Urban-rural contrasts in Central-Eastern European cities using MODIS 4 μm time series

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Introduction:

Middle infrared (MIR) region (wavelengths: 3-5 μm) is the mixing zone of emitted terrestrial radiation and reflected solar radiation.

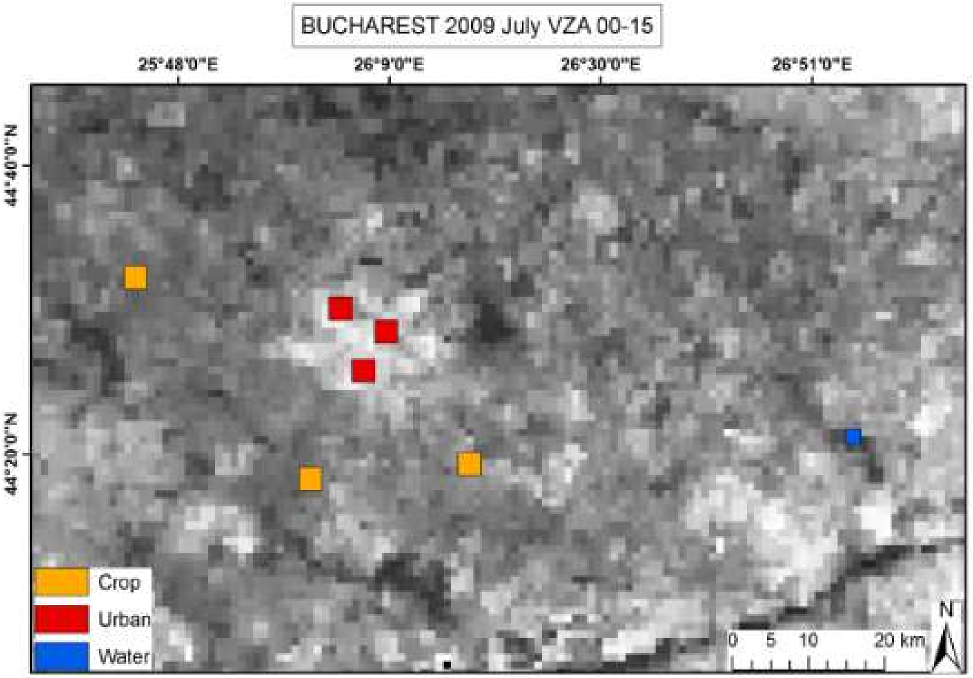
1 km MODIS band 23 (~4 μm) can "see through" urban atmospheric haze and pollution (*e.g.*,$PM_{2.5}$).

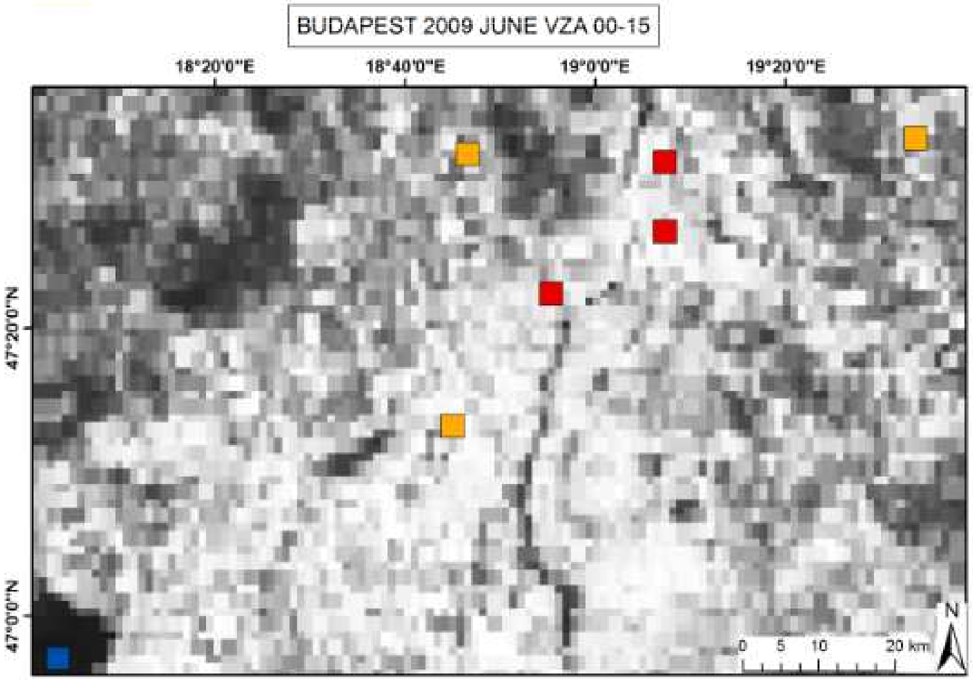
Green vegetation and open water appear "dark" in MIR due to absorption by water. Soils and dried vegetation appear "bright" and urban surfaces (roofs and roads) appear an intermediate "grey".

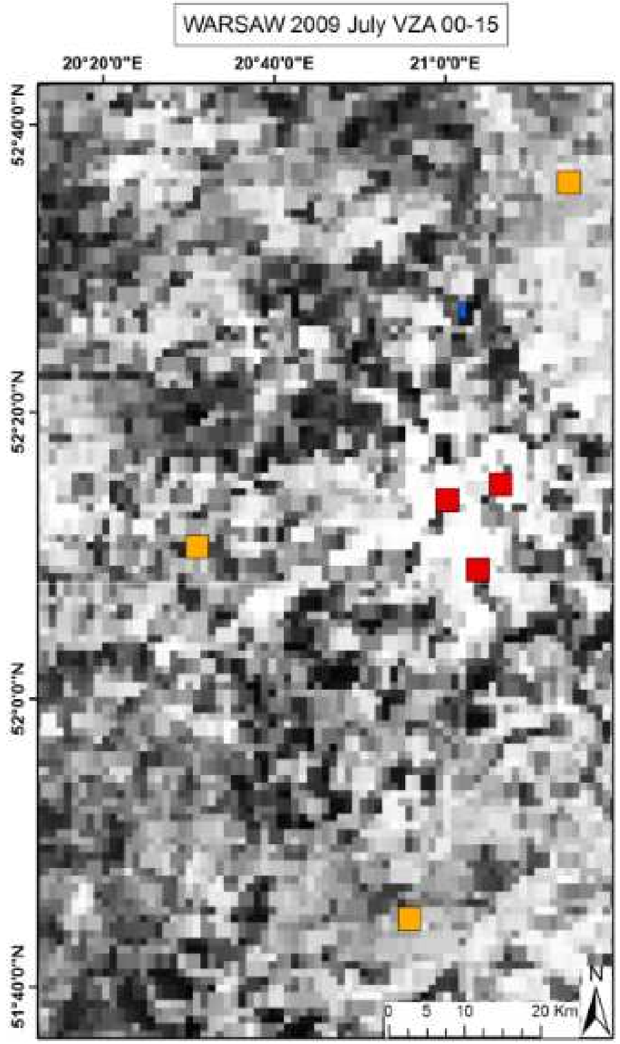
Study information:

- 3 Central European capital cities:
    - Bucharest, Romania
    - Budapest, Hungary
    - Warsaw, Poland
- We use Level 1B calibrated radiance data from ascending passes of Aqua MODIS band 23 during 2003 - 2012.
- the Normalized Difference Vegetation Index (NDVI) from April to October (vegetation season) from 2003 – 2012.
- These 1 km data are processed to reduce cloud cover using monthly maximum value compositing into four sensor view zenith angle (VZA) classes for analysis:

$0^\circ < x \leq 15^\circ$ $15^\circ < x \leq 30^\circ$ $30^\circ < x \leq 45^\circ$ $45^\circ < x \leq 60^\circ$







In each city we select a 3x3 pixel area in three strongly contrasting land cover classes: (1) urban, (2) agriculture, and (3) open water

- Henebry, G. M. Mapping human settlements using the mid-IR: advantages, prospects, and limitations in Urban Remote Sensing, Q. Weng and D. Quattrochi, Eds. Boca Raton, FL: CRC Press, 2007, 339-355.
- Krehbiel, C.P.; Kovalskyy, V.; Henebry, G.M. Exploring the middle infrared region for urban remote sensing: seasonal and view angle effects. Remote Sensing Letters 2013, 4, 1147-1155, doi: 10.1080/2150704X.2013.853891.
- Tomaszewska, M.; Kovalskyy, V.; Small, C.; Henebry, G. M. Viewing Global Megacities Through MODIS Radiance: Effects of Time of Year, Latitude, Land Cover, and View Zenith Angle, IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing 2016, doi: 10.1109/JSTARS.2016.2532740.

Study:

- **Questions**
  - How urban environment differs from rural during the year based on MIR (urban – rural contrast)? [classification issue]
  - Is the urban heat island effect evident in the shorter wavelengths of the MIR? [urban monitoring]
  - How MODIS 23 band radiance is varied by an influence of seasonality, land cover and viewing geometry? [classification/land cover changes/urban monitoring]

- Multiannual analyzes:
  - Multiannual average comparison
  - NDVI comparison
  - VZA effects (stronger radiance at nadir MIR radiance)
  - Accumulated radiance and the convex quadratic (CxQ) model

- Time series analyzes over years 2003 – 2012 from April to October
  - Comparison with weather information
  - Convex quadratic (CxQ) model for a particular year

Study:

- Examined the seasonality of MIR radiance over urban areas and nearby croplands and found the UHI varied in the MIR due to time of year

- Compared monthly mean MIR with normalized difference vegetation index (NDVI) to analyze contrasts between urban and rural areas. We found that the seasonal dynamic range of the MIR could exceed that of the NDVI.

- Explore the influence of latitude on MIR seasonality through the lens of the convex quadratic model that relates monthly MIR radiance with accumulated monthly MIR radiance.

- Explored the linkage between meteorological data and MIR radiance and found a range of response from strong to weak dependence of MIR radiance on maximum temperature and accumulated precipitation. Our results extend the understanding of the surface UHI.

Study:

- **Questions**
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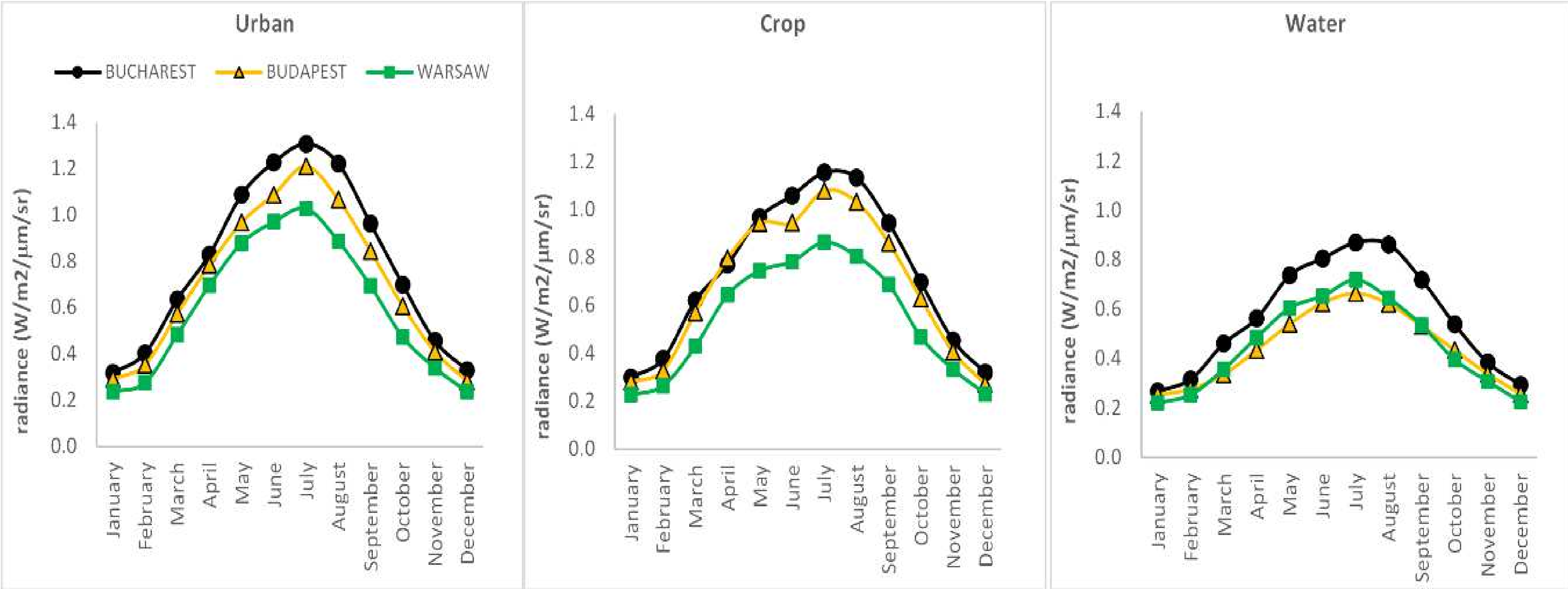
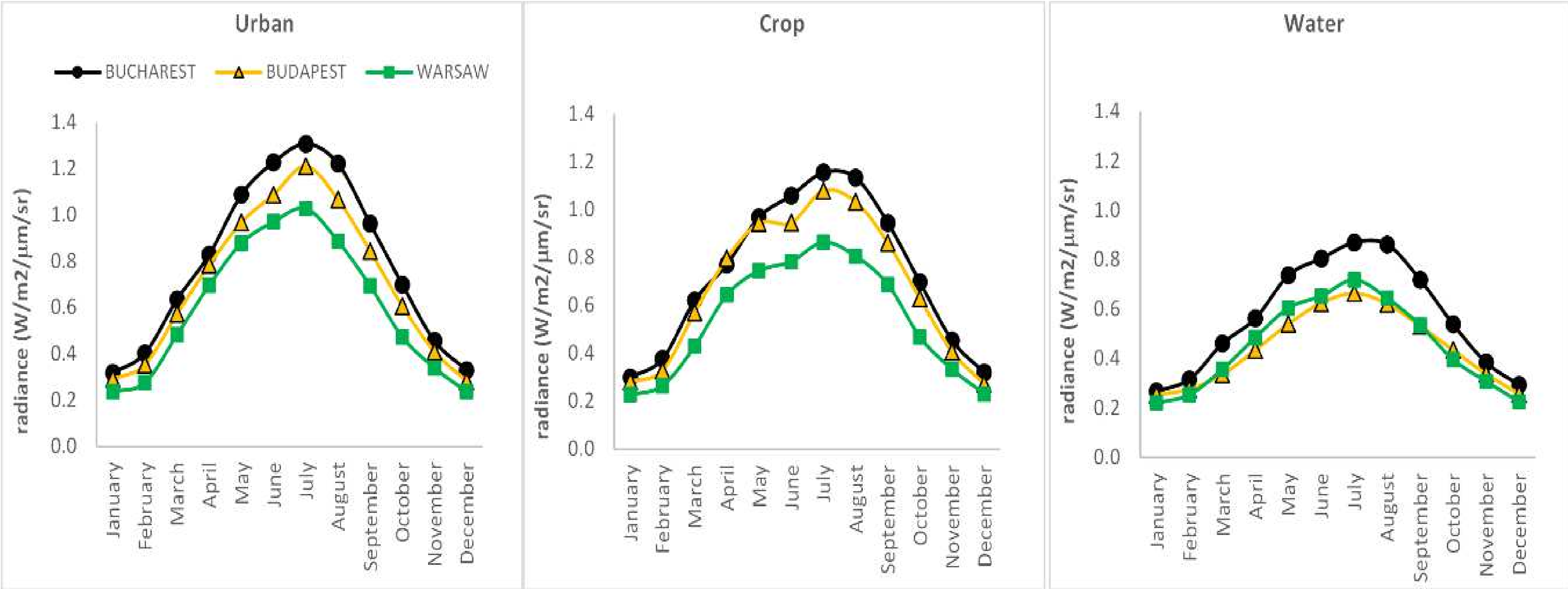


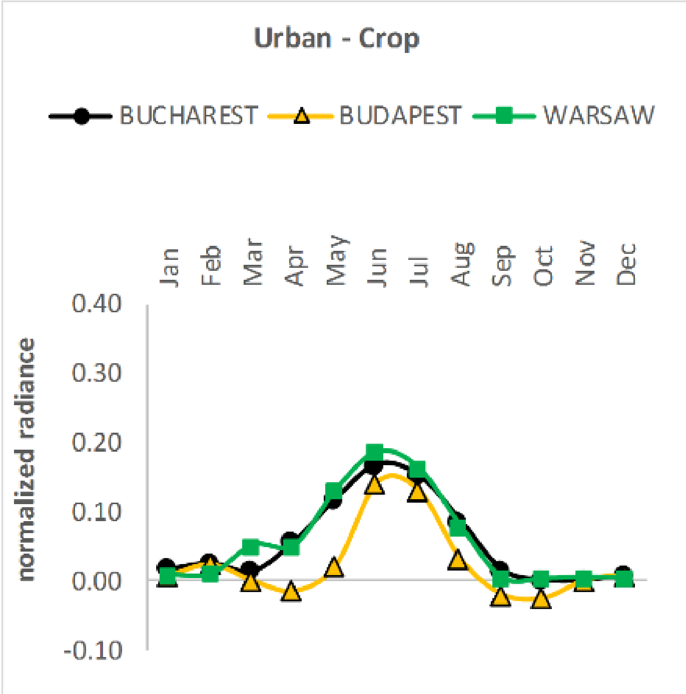
Multiannual average comparison:

- The unimodal seasonality peaks in July and is lowest during the winter months
- Values for Warsaw are lower than Bucharest and Budapest (seasonality and latitudinal effect)
- As the year progress, the differences between the cities increase and peak in mid-summer



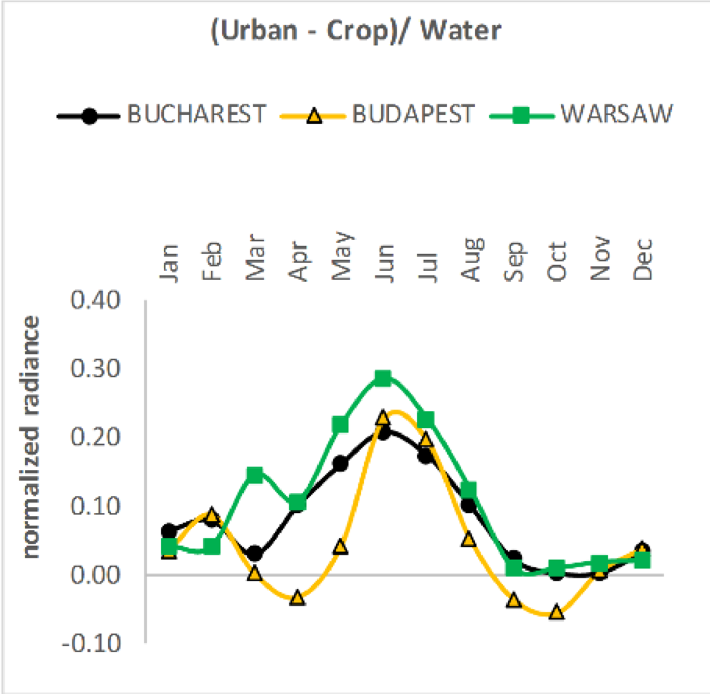
Multiannual average comparison:

- **Urban trajectories are almost symmetrical in contrast to croplands, which show a two-phase pattern that includes a pause or slowing of the increase of MIR radiance in June**
- **The dynamic ranges of water samples are more muted but show distinct seasonality**



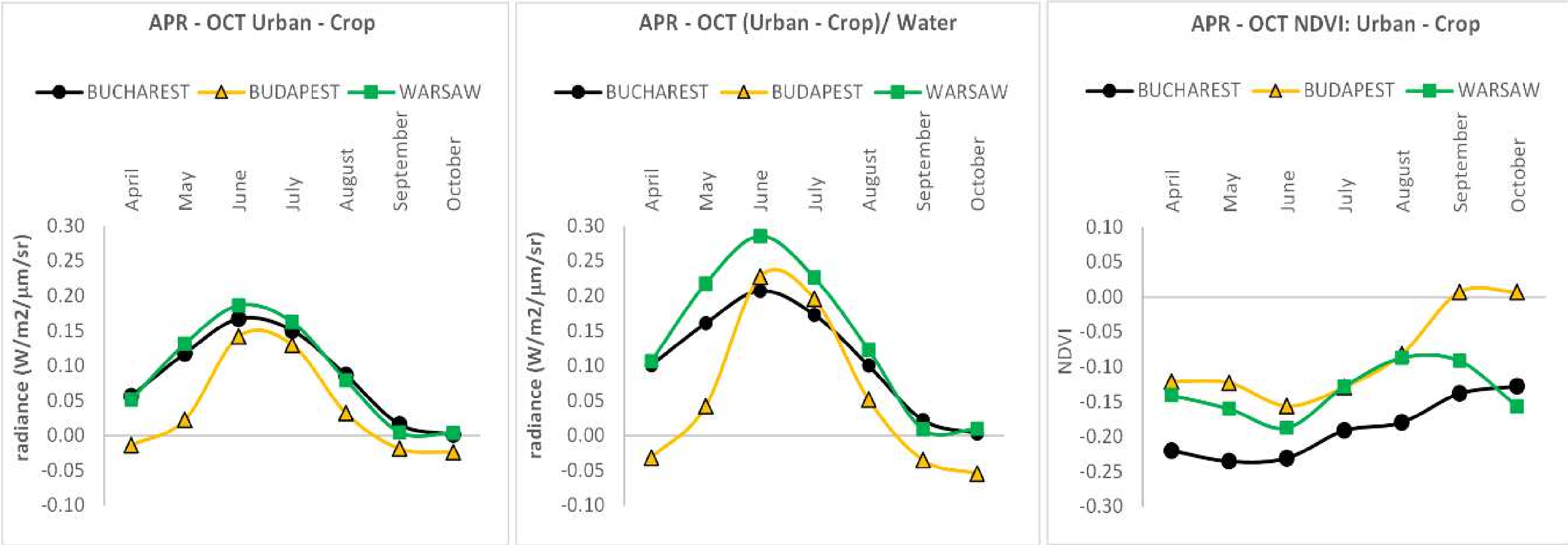
Radiance difference:

- Differences are lowest in Bucharest and the highest in Warsaw.
- In early spring (March) and autumn (September and October), the differences in Bucharest and Budapest are negligible but positive in Warsaw, suggesting snow cover might be attenuating MIR radiance in Poland.
- Negative values indicate higher MIR radiance from cropland than urban cover, which is to be expected from large expanses of MIR-bright bare soils that occur at planting and again at harvest.



Water normalization

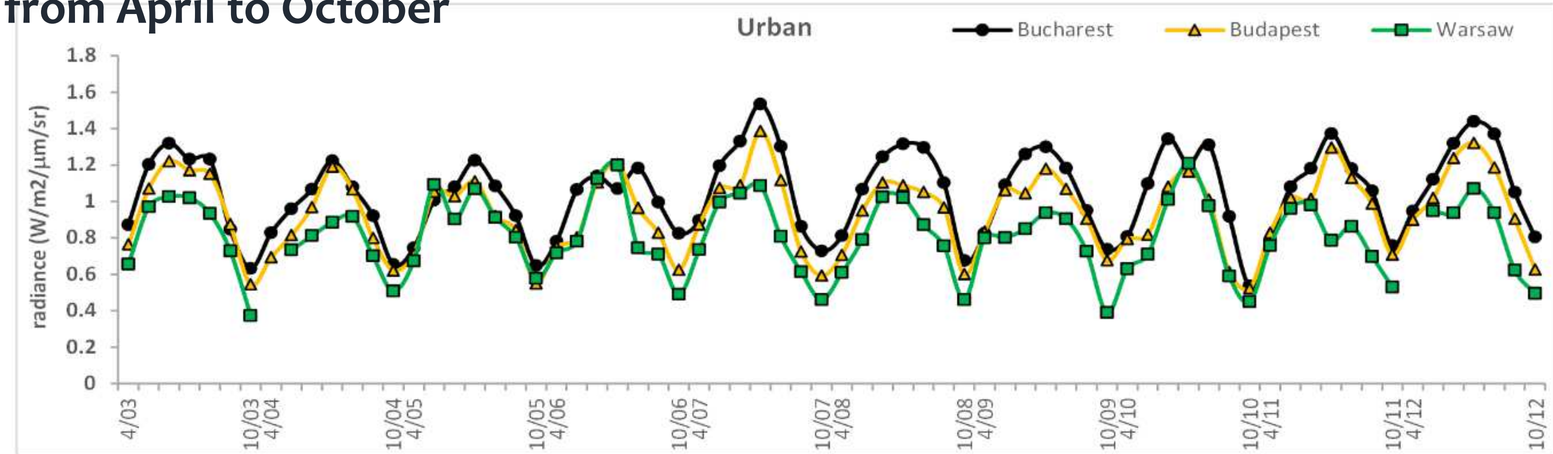
- The normalization helps to underscore the differences in MIR radiance values for Warsaw are consistently lower than Bucharest and Budapest
- Not all areas have sufficiently large bodies of open water nearby, and the depth of the lake or reservoir should affect how MIR-dark the surface is and, thus, how strong the normalization. A shallower or smaller lake may heat more quickly than a large body

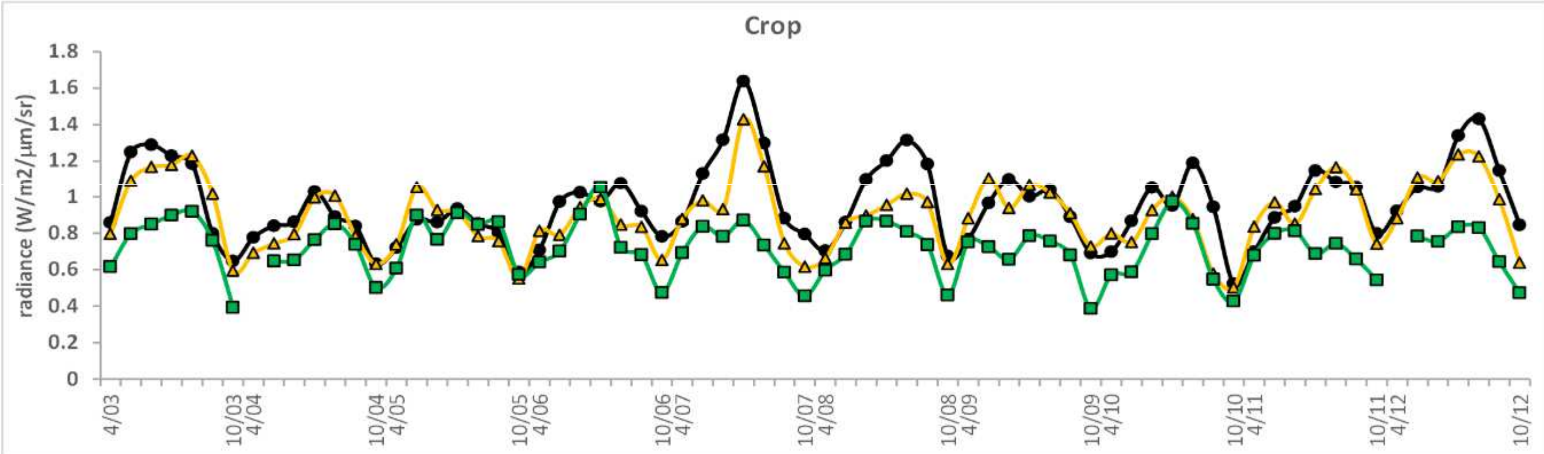


NDVI comparison:

- **Q: Does MIR radiance inversely mirror NDVI seasonality?**
- **The MIR shows a larger dynamic range than between land covers than the NDVI: ~0.30 vs. ~0.15.**
- **The changes in the normalized MIR radiances are rapid relative to the NDVI, particularly in the early growing season: the pace of divergence between city and cropland are faster in the MIR than the NDVI.**
- **An interesting feature occurs in October in Budapest where MIR radiance of croplands is greater than the city, and the NDVI of the city is larger than the croplands**

Time series analyzes over years 2003 – 2012 from April to October

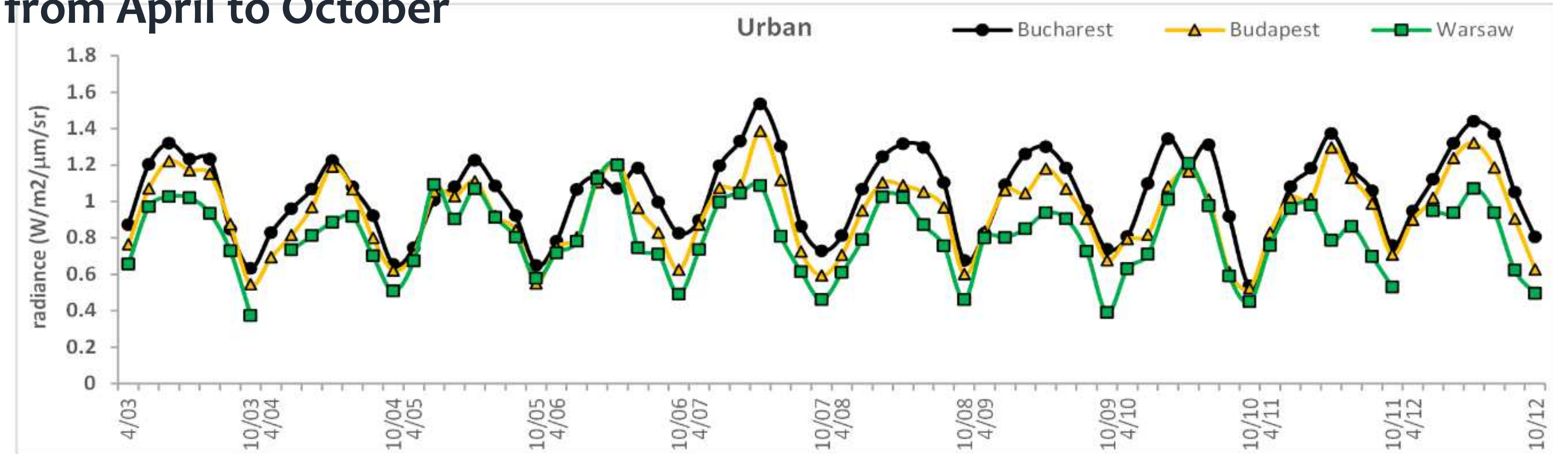


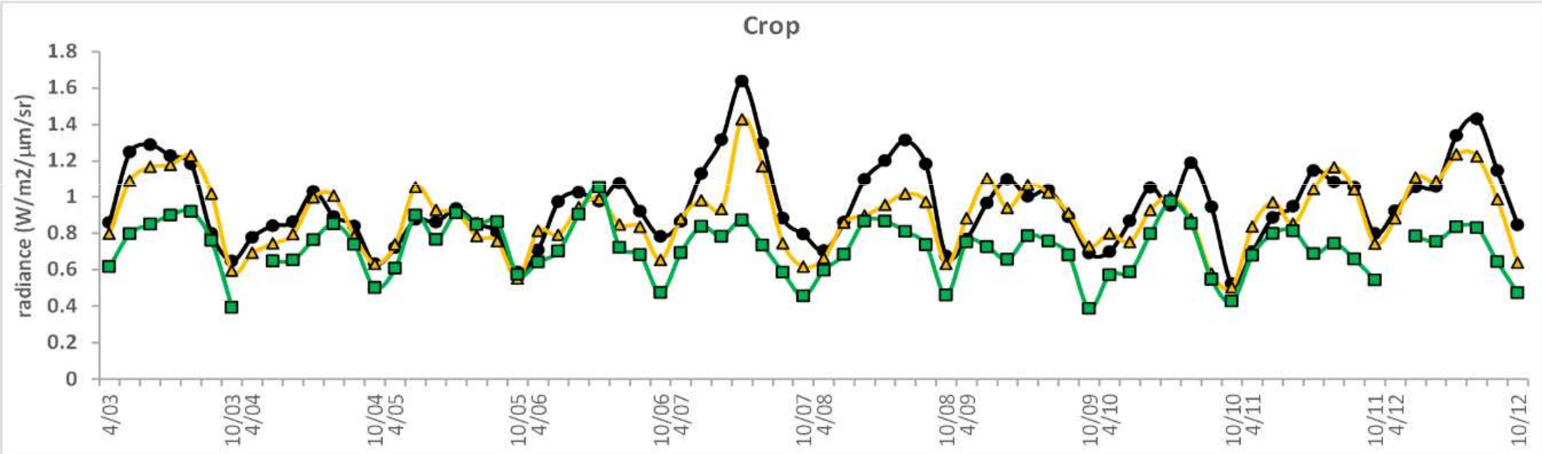


Bucharest:

- In 2007, the annual maximum MIR radiance was highest for both urban (1.53) and cropland (1.64) classes. There was a notable heat wave in southeastern Europe in 2007, with the average monthly maximum temperature reaching 27 °C and very low precipitation (520 mm)
- The lowest maximum MIR radiance in cropland occurred in 2005 (0.93) when the accumulated precipitation was the highest (1013.4 mm). Higher precipitation may increase vegetation cover, thereby darkening the surface in the MIR.

Time series analyzes over years 2003 – 2012 from April to October

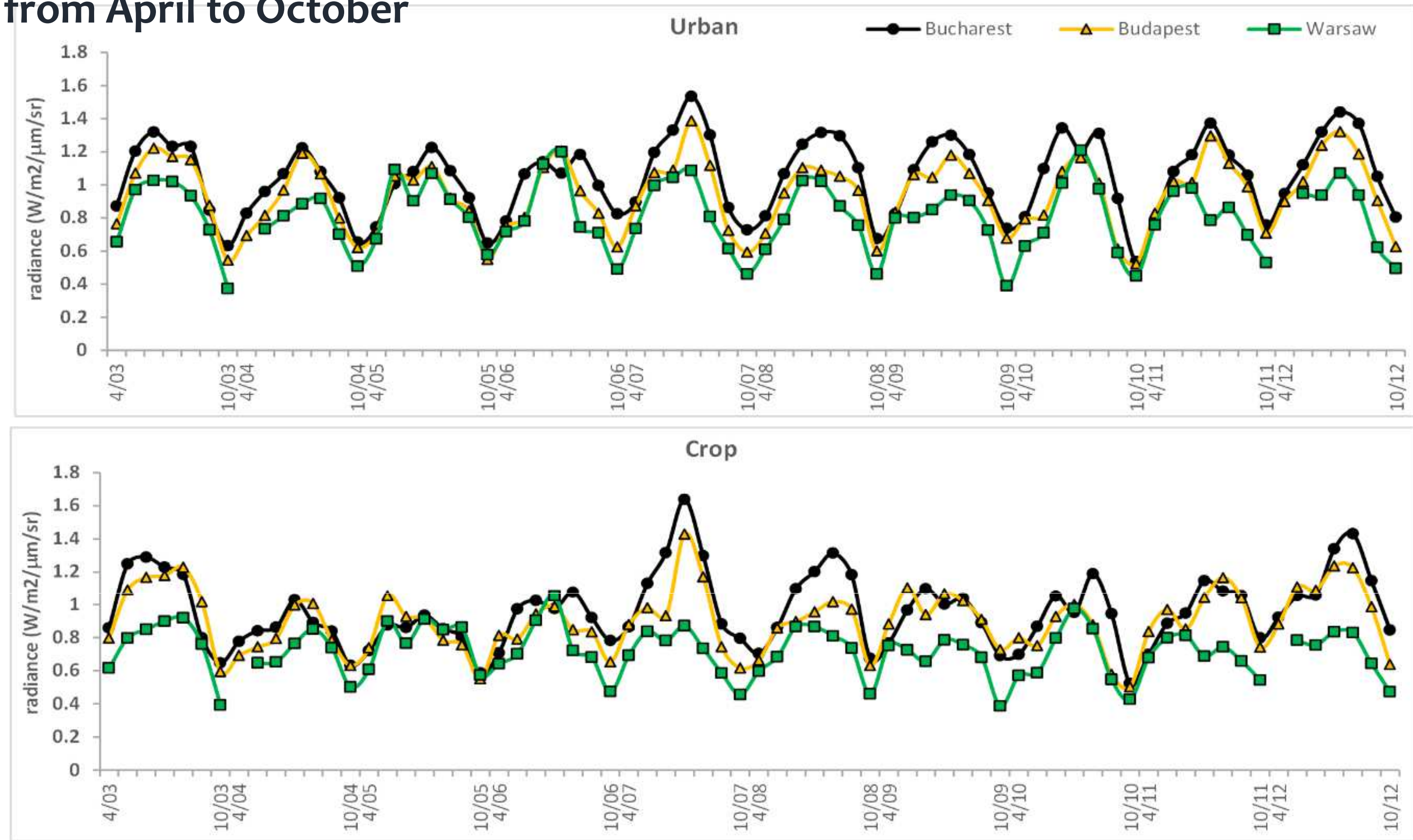




Budapest:

- The highest maximum MIR radiances occurred in 2007 with 1.39 for urban and 1.43 for cropland. During 2007, accumulated precipitation was below the mean from 2003-2012 and the maximum air temperature was higher
- The 2003 European heatwave impacted Budapest, However, the MIR radiance from the urban areas equaled the multiyear average; in contrast, the cropland's maximum MIR radiance was 10% greater than the average

Time series analyzes over years 2003 – 2012 from April to October



Warsaw:

- The extreme heat occurred in Poland in 2006: maximum air temperature was greatest, and precipitation was least. In 2006 the maximum urban MIR radiance was second highest, and the cropland MIR radiance was the highest

Snímek 16

R3 clear seasonal patterns and significant year difference; pont out heatwave ; divide into a few slides; differencs between classes
Rapsodia; 8.7.2016

Convex quadratic model (CxQ):

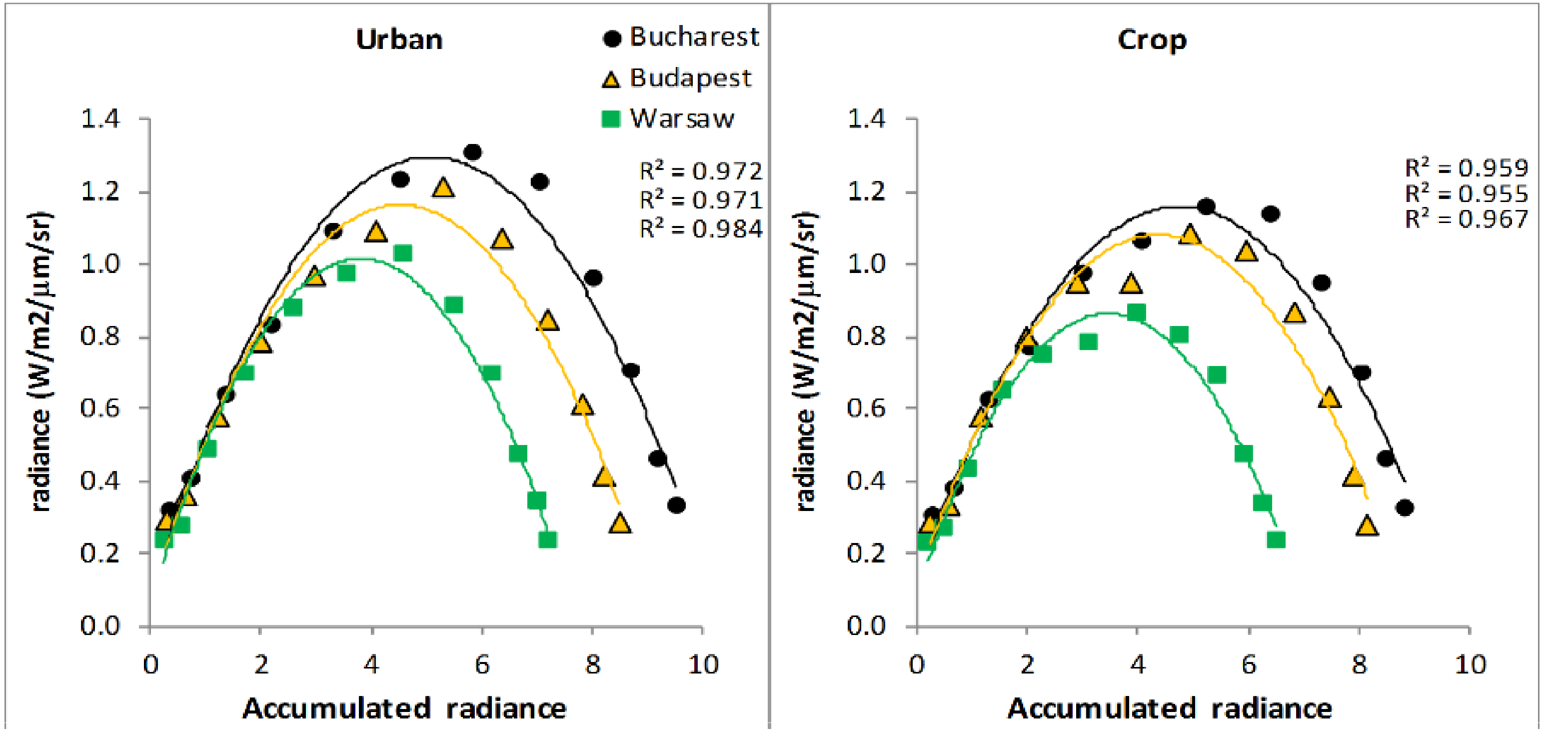
$$MIR_m = \alpha + \beta * AMMIR - \gamma * AMMIR^2$$

- MIR_m is the monthly value of MIR radiance
- AMMIR is the accumulated monthly MIR radiance
- and α, β, and γ are parameter coefficients

$Peak_{MIR} = \alpha - (\beta^2/4*\gamma)$ the peak value of MIR

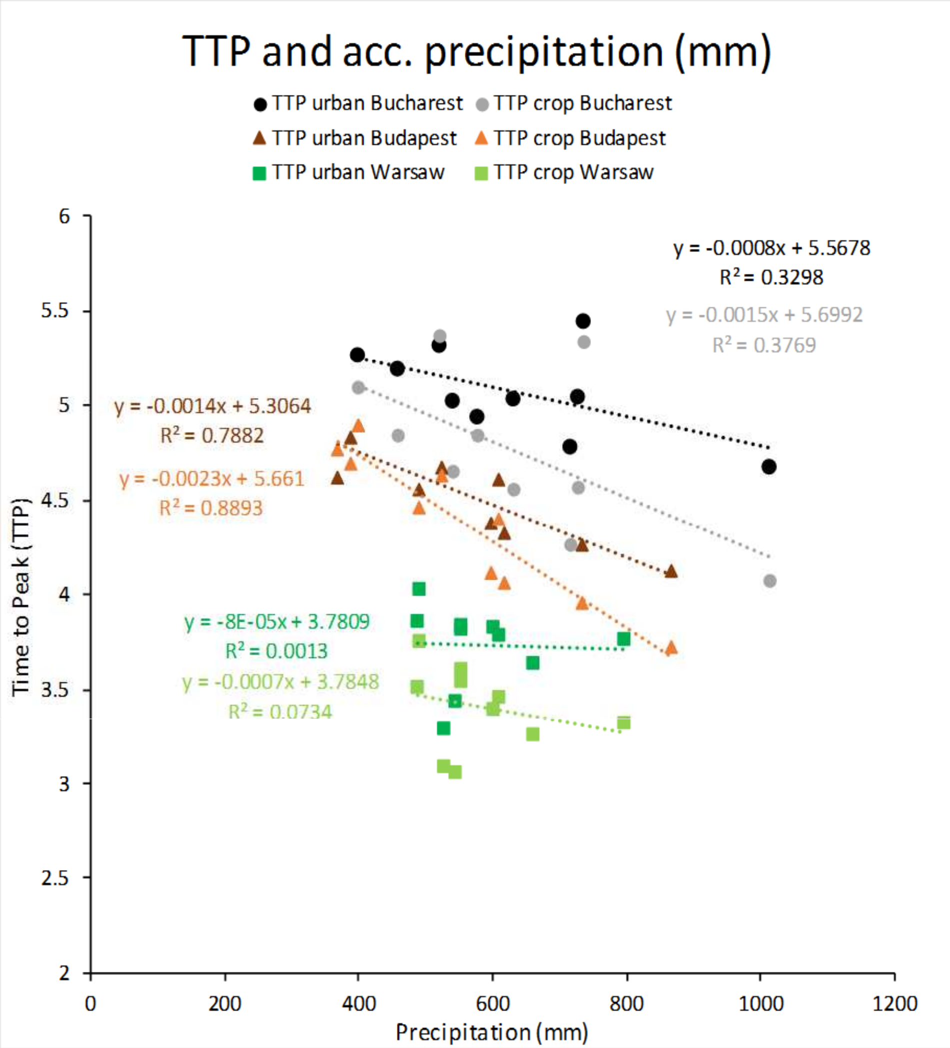
$TTP_{MIR} = -\beta/2*\gamma$ the accumulated MIR radiance at the point of the peak value of MIR

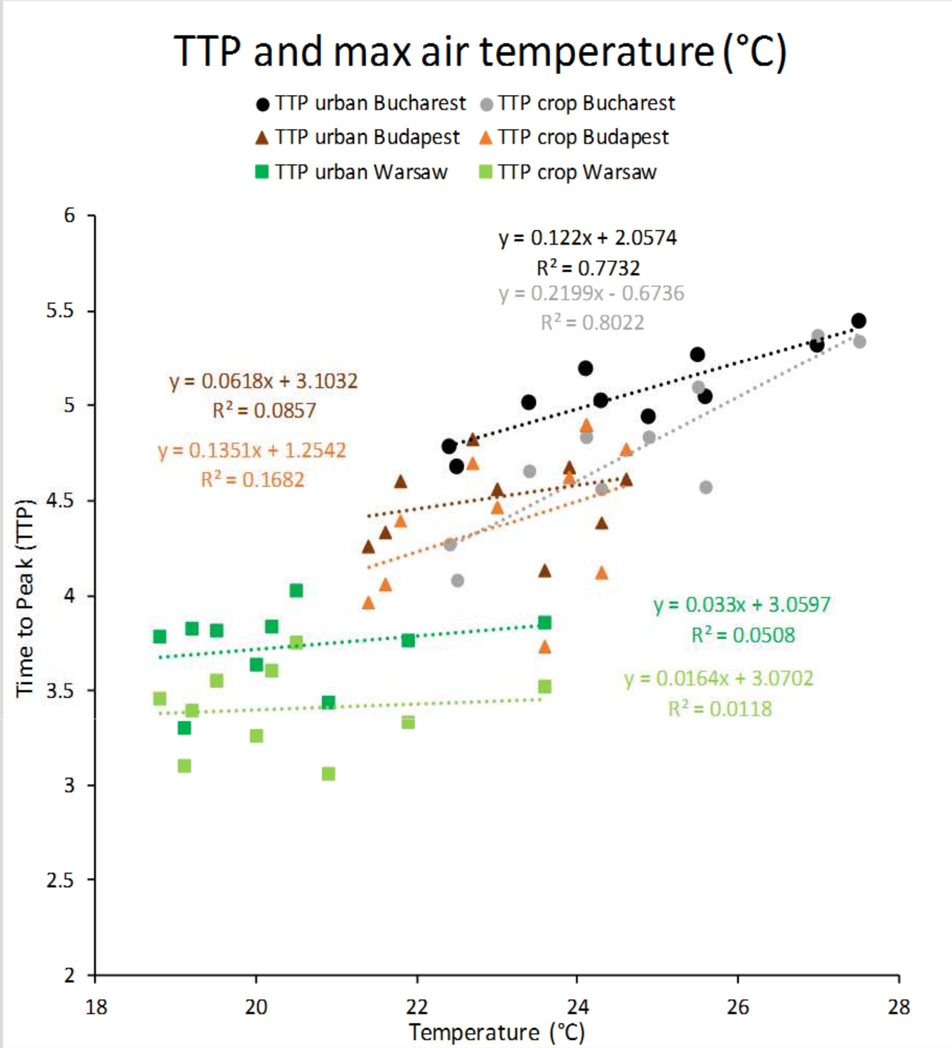
Explore the influence of latitude on MIR seasonality through the lens of the convex quadratic model that relates monthly MIR radiance with accumulated monthly MIR radiance.



Accumulated radiance and the convex quadratic (CxQ) model :

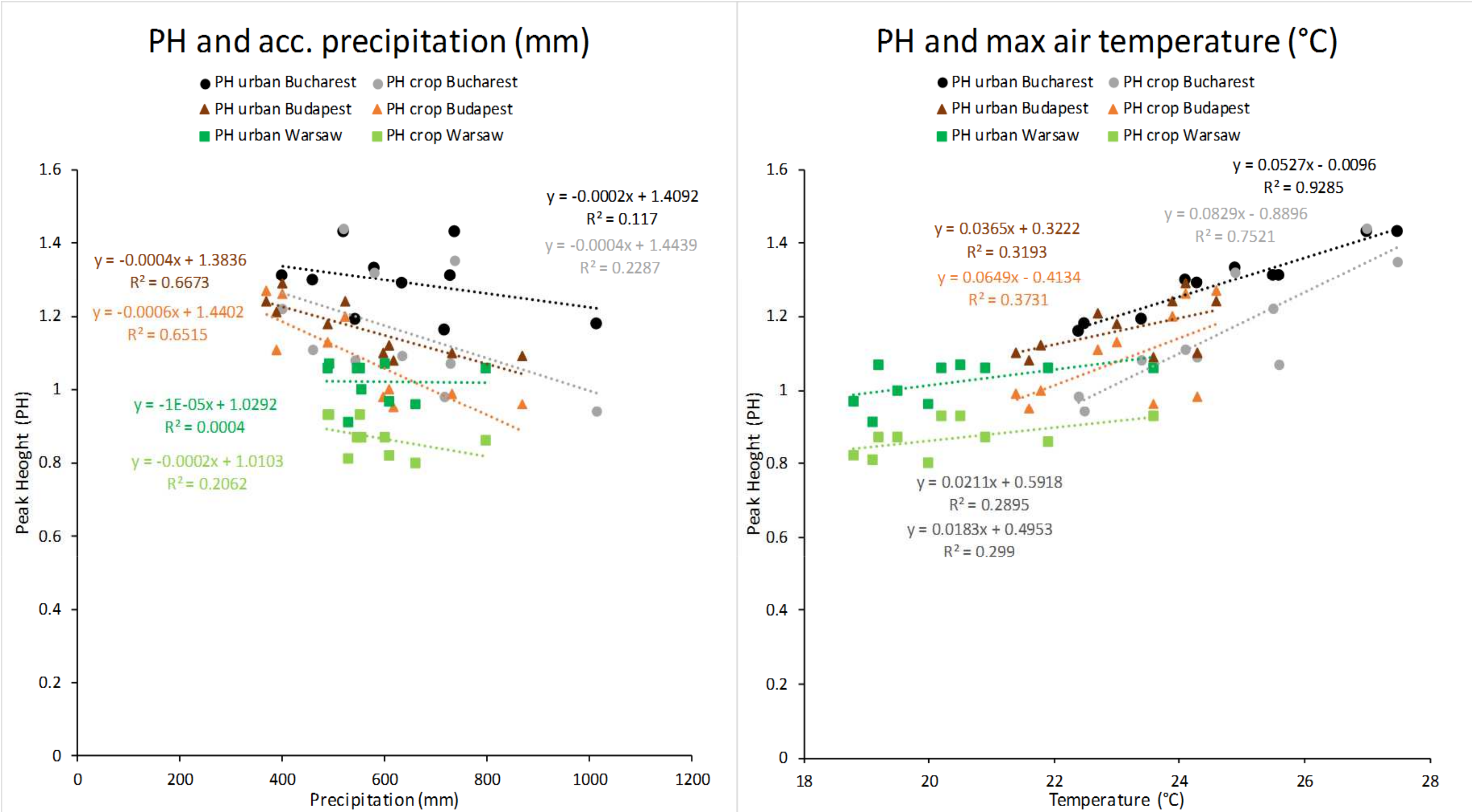
- The quadratic model reveals how much the accumulated MIR radiance varies by latitude
- For all cities in urban class, a very strong (r^2 higher than 0.97) parabolic pattern is visible.
- The highest accumulated monthly MIR has Bucharest (5.07 W m-2) with the peak of 1.29 (W m-2). The lowest values of TTP and PH has Warsaw.





Thermal Time Peak:

- **negative correlations with accumulated precipitation, but the strength of the relationships is strong in Budapest, marginal in Bucharest, and very weak in Warsaw**
- **strong positive correlations with maximum air temperature in Bucharest, but not in either Budapest or Warsaw**



Peak Height:

- negative correlations with accumulated precipitation
- strong positive correlations with maximum air temperature for Bucharest, the positive relationships for Budapest and Warsaw are modest

Results:

1) Based on seasonality of MIR radiance over urban areas and nearby croplands:

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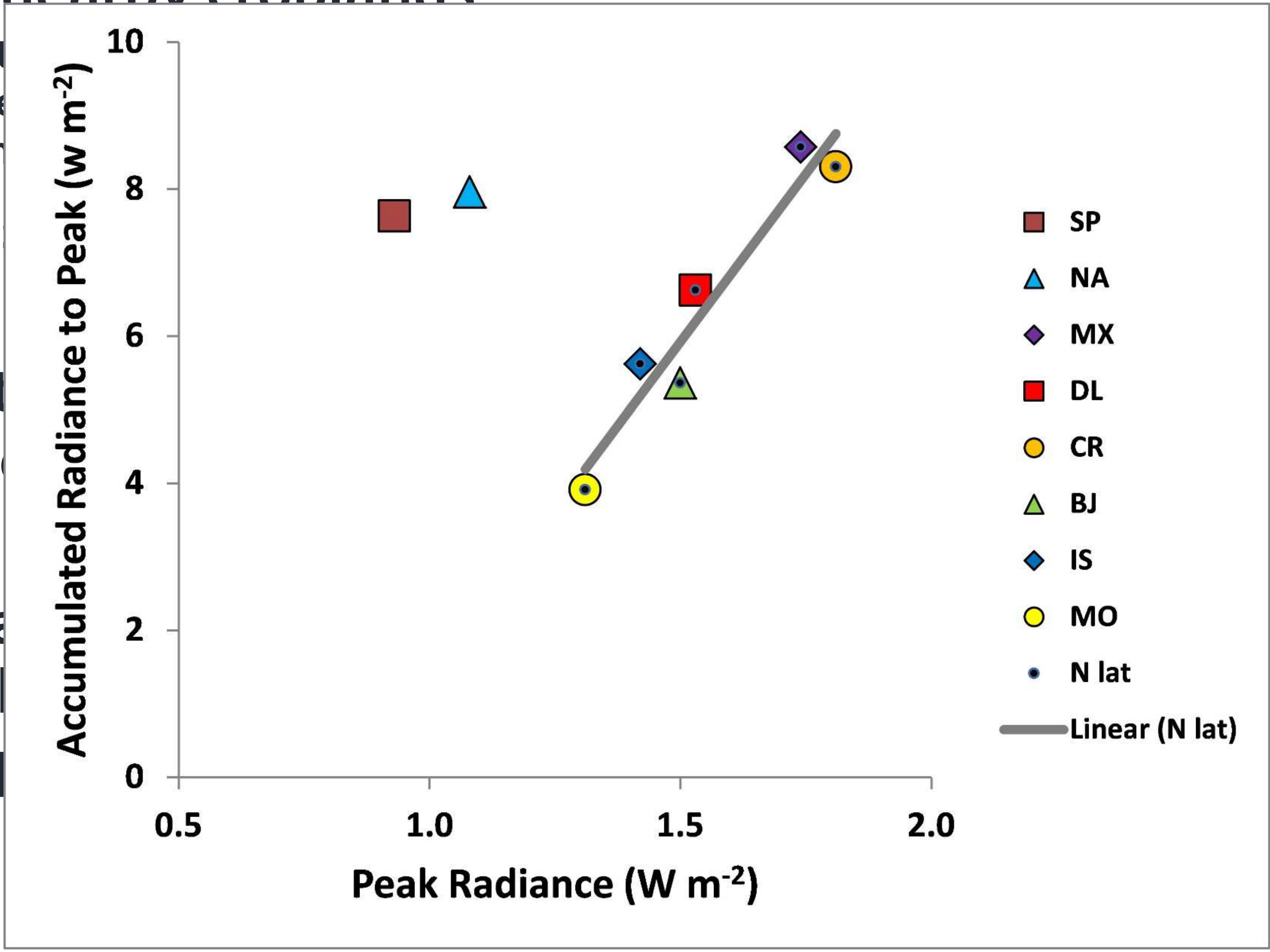

Results:

1) Based on seasonality of MIR radiance over urban areas and nearby croplands:
    - the UHI varied in the MIR due to time of year i.e. the cropland MIR could be larger than the urban MIR when there was more exposed soil at planting and harvest
2) The seasonal dynamic range of the MIR could exceed that of the NDVI
3) Latitude alone has a strong effect on the seasonal pattern of MIR radiance
4) Explored linkage between meteorological data and MIR radiance shows a range of response from strong to weak dependence of MIR radiance on maximum temperature and accumulated precipitation

SUMMING UP (1):

- Latitudinal variation affects the UHI in MIR due to the weaker insolation at higher latitudes and seasonality effect:

- The contrast between urban and cropland in the MIR is not constant due to changes in the amount and timing of exposed soils due to crop types and agricultural practices

Snímek 23

R6 3 take home msgs - one slide
Rapsodia; 8.7.2016

SUMMING UP (2):

- Climate as a factor (Warsaw is exposed to air masses from the Baltic Sea, more humid climate than Budapest. Bucharest is located in a different climate zone in warmer southeastern Europe)

- Temperature and precipitation modulate MIR seasonality, but not in a simple way:
  - Temperature may provide a proxy of insolation and dryness driving the land surface to a brighter MIR state
  - Precipitation may be driving the land surface to a darker MIR state through stimulating vegetation growth and development

R6 3 take home msgs - one slide
Rapsodia; 8.7.2016

SUMMING UP (3):

- The phenomenology of the MIR is not a simple inverse of the NDVI, but rather responds to surface conditions and environmental forcing in a manner that is complementary to vegetation indices; although the seasonal dynamic range of the MIR could exceed that of the NDVI

- The coarse spatial resolution (~1 km at nadir) of current orbital sensors with MIR capability makes it difficult to resolve the spatially heterogeneous land cover patterns of most cities

- NEXT STEP: Potential to compare the MIR behaviors of different elements in the urban fabric using Local Climate Zones (www.wudapt.org) - The World Urban Database and Access Portal Tools (WUDAPT) is an initiative to collect data on the form and function of cities around the world

Thanks for your attention!

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