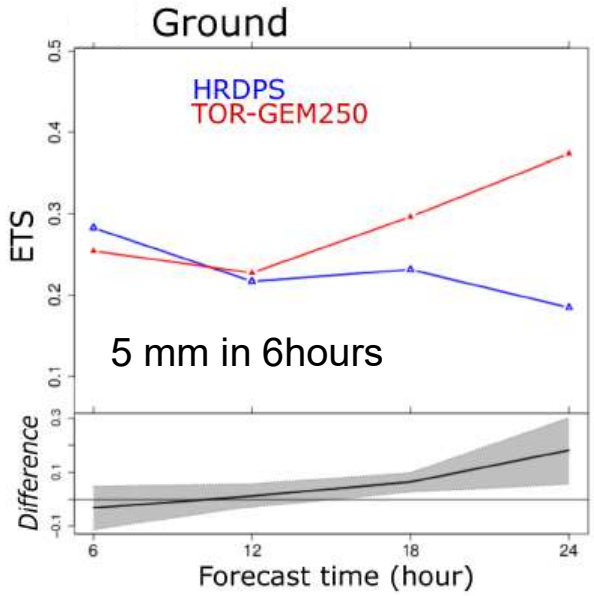
TOWARDS URBAN FLOODING PREDICTION: PRECIPITATION (STATS)

Performance improved for subkm urban-scale forecasts (4 months)

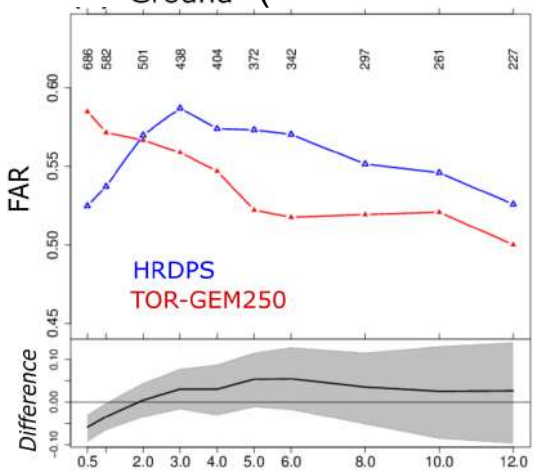
- **GAPS**:
- Maps: difficult to evaluate, precipitation analysis not yet at sub-km scales (currently ~km) and the background model sees less details
- In situ obs : sub-km performs better in the afternoon, far enough from the initialization (good for services in summer)
- Tendency to produce too much small precipitation events

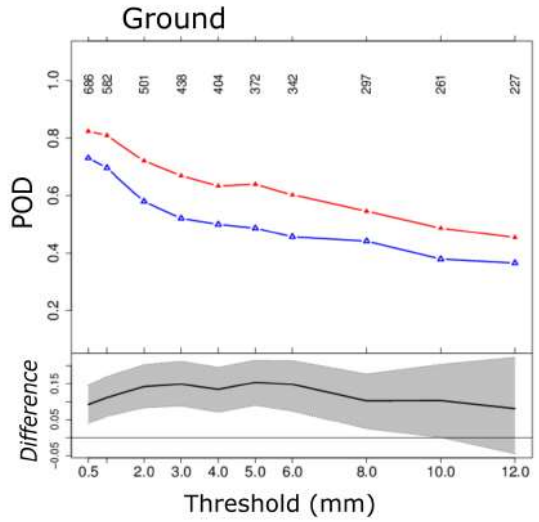


Toronto, Leroyer et al. 2022



Ground (12→24 lead time)



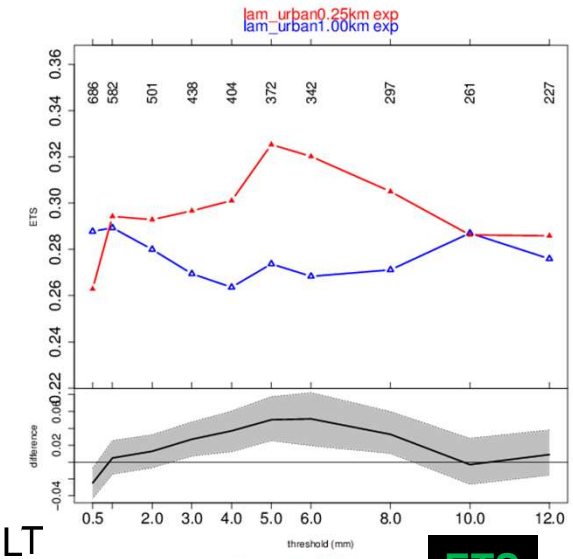


250 M VERSUS 1 KM : CAN WE SEE IMPROVEMENT AT GRID POINTS ?

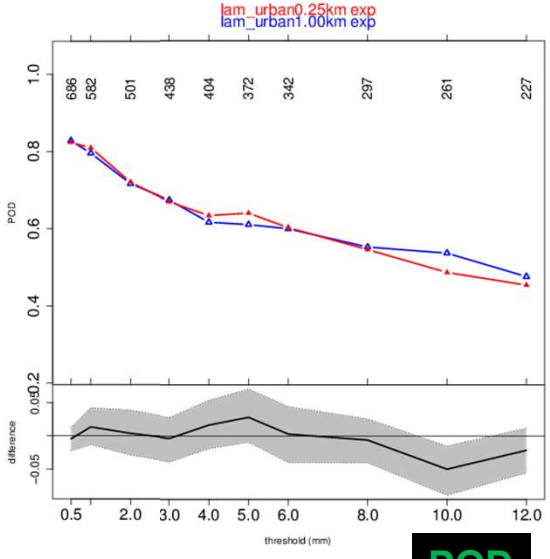
Ground

12-24 LT

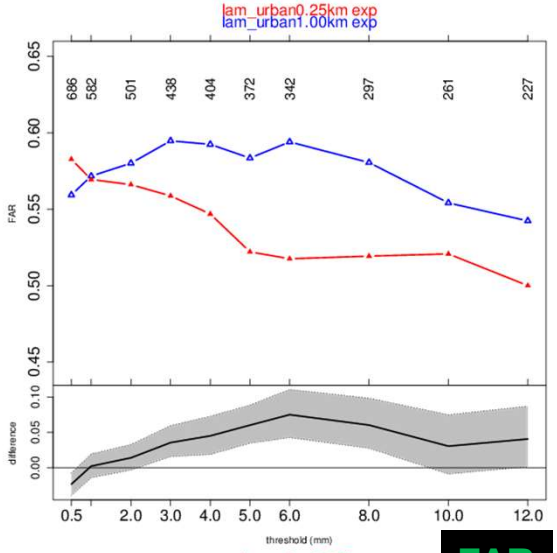
Roof



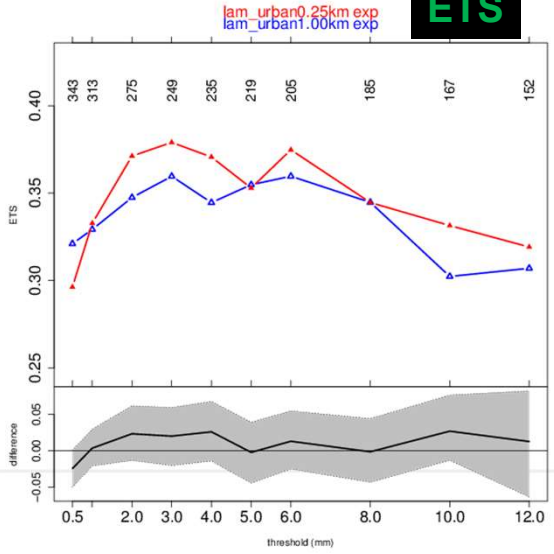
ETS

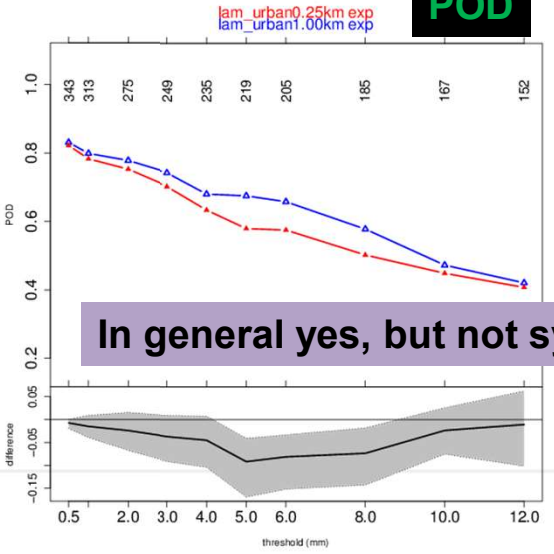


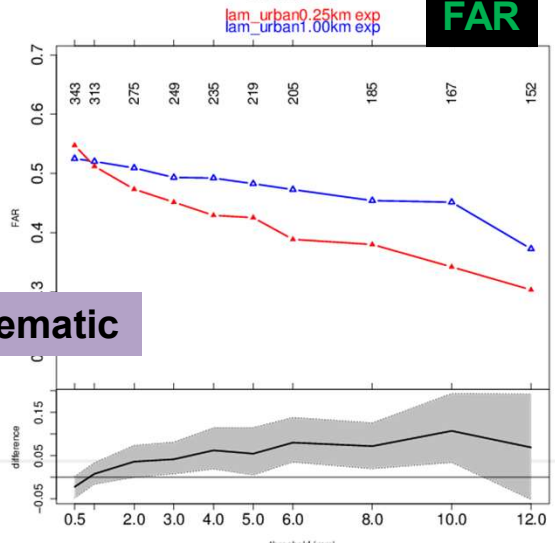
POD



FAR







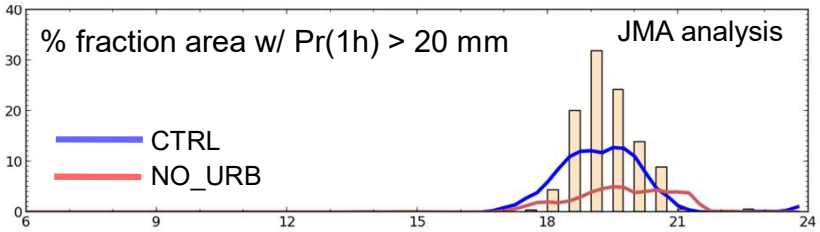
In general yes, but not systematic

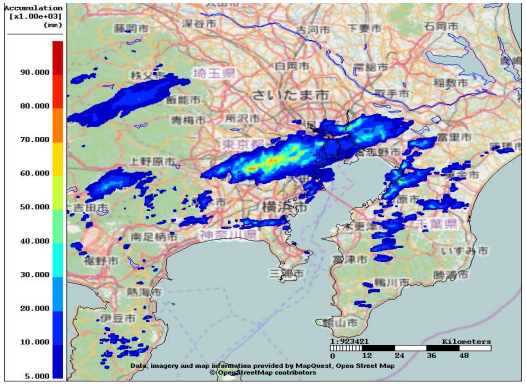
HEAVY RAINFALL CASE STUDIES (1)

- **TOMACS (TOKYO)**

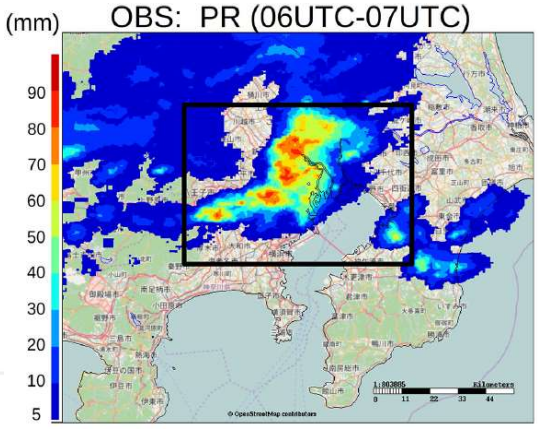
TOkyo Metropolitan Area Convection Study
26 Aug. 2011

***Bélair, S., et al. 2018**. Role and impact of the urban Environment in a Numerical Forecast of an Intense Summertime Precipitation Event over Tokyo, J. Meteor. Soc. Japan., volume 96A, Pages 77-94.*

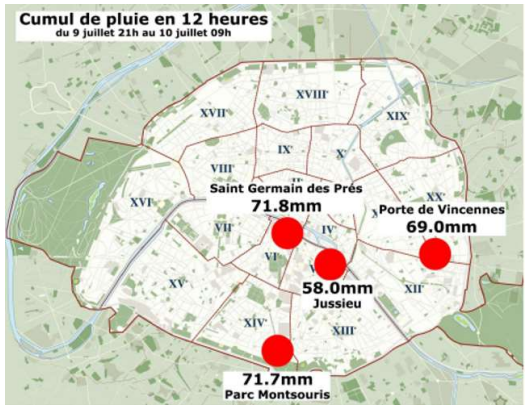




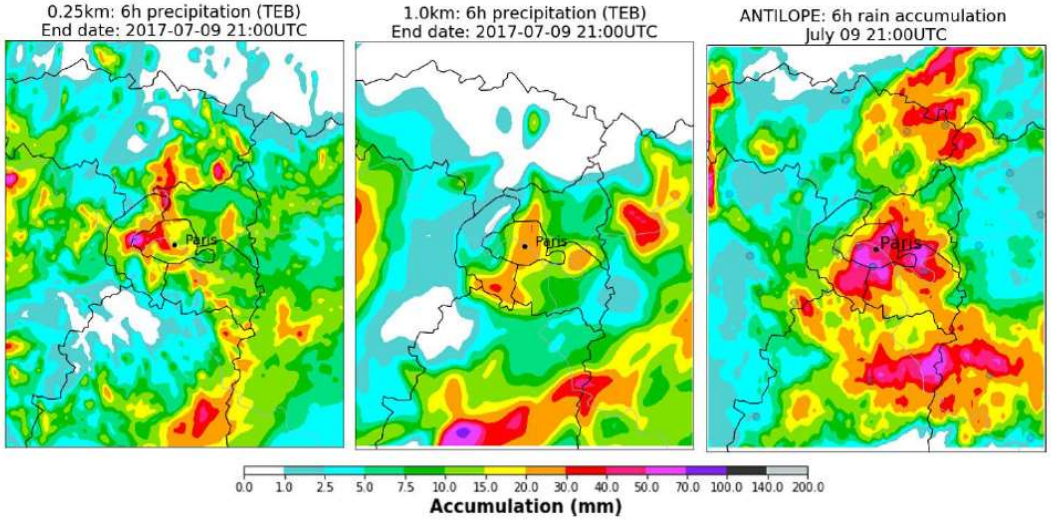
250m
total Precip
06UTC-07UTC



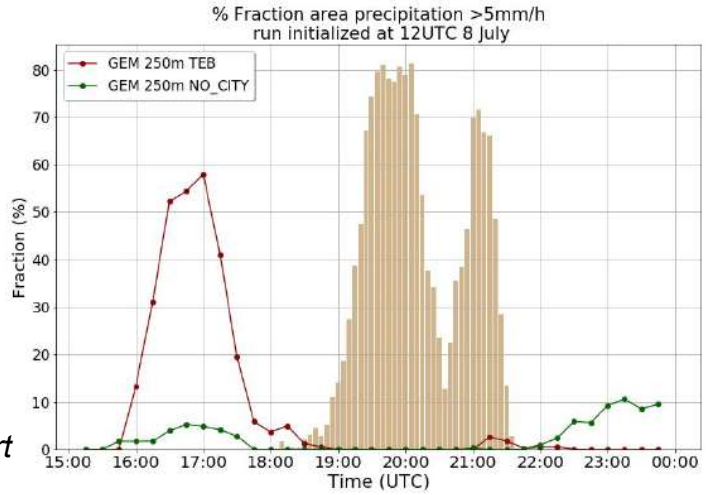
HEAVY RAINFALL CASE STUDIES (2)

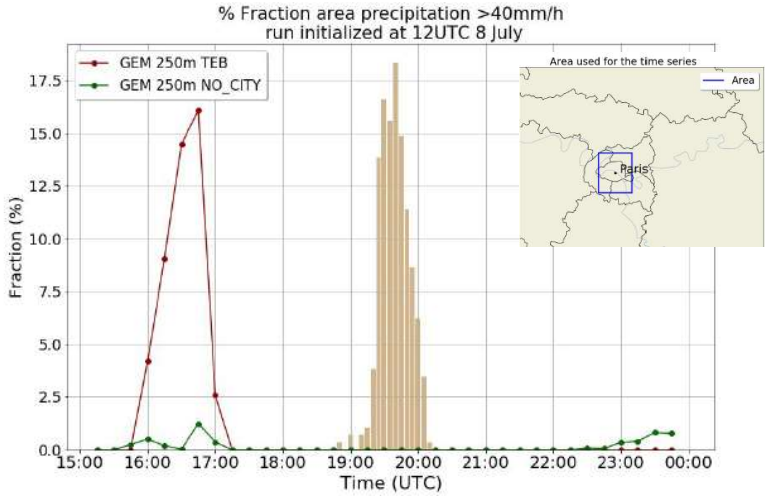


Paris2024 WMO Reasearch and Demonstration Project

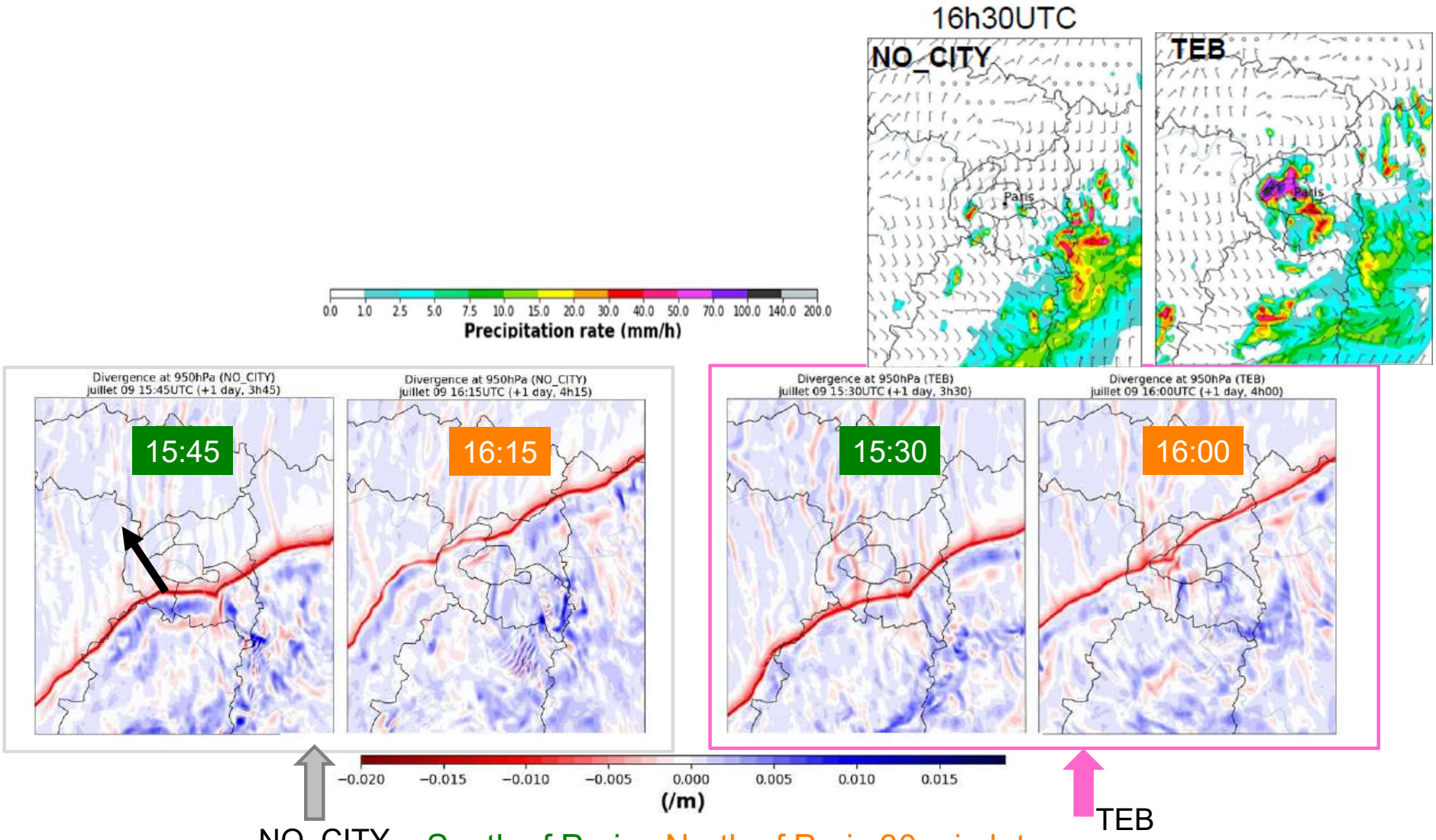


- Very difficult case as explored in the RDP exercice
- Best results obtained : suffer from the double penalty if compared with grid point obs.





Forster, A., et al 2020, MRD internal report



→ The urban area accelerates the displacement of the convergence area upwind but slower the propagation over the cit

CHALLENGES TO TRANSLATE INTO HECTOMETRIC OPERATIONAL NWP

- Kilometer scale NWP gets “all” the attention
  - Recent important advances in data assimilation (radar with the Latent heat nudging method *Jacques and Michelson (2022)*)
  - Still a lot to go on the modernization of physics (GEM5, version ‘retrophysics’ and multiple new options)
  - Surface : current target to change the soil-vegetation scheme (ISBA → SVS), small lakes, new description
- Hectometric prediction often seen as an extension of the kilometer scale NWP
  - Just a downscaling (one-way) ?
  - Vulnerability to the large-scale lateral boundaries
  - No consensus on the scientific / operational targets (convection versus urban-scale)
- Minimizing the importance of details in the set-up and configuration
  - Concept of relocatable windows is an attractive idea, but difficult to get robustness
  - conclusions might be erroneous and provide lack of trust
  - Surface representation and initialization : more important than ever
- Artificial Intelligence gets now “some” part of the attention.

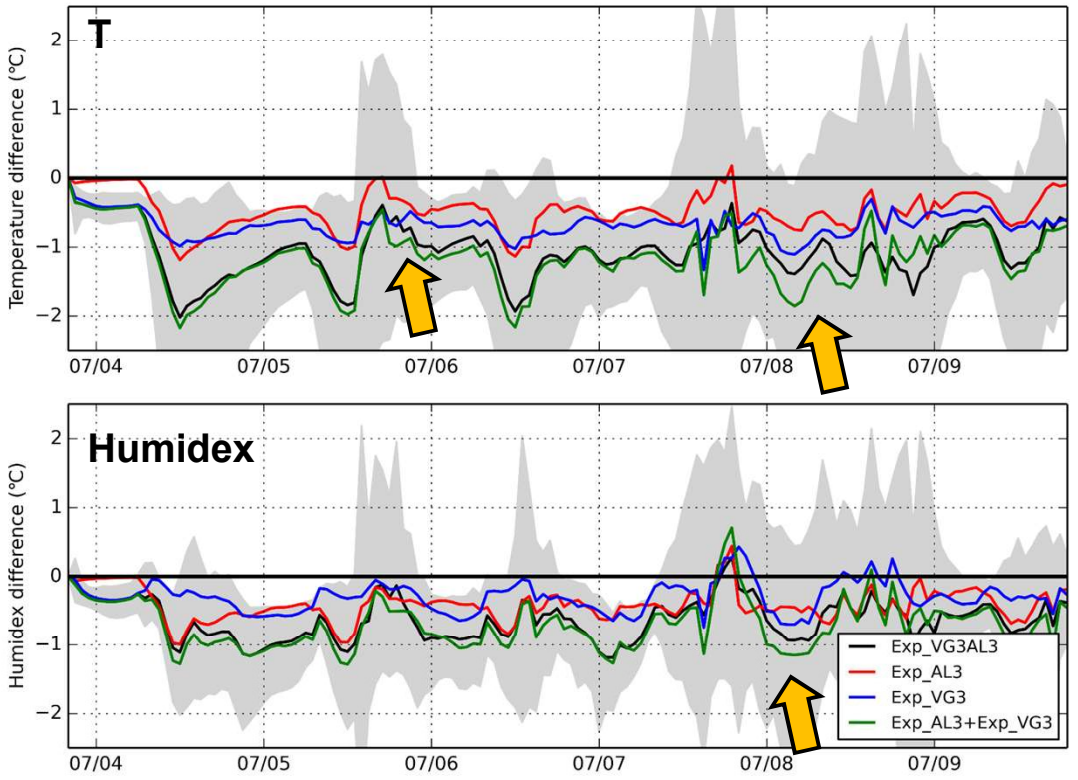
BEYOND NWP : A NUMERICAL PLATFORM FOR CLIMATE ADAPTATION

Categories for heat reduction

- Albedo **A**
- Vegetation **B**
- Water management **B**
- Anthropo-genic fluxes
- Combinations (A+B)

Non-linear response

scenario_(A+B) ≠ scenario_A + scenario_B
black ≠ green



Here: Experiment over Toronto (July event)

- In general (not always), ***combined scenarios have slightly less impact than the parts***
- NWP tool provides the most complete overview of scenarios impacts

CONCLUSIONS

- *Hectometric NWP is **fascinating***
  - Realistic details of the mesoscale processes interactions
  - 250 m : beginning for cloud resolving
  - Urban heterogeneity represented, impact of complex differential heating and topography, turbulence
  - With a detailed state-of-the-art set-up, conclusive objective evaluation (even with the double penalty problem)
  - Continuing the coupling (urban vegetation, BEM)
- *The road for hectometric NWP is still **unpaved***
  - Not all studies provide the same conclusions in the scale comparison
  - More difficult to see improvment for the wind as compared to km. At these scales, errors/inexactitudes can be magnified (frontal zone location, time/space errors)
  - Results sensitive to the surface description (local fronts), spin-up & initialization, large-scale modeling (waves)

➢ Even if national centers might not have yet hectometric NWP as their reference forecasts, efforts should continue. It should work!

Thanks for your attention !

https://profils-profiles.science.gc.ca/en/profile/sylvie-leroyer-phd

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Photo @**Jonathan Gazze**