NCAR Workshop:
WUDAPT to Modeling
Jan 13, 2023, Boulder Co

Overview Perspective: WUDAPT and Modeling to Facilitate Addressing Urbanization and Climate Change Exacerbated Risks Issues

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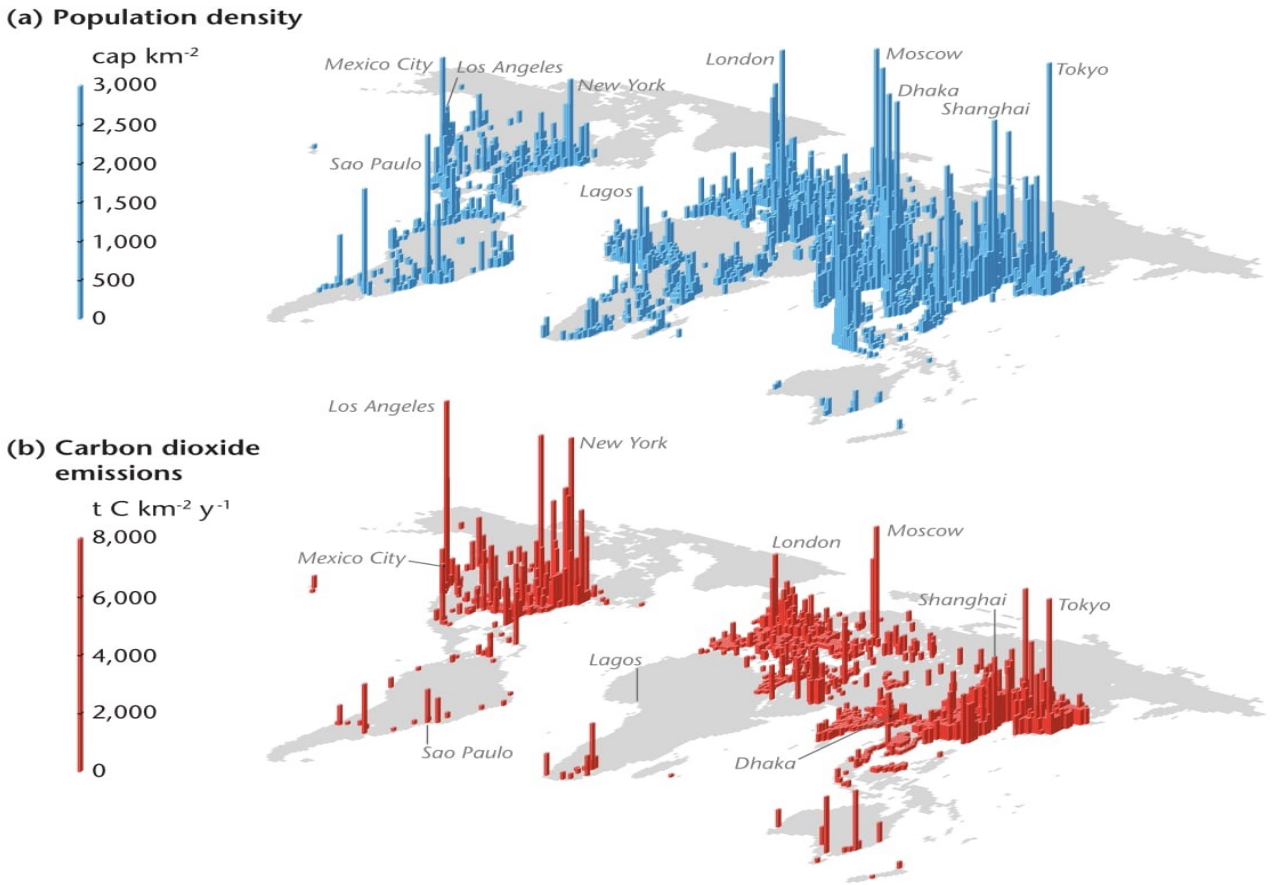
Presentation Outline

- Overview of WUDAPT Background & Perspective
- Suggested strategy and approaches
- Path Forward Strategy; Testbeds
- Discussion

Urbanization and Climate Change Focus
WUDAPT a data infrastructure for Urban Modeling tools



World Population
2000 > 1/2 Urban
2050 > 2/3 Urban
2100 > 3/4 Urban

GHG/Anthropocene
RPG Climate projections

Cities have profound impacts at urban scales but <3% of land area is urbanised. Their impact at regional and global scales is due to the accumulated emissions of all cities – small size but big impact. They are responsible for 70+% of CO2 emissions.

Source: Oke et al. (2017) Urban Climates. CUP

Modeling Tools needed!

Hazards and Risks in the Urban Environment

- Poor air quality and peak pollution episodes
- Extreme heat/cold and human thermal stress
- Hurricanes, typhoons, extreme local winds
- Wild fires, sand and dust storms
- Urban floods
- Sea-level rise due to climate change
- Energy and water sustainability
- Public health problems caused by the previous
- Climate change: urban emissions of GHG
- **Domino effect:** a single extreme event can lead to new hazards and a broad breakdown of a city's infrastructure







WMO OMM

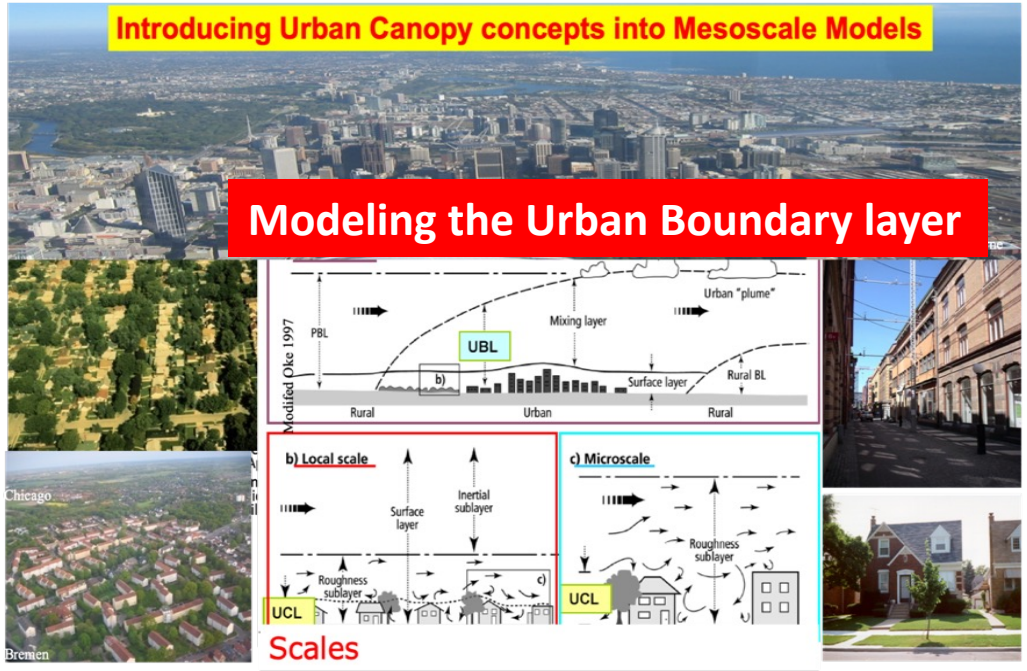
WUDAPT: A framework and infrastructure for "Fit for Purpose" urban applications

Urban areas are composed of aggregates of various 3-D morphological structures, impervious surfaces, and natural biota, responsible for creating canopy boundary layers.

Urbanization, population growth, and climate changes exacerbate a variety of risks.

Modeling treatments of canopy flows for Fit-for-Purpose (FFP) modeling can be treated with scale dependent sets of urban parameterizations (UCPs) and appropriate Form and Functional data.

WUDAPT'S goal is to generate such data on worldwide bases and an infrastructure for both generating appropriate data and supporting model implementation.



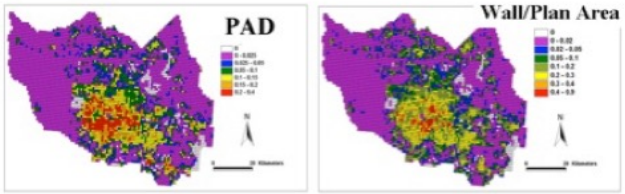
NOTEWORTHY!

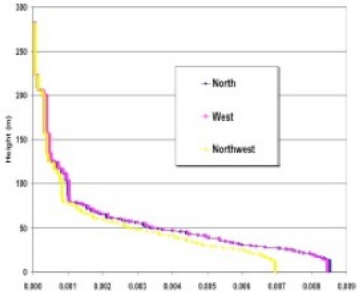
UCPs required to resolve urban scale features in models.

Each grid has unique set of UCPs

Example UCPs in NUDAPT for Harris County-Houston

1 km gridded fields from processed digitized lidar data

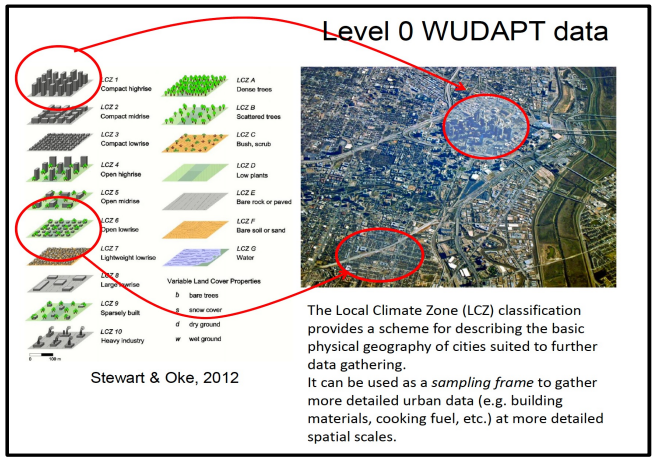




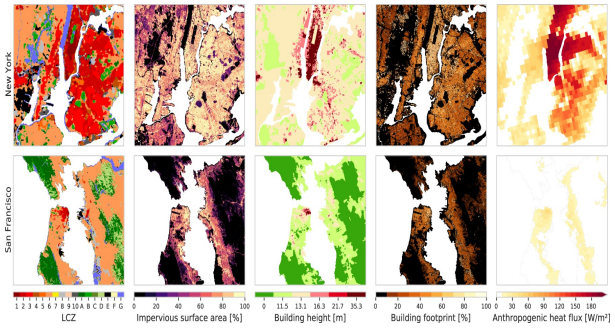
Gridded Frontal Area (packing density) Index as a function of height and approach angle of wind (based on Lidar data).

WUDAPT* STRATEGIC OVERVIEW

Major efforts &achievement in WUDAPT first decade



Maps of LCZ and UCPs from regional/global maps

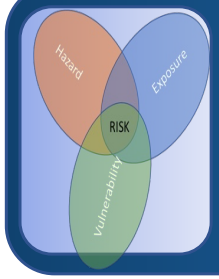


Level 0

- Local Climate Zone (LCZ) and UCP ranges
- Categorize city neighborhoods into LCZ classes
- Local Experts provide Training Areas
- Google Earth, Landsat and Saga
- City Specific to regional to Global LCZ Maps

Level 1

- More Precise UCP for each LCZ
- Focus on Form (e.g., building heights, street Width…) Function and Building Materials
- New Tools: DSC, UCP, UBEM
- Testbed as means to implementation



Level 2

- Fit for Purpose Applications &Analyses
- Links to various multiscale tools
- Current and future climate projections
- WUDAPT to Global Climate Models

**** World Urban Database and Access Portal Tools***

PATH FORWARD ACTIVITIES

Advanced methodologies

DSC,
UBEM
GHG..

TESTBED Fit for Purpose Applications

LCZ based WRF, uCLM
Multiscale linkages
RCP* assessments
MPAS support**
GHG Emissions projections
Hazards risk assessments

…..

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**Reactive Concentration Pathways*
*** Model Prediction Across Scales*

WUDAPT First Decade

- Developed methodology that generated LCZ maps from satellite data.
- Capability to generate Regional Maps, Then Global Maps
- Implementing global LCZ products into WRF
- Implementing LCZ global maps into CLM5
- Initial DSC development now able to generate 3-D building data based on OSM data.
- UCP Tool capable of generating UCPs from 3-D data
- Prototype UBEM based on Building archetypes and TABULA Data dictionary
- Over 400 Peer reviewed JA on LCZ

WUDAPT Decade

The WUDAPT Decade

JKS. Ching, G. Mills, B. Bechtel, M. Demuzere, D. Aliaga, C. Ren, M.M.F. Wong, D. Niyogi, M. Neophytou, A. Middel, I. Stewart, L. See, S. Arunachalam, Y. Shi

2011
Emergence of LCZ Concept: Croucher ASI, Hong Kong

2012
Proof of Concept LCZ to WUDAPT at ICUC8, DUBLIN IR

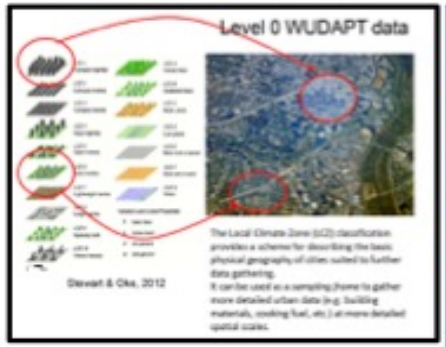
2013
LCZ Workshop, Dublin IR
Training Areas from Satellite

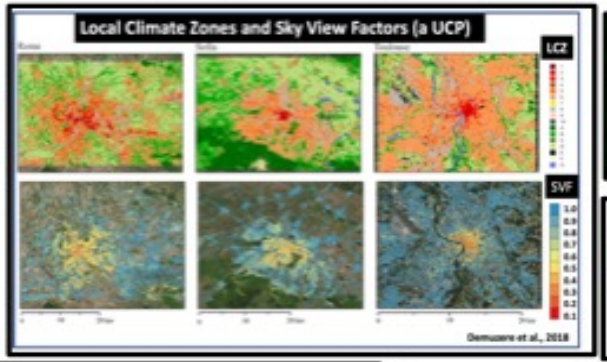
2015
LCZ Training Workshop
ICUC-9, Toulouse Fr
City Specific LCZ maps
HUMINEX (Quality)

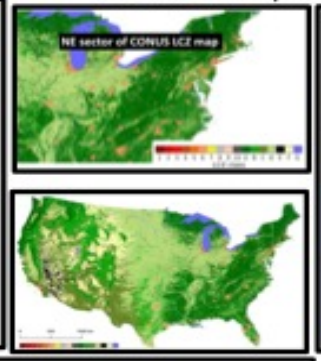
2018
ICUC-10, NYC,
City Specific LCZ maps
Proposed LCZ City-Regions-Global maps

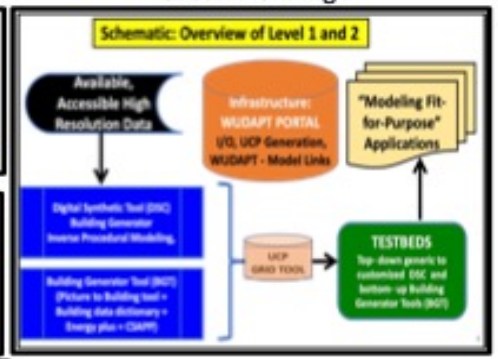
2020 – 2022
AMS-BUE Boston
DSC, UBEM Tools
Regional Maps,
LCZ Generator, UCP Tools
Global LCZ maps

Future
Level 1&2 Testbeds
Fit for Purpose Applications
- Intraurban WX, AQ
- Sustainability
- Urban Planning









MOTIVATIONS
- Climate Change, Enhanced risks
- Urbanization (2000-50%; 2075- 75%)
- Need for Urban Services
- Science-Based Intraurban Modeling
  - Urban Canopy Algorithms
  - Weather, Air Quality, Climate,
  - Energy, GHG systems
  - Urban Projections

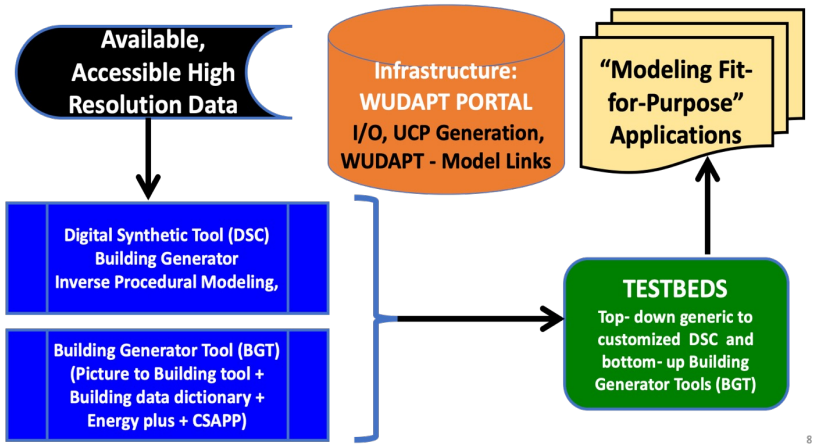
KEY PARADIGMS, APPROACHES
- Universal LCZ foundation
- Multiple Community based collaborations
- Innovation and methodology driven
- Strategic Hierarchical approach,
- Advanced Quality Assurance
- Dynamic LCZ change Implications
- Testbeds for
  - Methods evaluation
  - Fit for Purpose (FFP)Applications

MAJOR OUTCOMES
- Unique City Specific LCZ maps
- Intra-urban Baseline and Prospective Studies capabilities
- Regional and Global LCZ Maps
- Building to block scale Form and Function details
- Addressing Climate Change Risks
- 300+ Journal Articles and growing

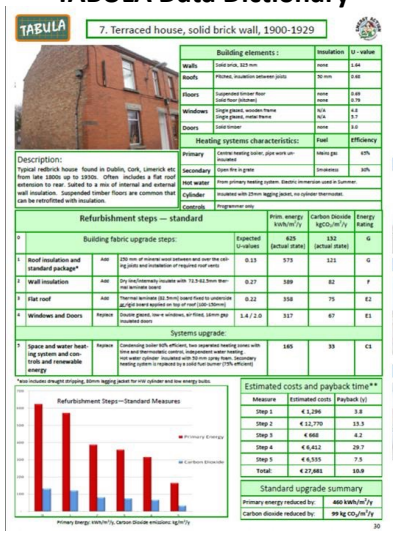
GET INVOLVED!
- Advanced UCPs information
- Fit for Purpose Applications
- Future Projections
- Intraurban GCM-UCLM-LCZ
- WUDAPT Testbeds
  - WUDAPT UCP to WRF
  - WUDAPT to CMAQ
  - WUDAPT to CMAS

WUDAPT Level 1 &2 Methods Developments Underway

Schematic: Overview of Level 1 and 2



TABULA Data Dictionary



Prototype UBEM

Building Archetype

Rating		UMI	
kWh/m2/y r	kgCO2m2/y r	kWh/m2/y r	kgCO2m2/y r
377	104.2	372	102.8
480	132.6	410	113.3
369	102	396	109.4
382	105.6	398	110
350	96.7	388	107.2
366	101.1	383	105.8
384	106.1	409	113
425	117.4	399	110.2
377	104.2	383	105.8

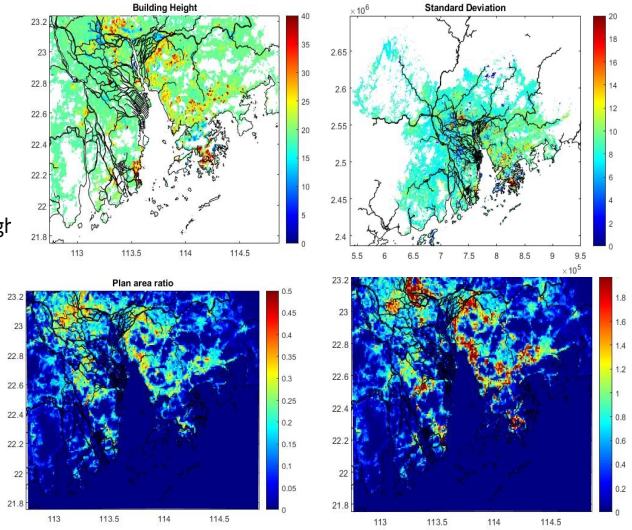
Level 1&2: Computing scale dependent Urban Canopy Parameters (UCPs) given digitized urban morphology from High-Res Google type satellite imagery based on WUDAPT's **Digital Synthetic City (DSC) tool**

DSC digitizes urban features

Therefore: UCPs can be generated for each and all grids in domain & Grid size is a user choice

Examples using Level 1 UCP Tool

- Building Height
- Plan area ratio
- Building surface to plan area ratio
- Standard deviation of building heigh
- Urban Fraction



WUDAPT tool for generating level 1&2 form-based UCPs (courtesy of M. Wong)

Path Forward Strategies and Approaches

- Collaborating community leveraging TESTBED Concept based on various FFP urban applications with LCZ based UCPs into uWRF on Themes
- Running CESM/UCLM with WUDAPT Simulations
- Using UBEM in AH and GHG emissions.
- Pilot Testbeds sought – Stakeholders?

So, just what do we mean by "TESTBEDS?"

Some definitions: TESTBED are:

- **Platforms for conducting rigorous, transparent, and replicable TESTING of scientific theories, computational tools, and new technologies. …used across many disciplines to research new product developments …..from …… prototype development (*Wikipedia)***
- **Any device, facility, or means for testing something in development. (*Miriam-Webster)***
- **Subject/platform Testing Product or purpose. (*Generic)***

Definition following Wikipedia. Proposed WUDAPT TESTBEDS are:

"Enterprises that supports activities leading to rigorous, transparent and replicable testing of methods and approaches

TO ACQUIRE & IMPLEMENT WUDAPT PRODUCTS INTO MODELING TOOLS

for prototype applications that address urbanization and climate change induced risks."

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Acquiring, implementing data for models

- **ACQUIRING UCP data methodologies**
  - **UCPS from LCZ maps**
  - **Generating HiRes building data using DSC**
- **Building Energy Modeling tool**
- **Prototype WUDAPT based Urban modeling**
  - **LCZ based uWRF**
  - **DSC based uWRF**
- **Prototype LCZ based CESM/CLM5-Global LCZ**
- **Prototype MPAS**
  - **w/LCZ**
  - **w/DSC**

PROTOTYPE Applications

- **CLIMATE CHANGE RISKS, RPGs**
  - **Extreme Heat**
  - **Extreme Weather**
    - **Storminess – Flooding**
    - **Wildfires**
- **AIR QUALITY**
- **URBAN PLANNING**
  - **Adaptability**
  - **Sustainability**
  - **Dynamic Growth**

Takeaway Points of WUDAPT TESTBEDS

- Given that:
  - Every major city is unique in terms of LCZ, UCP at block scales
  - LCZ based UCPs being implemented into Mesoscale-Global climate modeling systems for mesoscale (intraurban scale) weather and for global climate assessment modeling.
  - Advanced WUDAPT methodologies for generating UCPs, and tools for BEMs and AH/GHG emissions continues
  - Prototype intraurban modeling at meso to global scales now possible for myriad of TESTBED applications
- **Therefore, TESTBEDS:**
  - **Can contribute to testing/evaluating R&D Methodologies**
  - **Can explore means to extend current UCP outcomes to prospective "dynamic" situations for "What if City evolution", adaptation, sustainability … scenarios.**
  - **Are a strategic tactical approach by variety of communities impacted by urbanization and climate changes to address issues impacting their communities. Efforts contribute to establishing a proven template of prototypic applications**
  - **Are scalable e.g., city specific, regional, RPGs**
  - **Implement UCPs into MPAS systems**

Likely and other suggested TESTBEDS

- DSC, 3D city generation tool testing with DOE's Integrated Field Laboratories IFL's; e.g.,Chicago, Phoenix, Baltimore, Austin
- CMAS: Test various "Fit for Purpose" prototype demonstration city specific model application studies to create template using LCZ maps.
- Stakeholders: Explore collaborations on issues such as intraurban variations in heat exposures during extreme heat waves, air quality, etc
- Linkage to micro climate variability based on downscaling using UMEP tools
- Initiate linking UCPtool into MPAS modeling framework.
- Inputs to Digital Twin developments

End

Proposed Pilot AQ themed TESTBED Modeling studies towards evaluating and utilizing WUDAPT advances

Some theme for AQ TESTBEDs

- **FFP urban and intraurban AQ modeling applications**
  - **Demonstrate and explore application as design templates of applying CMAQ at local scales**
  - **Running CMAQ with MPAS, or regular grid system**
  - **Performing SinG-type modeling for AQ exposure modeling**
- **Siting WX and AQ observations in context of LCZ**
- **Prospective of future city design**
- **Design Applications for supporting Environmental Justice**
- **Incorporating WUDAPT into GCMs**
- **Training for links to running WUDAPT to AQ FFP applications**
- **Advancing further discussions vis WUDAPT Forum**

uWRF, uCLM applied to Climate& Air Quality issues

- **Preprocessor to CMAQ**
- **CMAQ & CMAS Regional and intra- Urban Assessments**
  - **Smoke and dust transport**
  - **Environmental Justice**
  - **Extreme event (Heat, Flooding…_)**
  - **Urban planning Support**
    - **Urban design (Future Cities)**
    - **Greening scenerios**
    - **Urbanization**
- **UBEM Emission characterizations**
  - **GHG**
  - **Anthropogenic Heating**
- **Street level Exposure Modeling**
  - **ADMS Prototype**
  - **SinG Prototype**

Aspects and Considerations for initiating a TESTBED from an Air Quality perspective for a WUDAPT & CMAS* collaboration

- **Urbanization:**
  - **Population of Urban Areas >50% in 2200; Projected 75%^ in 2275**
  - **Major source of air polluting and GHG emission**
- **WUDAPT (2012-22-00) LCZ-UCP capable of simulating Wx at urban (1km) and intraurban (100m) scales**
  - **IAUC and AMS Community collaborations**
  - **Generates maps of LCZ and UCPs (Note that such maps change with time (see wrf modeling for PRD))**
  - **City maps worldwide has unique LCZ, UCPs signatures**
  - **Preprocessor to CMAQ, WRF-CHEM, etc**
- **Model applications**
  - **Climate Change induced Extreme Risks**
    - **Extreme heat, Urban flooding modeling, Drought**
    - **Regional contexts**
  - **Policy: Environmental Justice issues an EPA-ORD Priority**
  - **Urban growth Projections and Urban planning, Scenerios Design Sustainability, Resilience,**
- **Modeling links (Fine scale AQ to street level exposure)**
  - **UMEP**
  - **Envi-Met**
  - **ADMS to Exposure modeling- link WUDAPT to Street level exposure modeling (ADMS, SinG…..)**
- **Anticipated Climate modeling**
  - **Ready to engage with Global LCZ map**
  - **Incorporate into EASM-UCLIM pending**
  - **RCP projections**

* Community Modeling and Analyses System (CMAS)

Urban (1–10) and natural (A–G) Local Climate Zone definitions
(adapted from Table 2 in Stewart and Oke *et al*. 2010

Level 0 Paradigm:

Generate maps based on Local Climate Zone Classification Scheme and Lookup Table of UCPs for each LCZ class

UCP values associated with LCZ classes

LCZ	λ_B	λ_I	λ_V	H	SVF	AHF	IMD
1. Compact high-rise	40–60	40–60	<10	>25	0.2–0.4	50–300	>80
2. Compact midrise	40–70	30–50	<20	10–25	0.3–0.6	<75	>70
3. Compact low-rise	40–70	20–50	<30	3–10	0.2–0.6	<75	>60
4. Open high-rise	20–40	30–40	30–40	>25	0.5–0.7	<50	50–80
5. Open midrise	20–40	30–50	20–40	10–25	0.5–0.8	<25	50–80
6. Open low-rise	20–40	20–50	30–60	3–10	0.6–0.9	<25	40-90
7. Lightweight low-rise	60–90	<20	<30	2–4	0.2–0.5	<35	>60
8. Large low-rise	30–50	40–50	<20	3–10	>0.7	<50	>70
9. Sparsely built	10–20	<20	60–80	3–10	>0.8	<10	10-40
10. Heavy industry	20–30	20–40	40–50	5–15	0.6–0.9	>300	>40
A. Dense trees	<10	<10	>90	3–30	<0.4	0	<20
B. Scattered trees	<10	<10	>90	3–15	0.5–0.8	0	<20
C. Bush, scrub	<10	<10	>90	<2	0.7–0.9	0	<20
D. Low plants	<10	<10	>90	<1	>0.9	0	<20
E. Bare rock or paved	<10	>90	<10	<0.25	>0.9	0	>90
F. Bare soil or sand	<10	<10	>90	<0.25	>0.9	0	<20
G. Water	<10	<10	>90	–	>0.9	0	<20

https://doi.org/10.1371/journal.pone.0214474.t001