"Weather-driven Wind and Turbulence Predictions within the Urban Environment in Support of Low-Level Aerial Operations"

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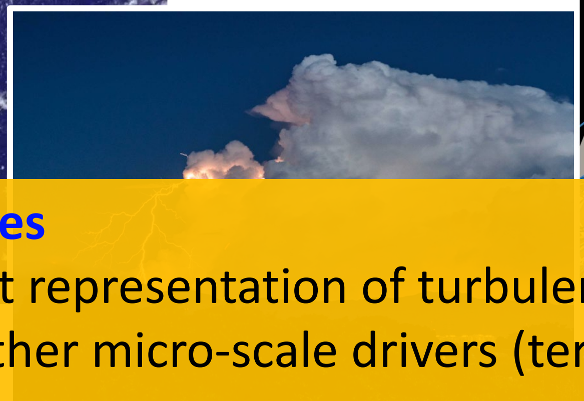
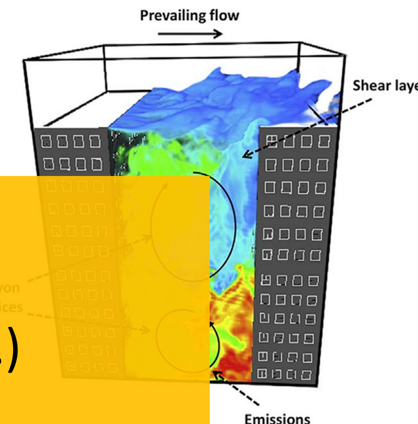
Matthias Steiner, Hailey Shin, Robert Sharman

November 9th 2021
Session: Emerging Science of Aviation Turbulence and Future Challenges
TURBULENCE MITIGATION WORKSHOP IV (virtual)

Prediction of Weather Across Multiple Scales





Weather System Scale | Thunderstorm Scale | City Scale | Building/Street Scale

100 km | 10 km | 1 km | 100 m | 10 m | 1 m

Advantages
- Explicit representation of turbulence
- And other micro-scale drivers (terrain, **urban**, clouds …)

Limitation
- Conventional CPU-based models are not efficient for real-time predictions beyond ~100m
- Slows pace of scientific exploration and discovery

Range of Scales

Global NWP Models
GFS, MPAS, FV3 (~30 km)

Mesoscale NWP Models
WRF [RAP 13 km, HRRR 3 km]

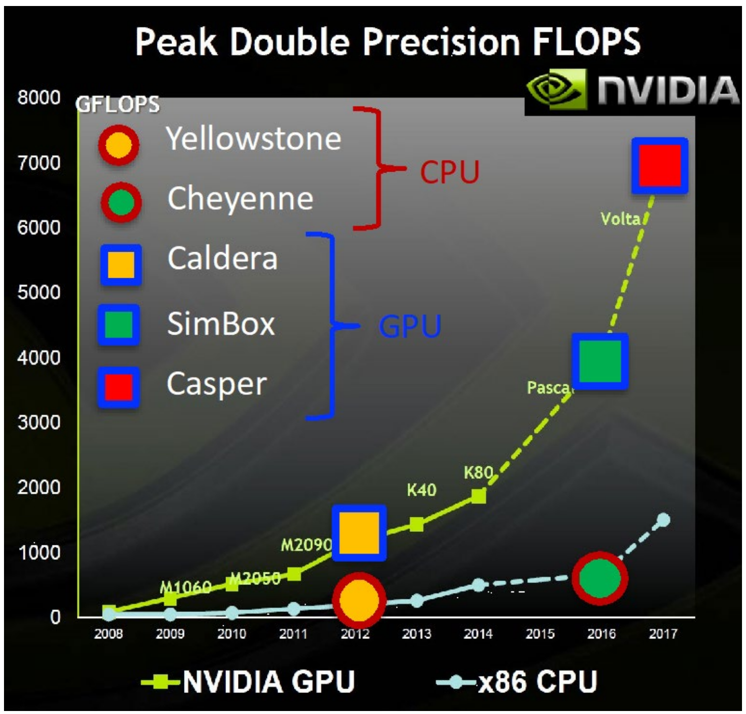
Microscale "Research" Models
Large-eddy simulation (LES)
FastEddy® (<100 m)

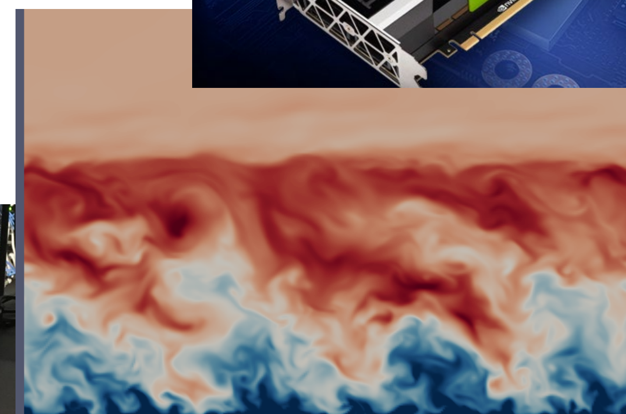
Increasingly resolving atmospheric processes explicitly →

FastEddy®: NCAR/RAL's GPU-resident LES model

Accelerated-GPU computing is the solution!

- Dynamical core for Atmospheric Boundary Layer flow simulations
- Potential to provide real-time forecasts at meter-scale
- Incorporates explicit urban modeling capabilities





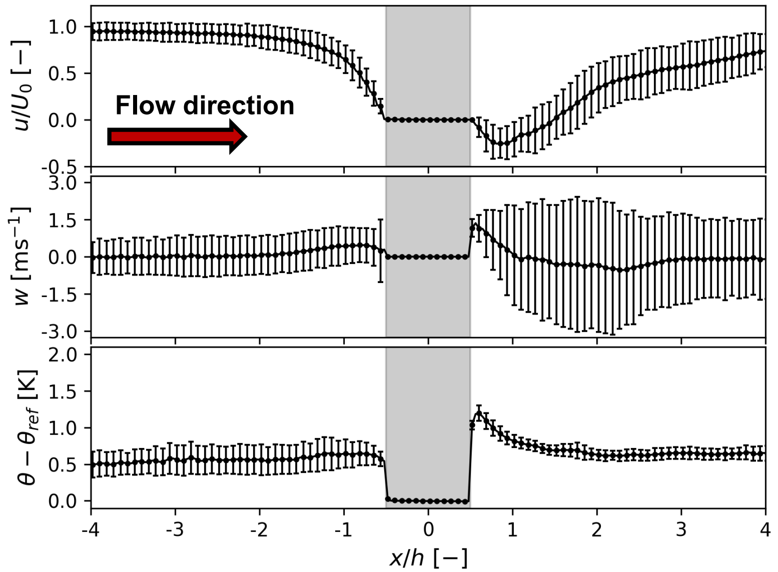
Significant speed up!!!
1 GPU ~ 256 CPU cores

dx = 5 m (3km x 3km x 2km) on 32 GPUs runs at real-time pace!!!

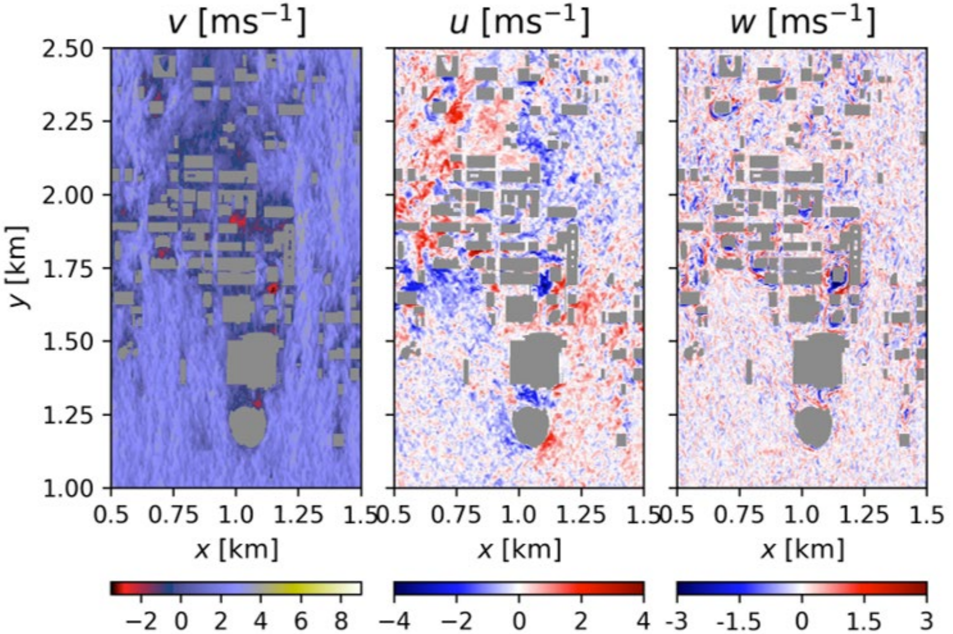
Sauer and Muñoz-Esparza (JAMES 2020)

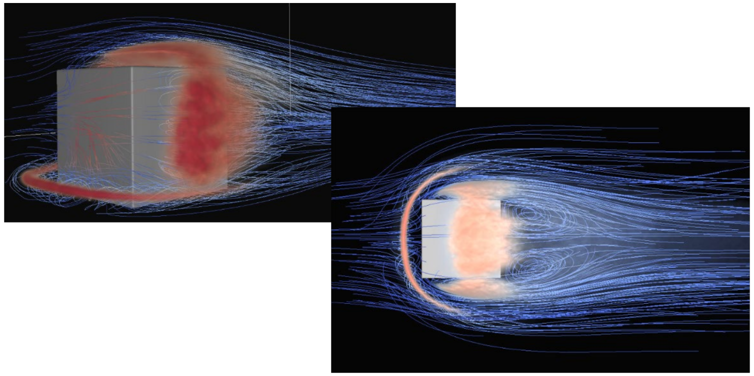
Explicit modeling of urban effects

- Flow obstacles are modeled through immersed volumetric body forces (IBFM*)
- Extended the original IBFM to handle thermal effects & to be scale-independent



Urban FastEddy® over downtown OKC (Δ = 2 m)



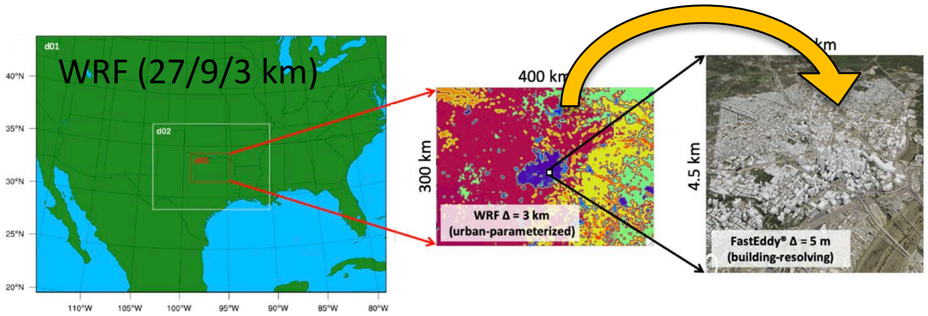


Validation with OKC Joint Urban 2003 field campaign (wind speed, turbulence and dispersion)

Muñoz-Esparza, Sauer, et al. (JAMES 2020)

*Chan & Leach (2007), Smolarkiewicz et al. (2007)

WRF-to-FastEddy® coupling over downtown Dallas

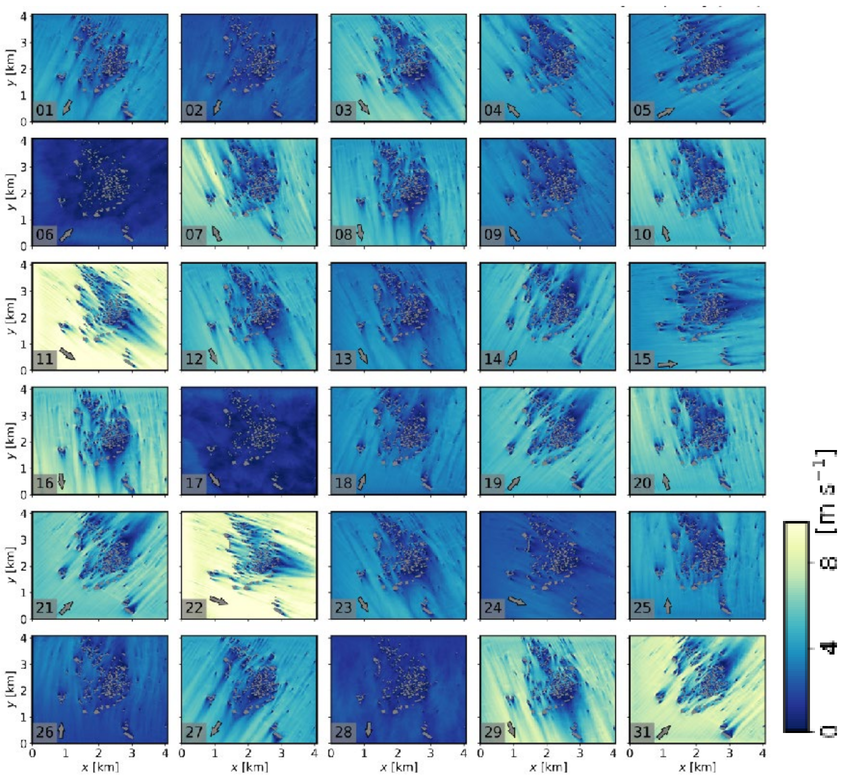


Meso-micro coupling requires generation of resolved turbulence: **"Cell Perturbation Method"** [Muñoz-Esparza et al., 2014, 2015, 2018]

FastEddy® (Δ=5m)

<u>January 2018</u>

<u>at 12 LT (30 days)</u>



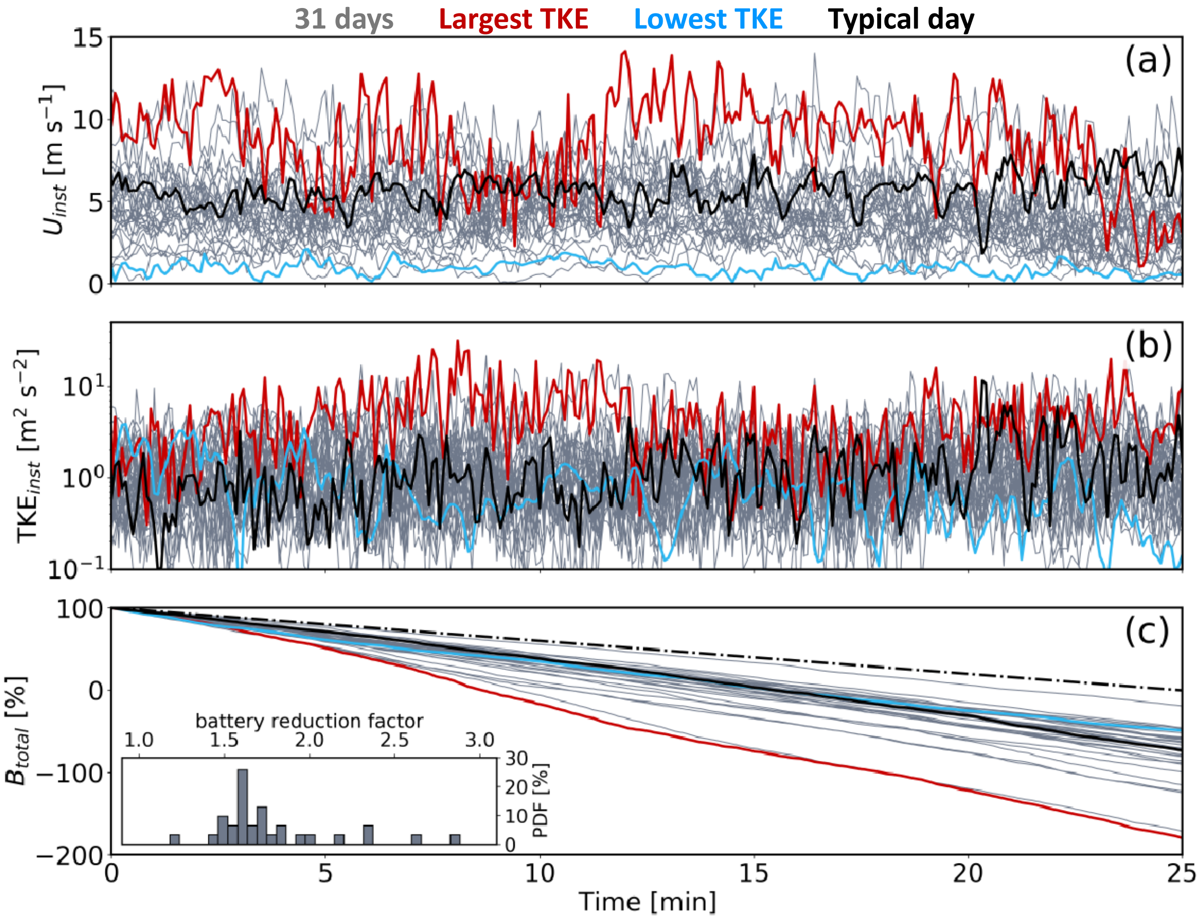
Time-averaged (30 min) mean wind speed distribution at z = 26 m

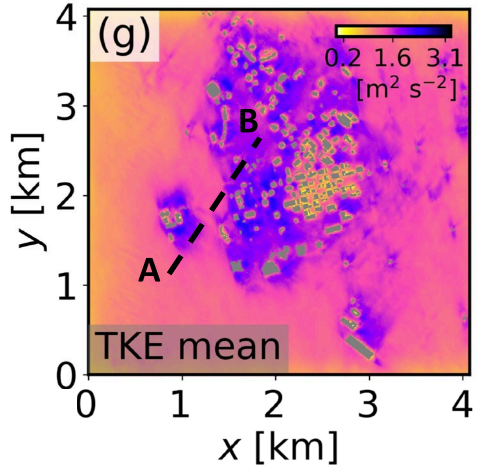
Role of day-to-day weather variability

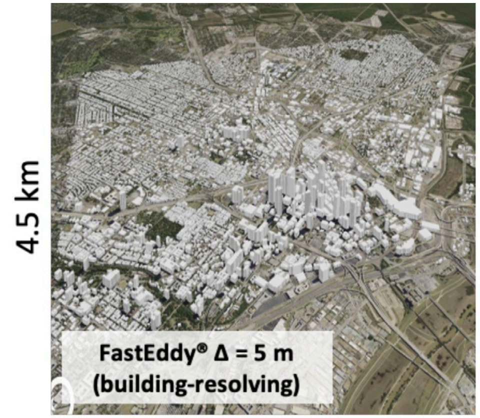
- Weather-driven street-scale predictions reveal a strong day-to-day variability -> a typical/representative day is NOT necessarily useful!
- Complex interaction with urban layout and atmospheric stability results in fundamental key differences [building wakes, canyon flows and turbulence regions]

Muñoz-Esparza et al. (AGU Advances 2021)

Urban weather impacts: a flying UAV example

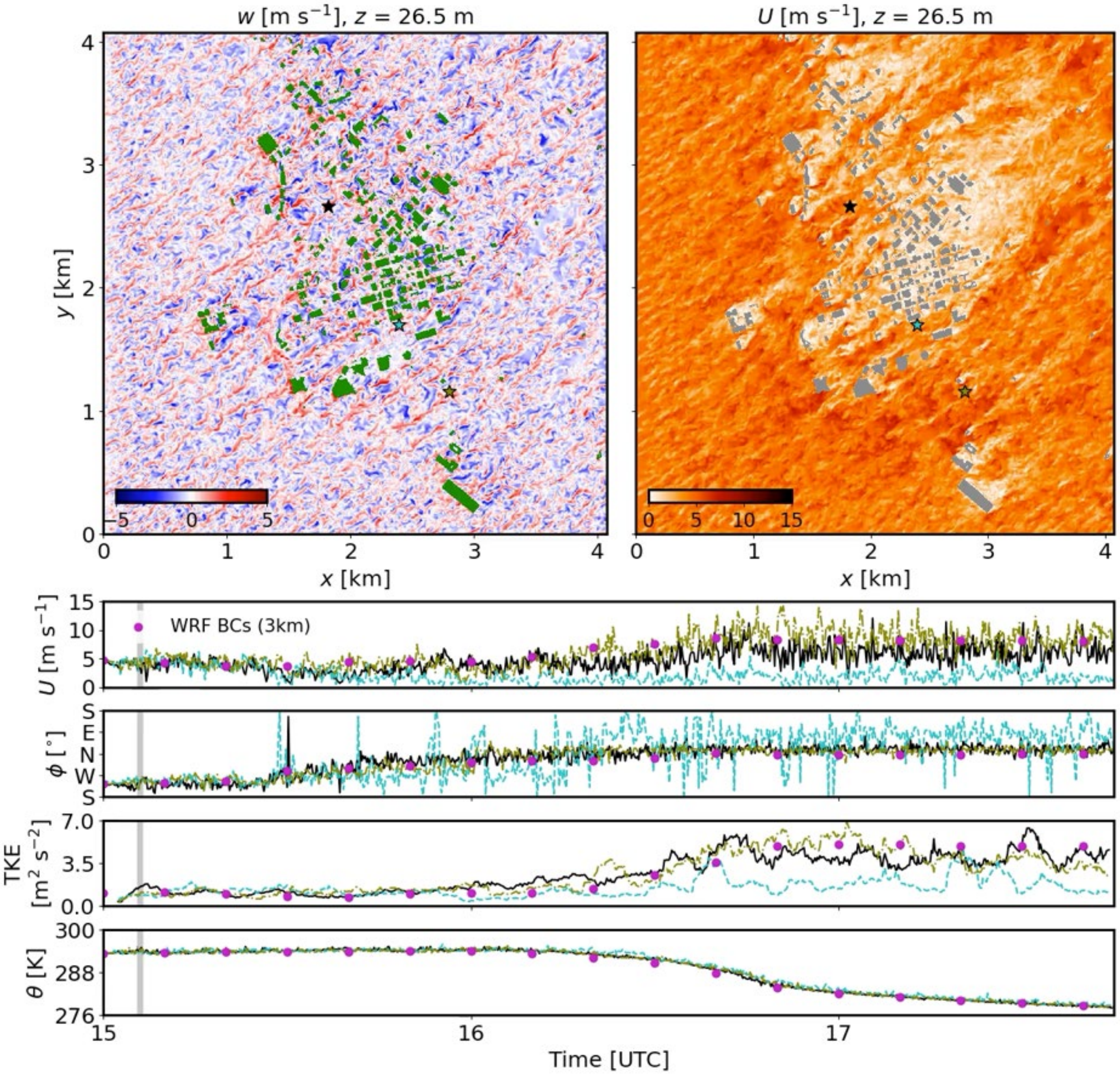


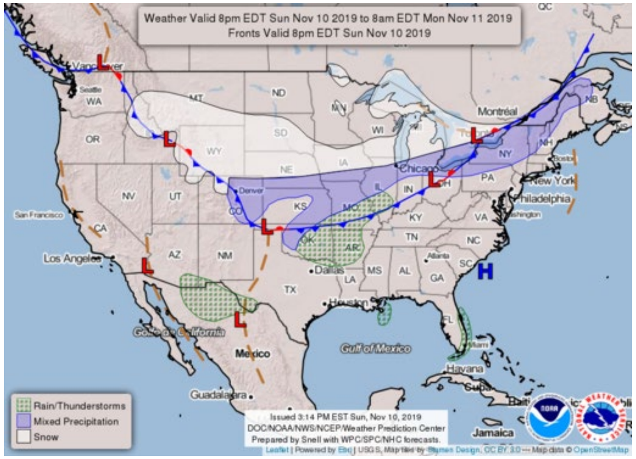




- UAV-experienced wind speed and TKE flying through the city
- Simple model for battery reduction illustrates the **significant impact of day-to-day weather variability** on TKE within the urban canopy

Rapid weather changes: a cold front





November 11th 2019 (WRF-to-FastEddy® simulation 15 – 18 UTC)

Within 1h:

- Almost 180 deg. wind shift
- Wind speed increases ~ 10 m s^{-1}
- Temperature drops ~15 K

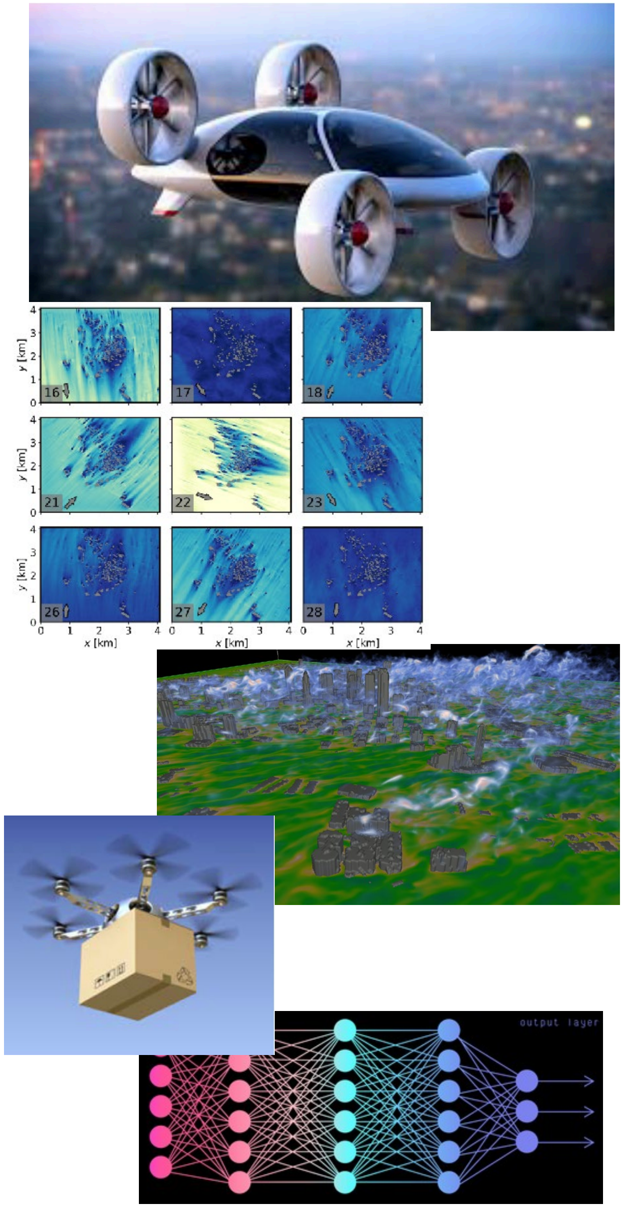
The tight connection between weather and city layout creates **unique local atmospheric conditions** -> require explicit modeling!

Conclusions

Wind and turbulence distributions in the urban environment are very complex (large-scale weather, local stability effects, urban canopy interactions…)

Require a multi-scale modeling strategy -> forecast only feasible with models such as FastEddy®

GPU efficiency allows for street-scale ensemble predictions at meter-scale!



Next Steps

- Deploying WRF-FastEddy® workflow at the cloud
- Extension to include drone-generated noise propagation capabilities
- Develop AI/ML reduced-order models for ultra-fast predictions of winds/turbulence