WRF-urban model and global LCZ data implementation

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Many thanks to the WRF team for independent data testing!

Updates and discussions

@ 2023 WUDAPT Workshop, NCAR

WRF-Urban: International collaborative effort

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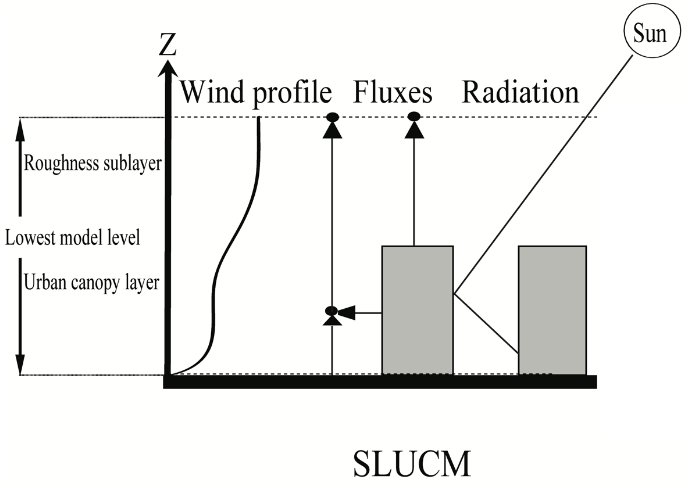
RMetS
Royal Meteorological Society

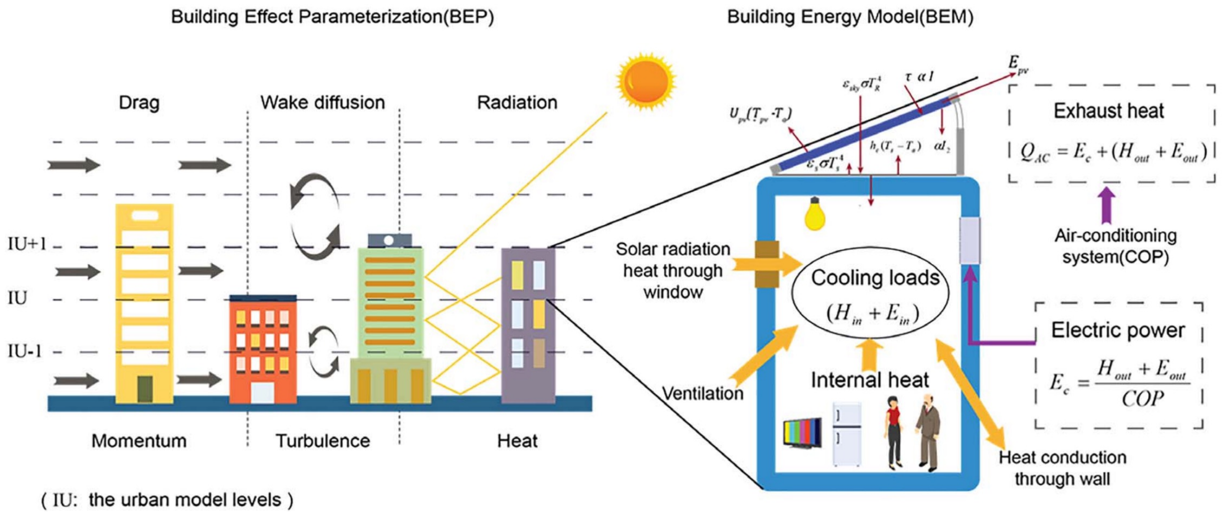
The integrated WRF/urban modelling system: development, evaluation, and applications to urban environmental problems

Fei Chen,[a*] Hiroyuki Kusaka,[b] Robert Bornstein,[c] Jason Ching,[d†] C. S. B. Grimmond,[e] Susanne Grossman-Clarke,[f] Thomas Loridan,[e] Kevin W. Manning,[a] Alberto Martilli,[g] Shiguang Miao,[h] David Sailor,[i] Francisco P. Salamanca,[g] Haider Taha,[j] Mukul Tewari,[a] Xuemei Wang,[k] Andrzej A. Wyszogrodzki[a] and Chaolin Zhang[h,l]

- a suite of urban canopy-process models
- Integrate multi-source multi-scale data of urban land use, building characteristics, and anthropogenic heat
- a companion urbanized land data assimilation system
- ability to couple WRF-Urban to urban-scale Computational Fluid Dynamic and Large Eddy Simulation models



Kusaka et al. 2001



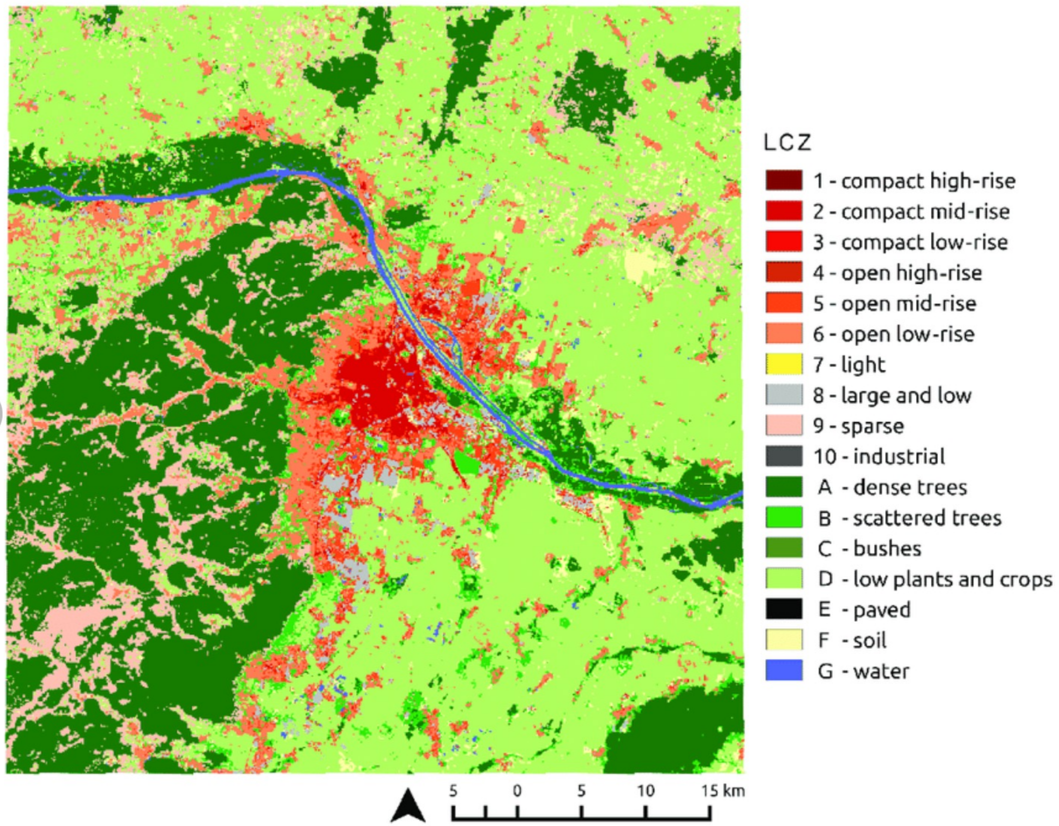
Martilli et al. 2002; Salamanca and Martilli 2010.

Google Scholar: more than 160 groups in 55 countries have used WRF-Urban

WRF-Urban model key inputs

Urban land type (e.g., LCZ) → WPS (geo_em* file) → WRF real.exe (wrfinput file) → WRF wrf.exe (wrfout* file) ← Urban parameter (URBPARM* file)

Urban land use type



WUDAPT derived LCZ map of Vienna, Austria for the ROI. [Colour figure can be viewed at wileyonlinelibrary.com].

Urban parameter table (URBPARM_LCZ.TBL)

```
# Urban Parameters depending on Urban type
# USGS

Number of urban categories: 11

#
#  Where there are multiple columns of values, the values refer, in
#  order, to: 1) Commercial, 2) High intensity residential, and 3) Low
#  intensity residential:  I.e.:
#
#  Index:        1              2              3             4            5            6              7
#  Type:  Comp High-Rise, Comp Mid-Rise, Comp Low-Rise, Op H-Rise, Op M-Rise, Op L-Rise, Lightweight L-Rise,
Asphalt


#
# ZR:   Roof level (building height)  [ m ]
#      (sf_urban_physics=1)

ZR: 37.5, 17.5, 6.5, 37.5, 17.5, 6.5, 3., 6.5, 6.5, 10., 10.

#
# SIGMA_ZED:  Standard Deviation of roof height  [ m ]
#      (sf_urban_physics=1)

SIGMA_ZED: 4.0,  3.0,  1.0, 1., 1., 1., 1., 1., 1., 1., 1.
```

Urban local climate zone (LCZ) categorization

WRF-urban (any urban scheme) is able to use LCZ since version 4.3
WRF namelist control: use_wudapt_lcz = 0 or 1

WRF land use type #

- 51 ← Compact highrise (1)
- 52 ← Compact midrise (2)
- 53 ← Compact lowrise (3)
- 54 ← Open highrise (4)
- 55 ← Open midrise (5)
- 56 ← Open lowrise (6)
- 57 ← Lightweight lowrise (7)
- 58 ← Large lowrise (8)
- 59 ← Sparsely built (9)
- 60 ← Heavy industry (10)
- Bare rock or paved (E) → 61

MODIS natural type (A–D)

MODIS natural type (F–G)

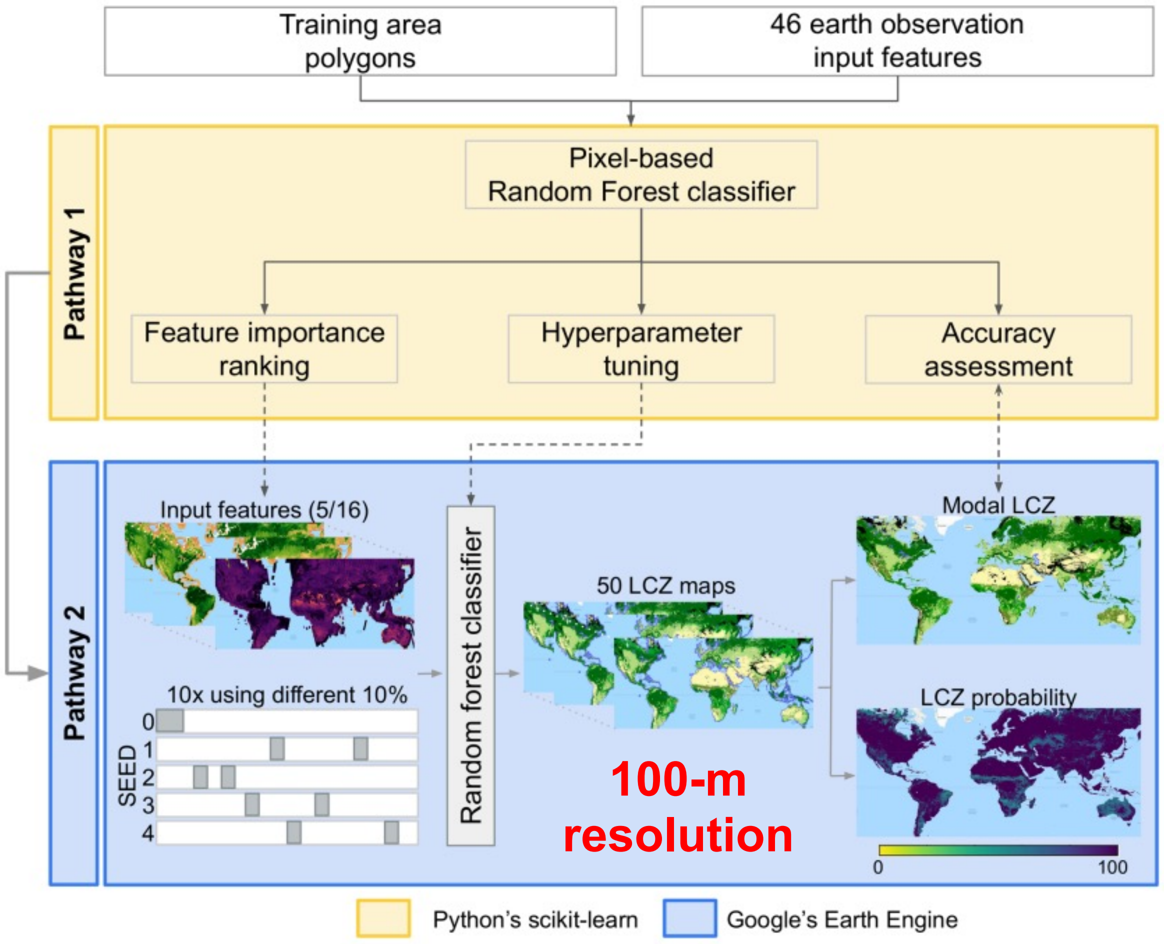
- Before WRF v4.4.2, LCZ is 31~41 in WRF
- Starting from WRF v4.4.2, LCZ is 51~61 to avoid overlapping with NLCD 1~40 land types

Previous efforts in developing LCZ data & tools for WRF-urban

Open Access Earth System Science Data

A global map of local climate zones to support earth system modelling and urban-scale environmental science

Matthias Demuzere[1], Jonas Kittner[1], Alberto Martilli[2], Gerald Mills[3], Christian Moede[1], Iain D. Stewart[4], Jasper van Vliet[5], and Benjamin Bechtel[1]



The Journal of Open Source Software

W2W: A Python package that injects WUDAPT's Local Climate Zone information in WRF

Matthias Demuzere[1¶], Daniel Argüeso[2], Andrea Zonato[3], and Jonas Kittner[1]

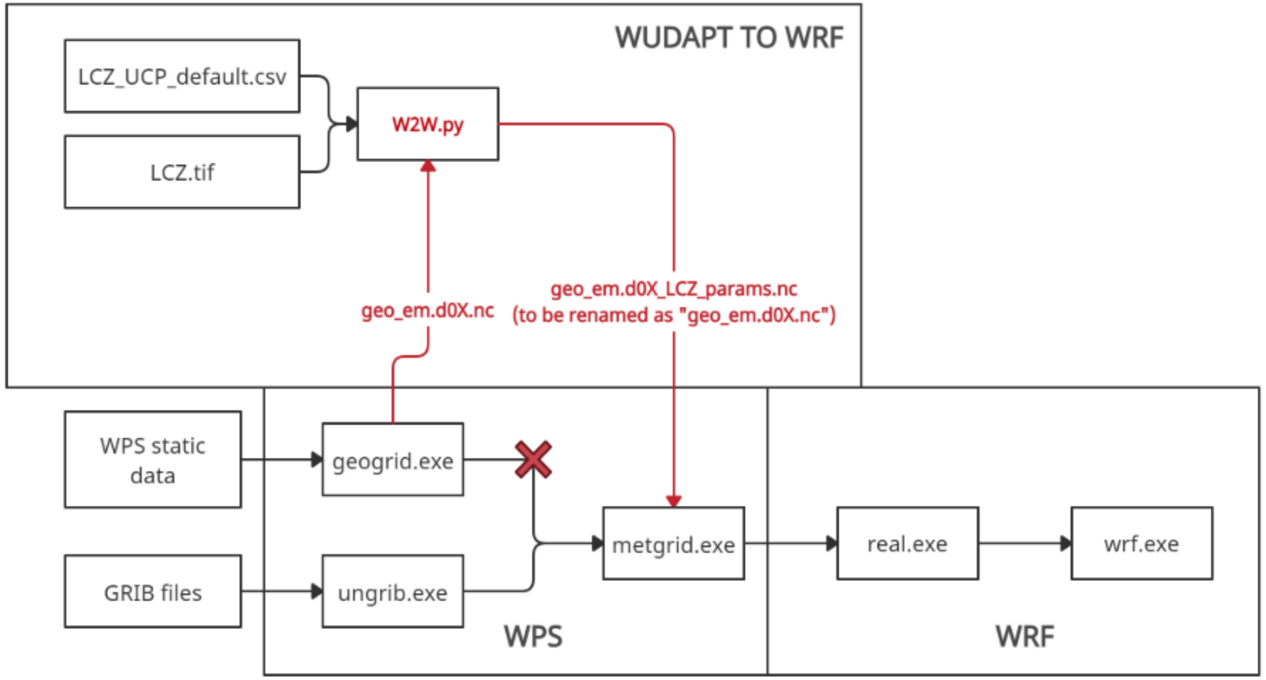


Figure 1: Modified workflow to set up and run a WRF simulation including urban parameters derived from LCZs using W2W.

Implementing the global 100-m LCZ data into WRF/WPS system

Raw LCZ data → **Tiled binary** data maps/files → WRF/WPS geogrid preprocessing → geo_em.d01.nc with urban category & parameter map → WRF model run

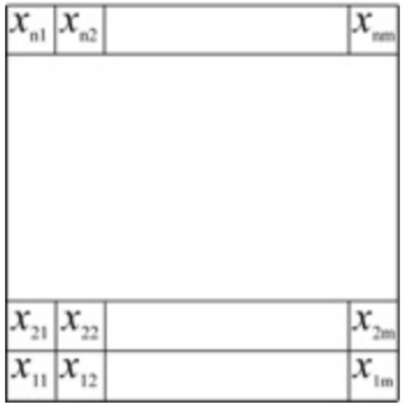
1. Writing Static Data (LCZ map) to the tiled Geogrid Binary Format

2. Optional regional mask (identify urban pixels; non-urban grids should have zero/missing values for parameters)

3. Data index file (store data map info)

update GEOGRID.TBL:
data path, averaging method, etc.

```
type=categorical
category_min=1
category_max=24
projection=regular_ll
dx=0.00833333
dy=0.00833333
known_x=1.0
known_y=1.0
known_lat=-89.99583
known_lon=-179.99583
wordsize=1
tile_x=1200
tile_y=1200
tile_z=1
units="category"
description="24-category USGS landuse"
```



```
33601-34800.12001-13200
33601-34800.13201-14400
33601-34800.14401-15600
33601-34800.15601-16800
33601-34800.16801-18000
33601-34800.18001-19200
33601-34800.19201-20400
33601-34800.20401-21600
34801-36000.00001-01200
34801-36000.01201-02400
34801-36000.02401-03600
34801-36000.03601-04800
```

Detailed instruction (WRF user guide):
https://www2.mmm.ucar.edu/wrf/users/docs/user_guide_v4/v4.3/users_guide_chap3.html#_Writing_Static_Data

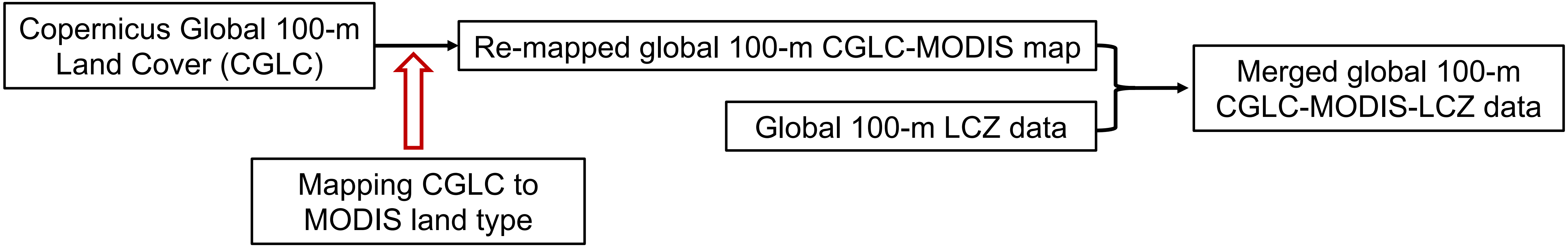
Implementing the global 100-m LCZ data into WRF/WPS system

Problem during implementation:

If only the LCZ map over global urban pixels is provided, then there are some inconsistencies between urban map used to generate LCZ data and the existing MODIS or USGS map in WRF/WPS, which leads to problems when overlaying the two.

For example, LCZ data identifies the pixel as non-urban while MODIS data identifies it as urban (land type=13), then WRF-urban will not recognize this pixel land type when LCZ capability is activated (use_wudapt_lcz = 1).

Solution: **create a consistent global land cover with LCZ for WRF/WPS implementation**



Mapping CGLC to MODIS land type category

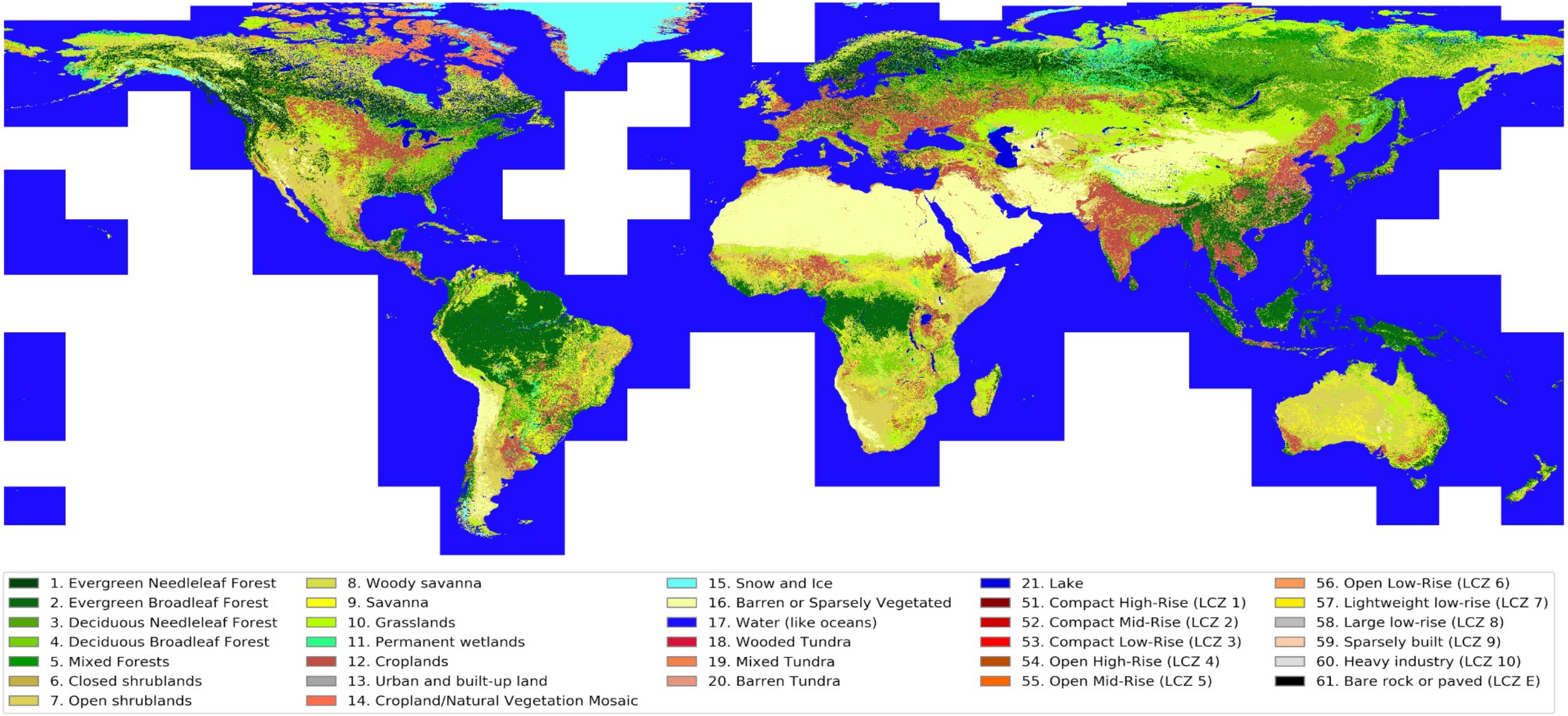
CGLC		MODIS-IGBP	
Value	Description	Value	Description
0	Unknown. No or not enough satellite data available.	22	*Unclassified**
20	Shrubs. Woody perennial plants with persistent and woody stems and without any defined main stem being less than 5 m tall. The shrub foliage can be either evergreen or deciduous.	6, 7, 9 or 10	See Table 2 for more information
30	Herbaceous vegetation. Plants without persistent stems or shoots above ground and lacking definite firm structure. Tree and shrub cover is less than 10 %.	6, 7, 9 or 10	6: Closed Shrublands 7: Open Shrublands: dominated by woody perennials (1-2m height) 10-60% cover. 9: Savannas: tree cover 10-30% (canopy >2m). 10: Grasslands
40	Cultivated and managed vegetation / agriculture. Lands covered with temporary crops followed by harvest and a bare soil period (e.g., single and multiple cropping systems). Note that perennial woody crops will be classified as the appropriate forest or shrub land cover type.	12	Croplands
50	Urban / built up. Land covered by buildings and other man-made structures.	13	Urban and Built-up Land
60	Bare / sparse vegetation. Lands with exposed soil, sand, or rocks and never has more than 10 % vegetated cover during any time of the year.	16	Barren or Sparsely Vegetated
70	Snow and ice. Lands under snow or ice cover throughout the year.	15	Snow and Ice
80	Permanent water bodies. Lakes, reservoirs, and rivers. Can be either fresh or salt-water bodies.	21	Lake
90	Herbaceous wetland. Lands with a permanent mixture of water and herbaceous or woody vegetation. The vegetation can be present in either salt, brackish, or freshwater.	11	Permanent Wetlands: permanently inundated lands with 30-60% water cover and >10% vegetated cover.
100	Moss and lichen.	19	Mixed Tundra
111	Closed forest, evergreen needle leaf. Tree canopy >70 %, almost all needle leaf trees remain green all year. Canopy is never without green foliage.	1	Evergreen Needleleaf Forest
112	Closed forest, evergreen broad leaf. Tree canopy >70 %, almost all broadleaf trees remain green year round. Canopy is never without green foliage.	2	Evergreen Broadleaf Forest
113	Closed forest, deciduous needle leaf. Tree canopy >70 %, consists of seasonal needle leaf tree communities with an annual cycle of leaf-on and leaf-off periods.	3	Deciduous Needleleaf Forest
114	Closed forest, deciduous broadleaf. Tree canopy >70 %, consists of seasonal broadleaf tree communities with an annual cycle of leaf-on and leaf-off periods.	4	Deciduous Broadleaf Forest
115	Closed forest, mixed.	5	Mixed Forests
116	Closed forest, not matching any of the other definitions.	5	Mixed Forests
121	Open forest, evergreen needle leaf. Top layer- trees 15-70 % and second layer- mixed of shrubs and grassland, almost all needle leaf trees remain green all year. Canopy is never without green foliage.	8	Woody Savannas: tree cover 30-60% (canopy >2m).
122	Open forest, evergreen broad leaf. Top layer- trees 15-70 % and second layer- mixed of shrubs and grassland, almost all broadleaf trees remain green year round. Canopy is never without green foliage.	8	Woody Savannas: tree cover 30-60% (canopy >2m).
123	Open forest, deciduous needle leaf. Top layer- trees 15-70 % and second layer- mixed of shrubs and grassland, consists of seasonal needle leaf tree communities with an annual cycle of leaf-on and leaf-off periods.	8	Woody Savannas: tree cover 30-60% (canopy >2m).
124	Open forest, deciduous broadleaf. Top layer- trees 15-70 % and second layer- mixed of shrubs and grassland, consists of seasonal broadleaf tree communities with an annual cycle of leaf-on and leaf-off periods.	8	Woody Savannas: tree cover 30-60% (canopy >2m).
125	Open forest, mixed.	8	Woody Savannas: tree cover 30-60% (canopy >2m).
126	Open forest, not matching any of the other definitions.	8	Woody Savannas: tree cover 30-60% (canopy >2m).
200	Oceans, seas. Can be either fresh or salt-water bodies.	17	Water (like oceans)

** Unclassified pixels are replaced by the modal class of the neighboring pixels. Neighbors are initially taken from a 3x3 window centered on the pixel of interest, a window that is allowed to grow until a modal class is found.*

Merging CGLC-MODIS and LCZ global 100-m dataset

CGLC-MODIS	LCZ	Action
Urban	Urban	Urban (built LCZs: 51 - 61, equalling LCZ 1 - 10 and E)
Urban	Natural	Natural LCZ to CGLC-MODIS class: • LCZ A → CGLC-MODIS 5 • LCZ B → CGLC-MODIS 12 • LCZ C → CGLC-MODIS 7 • LCZ D → CGLC-MODIS 10 • LCZ E → CGLC-MODIS 16 • LCZ F → CGLC-MODIS 16 • LCZ G → CGLC-MODIS 17
Natural	Urban	CGLC-MODIS Natural
Natural	Natural	CGLC-MODIS Natural

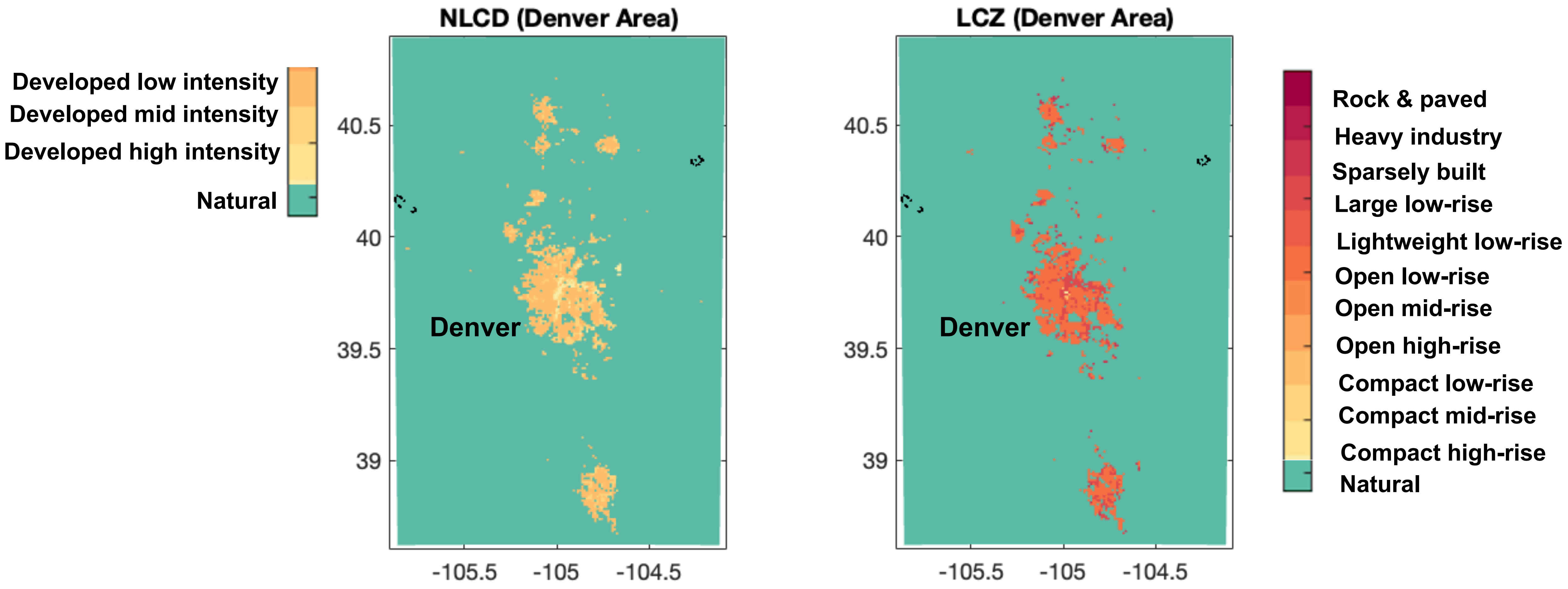
Global 100-m CGLC-MODIS-LCZ map implemented in WRF/WPS



Only work with MODIS land type in WPS!

This CGLC-MODIS-LCZ has a higher priority in WPS, so if chosen, it will be automatically overlaid upon the default WPS MODIS map for uncovered areas (i.e., two polar regions and oceans).

Example: NLCD vs LCZ for Denver urban areas



Key differences:

1. **More detailed urban types in LCZ categories**
2. **More urban pixels (surrounding big cities) identified by LCZ map**

Current status of the global LCZ implementation in WRF/WPS

1. Data production has been completed.
2. Comprehensive data testing and WRF test run with the LCZ data have been completed.
3. The data has been officially delivered to the WRF team at NCAR HPC system (Cheyenne):
   /glade/work/wrfhelp/WPS_GEOG/
4. The data (CGLC-MODIS-LCZ_100m) is publicly released on the WRF/WPS website for use:
   https://www2.mmm.ucar.edu/wrf/users/download/get_sources_wps_geog.html
5. The WPS related updates to use this dataset is submitted to GitHub for WRF team review:
   https://github.com/wrf-model/WPS/pull/214
6. A detailed documentation of generating the dataset is being written and will be published soon for public access and citation.

Challenges and Future directions

1. Updating and ingesting LCZ-based urban morphology/thermal parameters: See Andrea Zonato's presentation.
2. Consistent treatment of vegetation type in rural portion of the urban grids (prescribed natural vs dominant)
3. Global high-res (e.g., 100-m) dataset for urban morphology/thermal parameters
4. Global 2-D urban fraction of each pixel consistent with LCZ (currently urban fraction is prescribed in Table outside US).
5. Future projection of LCZ map?

Thank you!

If you are interested in our work, please email me: cenlinhe@ucar.edu