Update on Army Research Lab's Research on Urban-scale turbulence modeling

Chatt Williamson*, Ben MacCall, Robb Randall, Yansen Wang, Pat Collins and Chris Hocut

OFCM Session
22nd Annual GMU Conference on AT&D Modeling
19 June 2017
Mr. Chatt C. Williamson
Chief, Atmospheric Sensing Branch, U.S. Army Research Laboratory

Outline

- Business/Laboratory Overview
- Meteorological Sensor Array – Open for Business
- Atmospheric Transport Modeling
- Other Research of Community Interest

U.S. ARMY RDECOM®

U.S. Army Research Laboratory

ARL

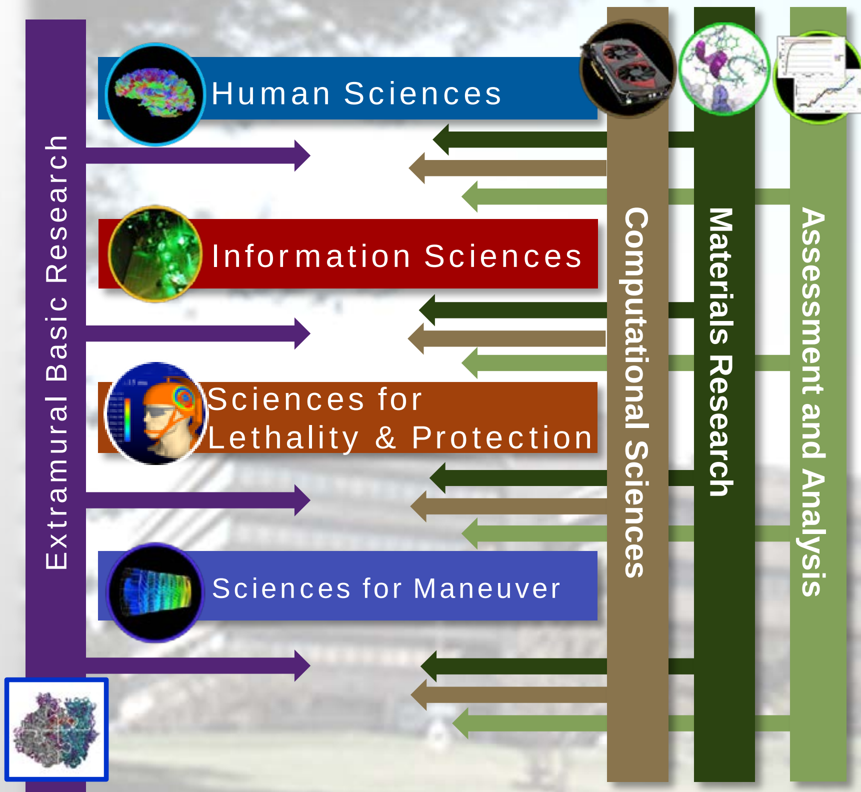
Mission

DISCOVER, INNOVATE, and TRANSITION Science and Technology to ensure dominant strategic land power

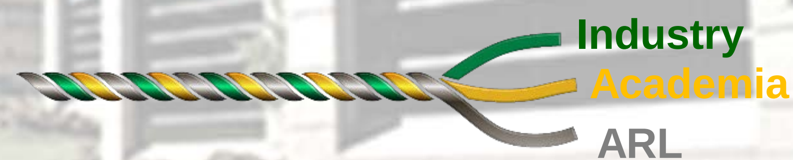
Strategic S&T Campaign Plan

- Intellectual Framework Providing Comprehensive & Measurable S&T Objectives/Outcomes
- Foundational Research to Ensure Readiness of the Future Force

S&T Campaign Plans



Open Campus Initiative

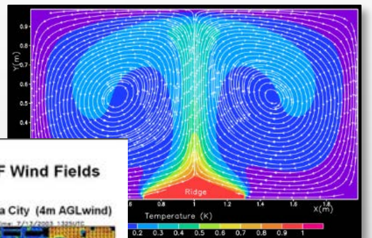


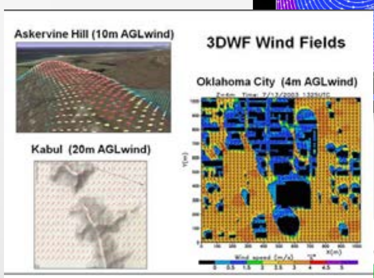
http://www.arl.army.mil/publications

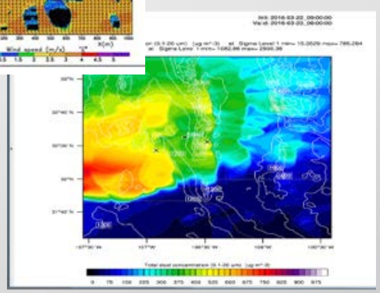

U.S. ARMY
RDECOM
ARL's New Research Centers
ARL
Aberdeen Proving Ground, MD
Center for Adaptive Soldier Technologies (CAST)
Novel Energetics Research Center (NERC)
Center for Human Injury and Performance (CHIP)
Adelphi, MD
Intelligent Systems Center (ISC)
Before
After
Center for Agile Materials Manufacturing Science (CAMMS)
Cyber Research Center (CRC)
Center for Semiconductor Materials and Device Modeling (CSDM)
Center for Research in Extreme Batteries (CREB)
Semiconductor Research Nanofab Center (SRNC)
Network Science Research Laboratory (NSRL)
Attacks
Spoofing (masquerading)
Selfish (no data-forwarding)
Man in the middle…
Data analysis and model development
Attack Impact Models
Cross domain attack graphs
Agent-Based Tutor
Environment
Learner
Tutoring Agents
Training Environment
Learner
EL Paso, TX
Center for Cyber Analysis and Assessment
Orlando, FL
Center for Adaptive Instructional Sciences
White Sands Missile Range, NM
Atmospheric Sciences Center (ASC)
The Nation's Premier Laboratory for Land Forces

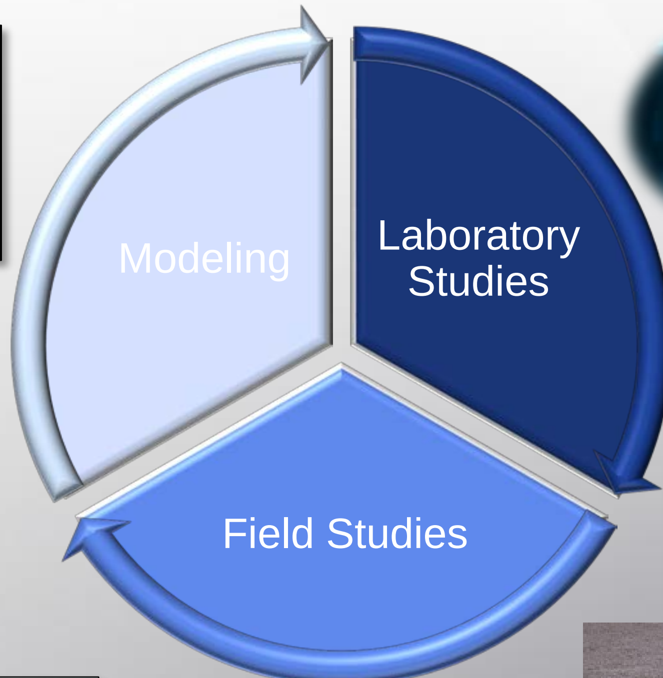
Atmospheric Science Center

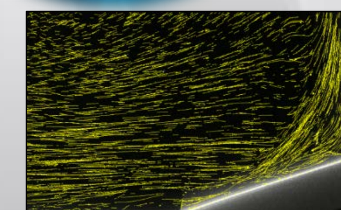
Bring together government, industry, and academia to advance atmospheric science and its application to critical defense technologies through a collaborative, innovative research ecosystem.

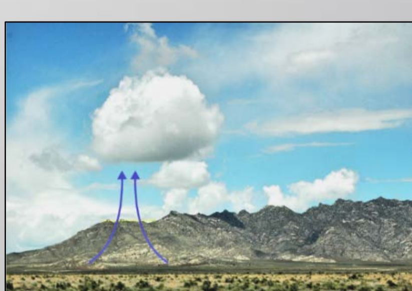


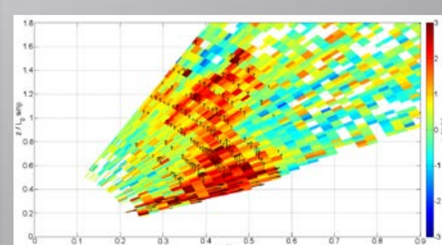












The Nation's Premier Laboratory for Land Forces

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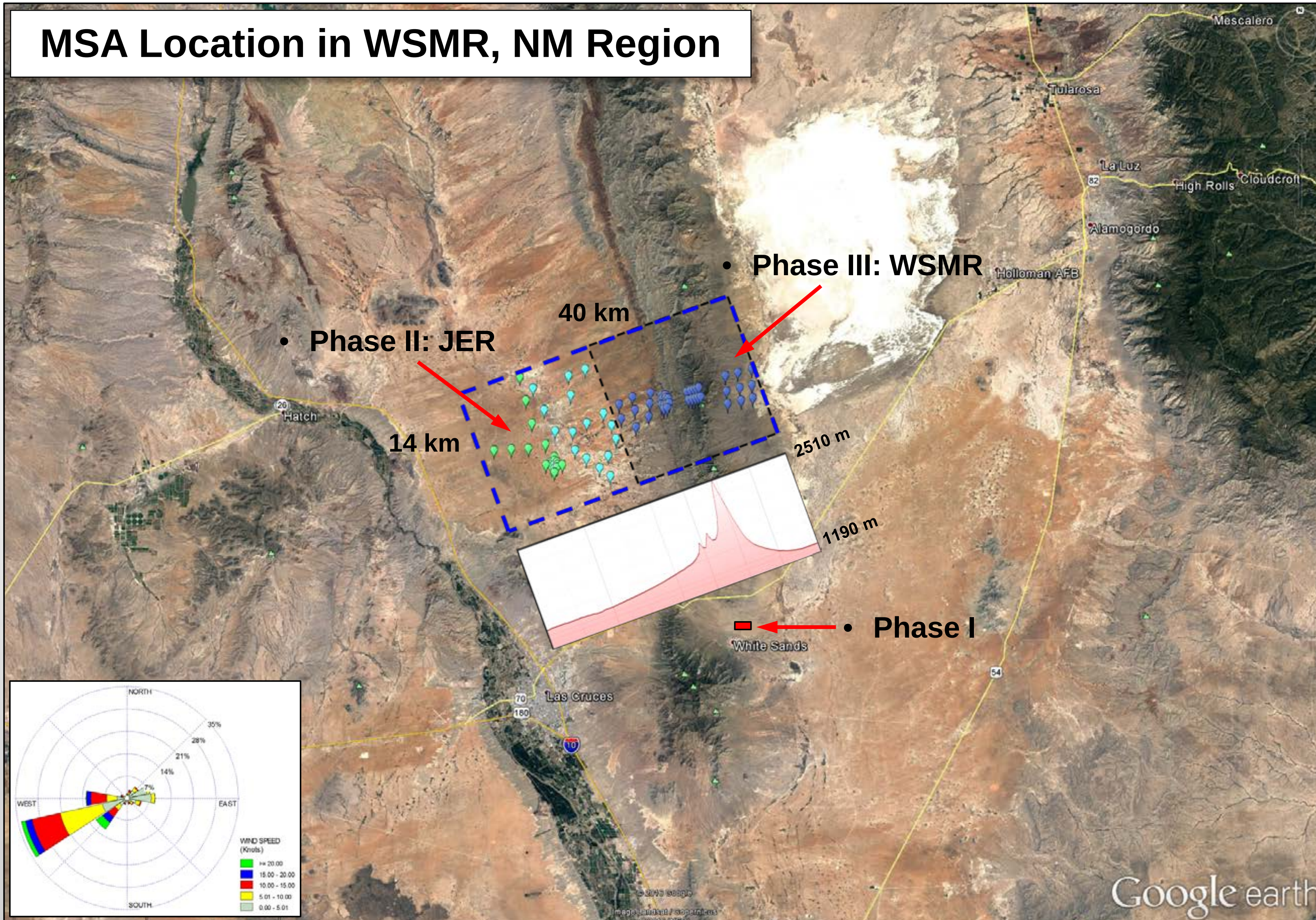
- **Meteorological Sensor Array – Open for Business**
- Atmospheric Transport Modeling
- Other Research of Community Interest

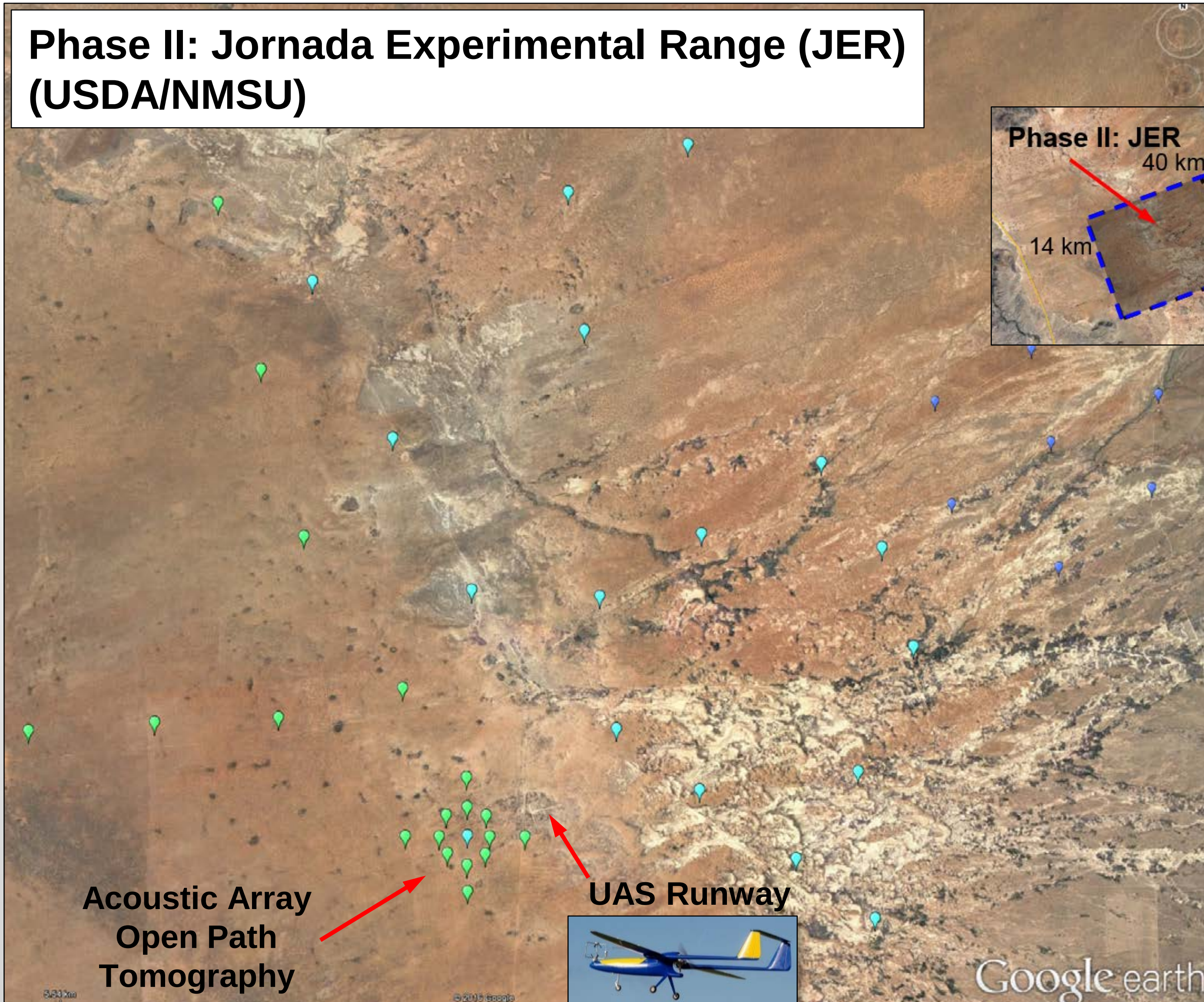
Meteorological Sensor Array

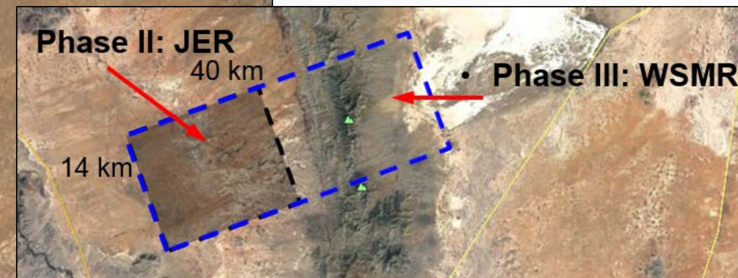
MSA Update: Open for Business



MSA Update: Tower Installation

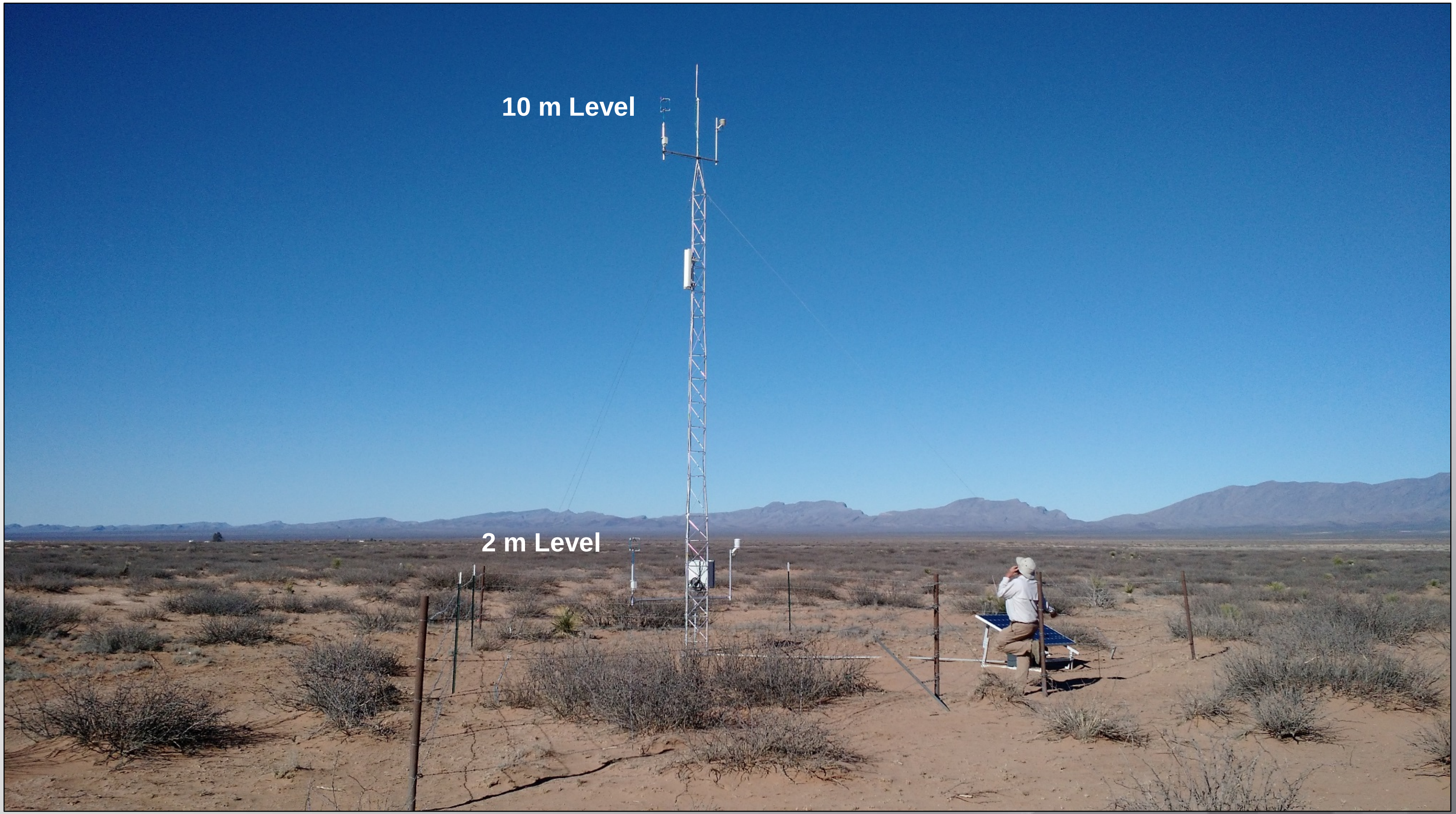
Phase II: Jornada Experimental Range (JER) (USDA/NMSU)





1st tower installed
1 Dec 2016

MSA Update Instumentation

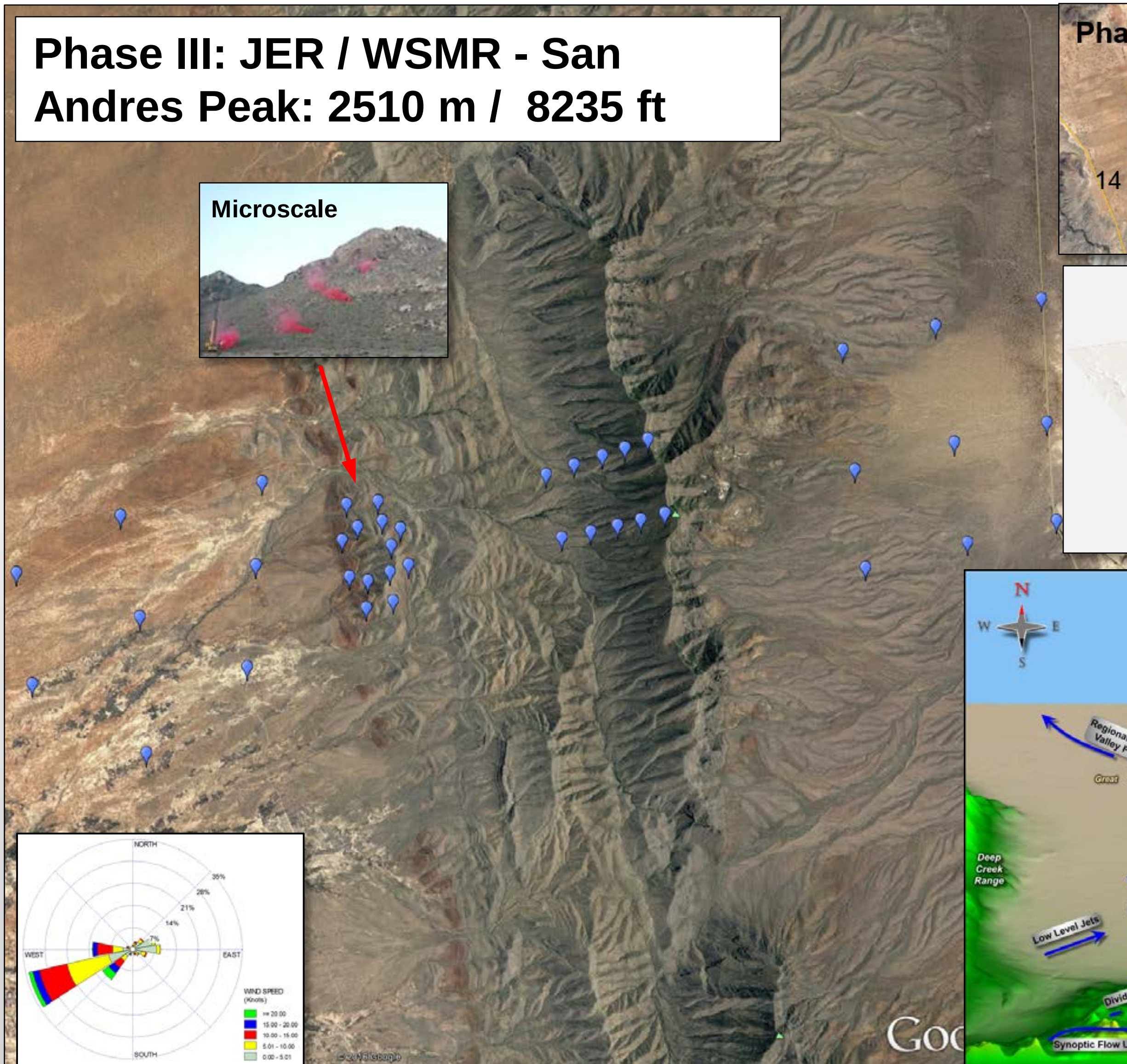


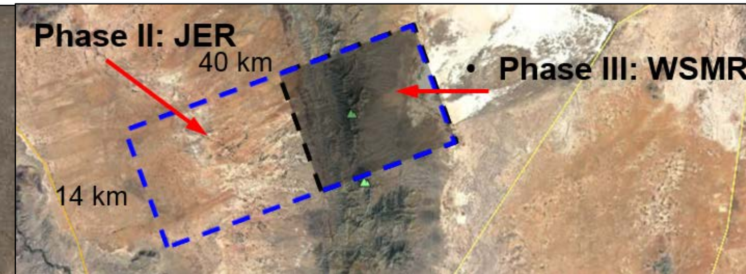
2 m Level: U, WD, T, RH, p
10 m Level: U, WD, T

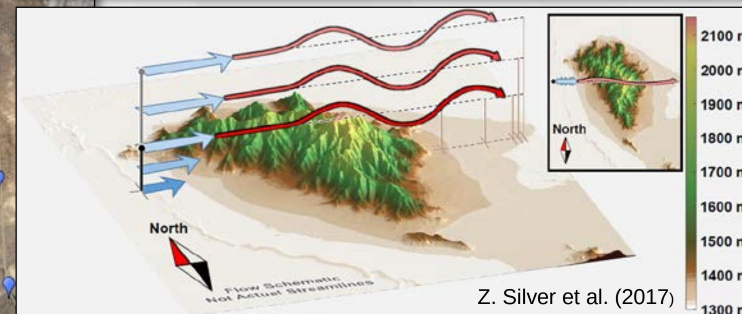
Soil moisture probes at 5, 10, 25 and 50 cm, rain gauge, pyranometer.

MSA: Process Studies

Phase III: JER / WSMR - San Andres Peak: 2510 m / 8235 ft







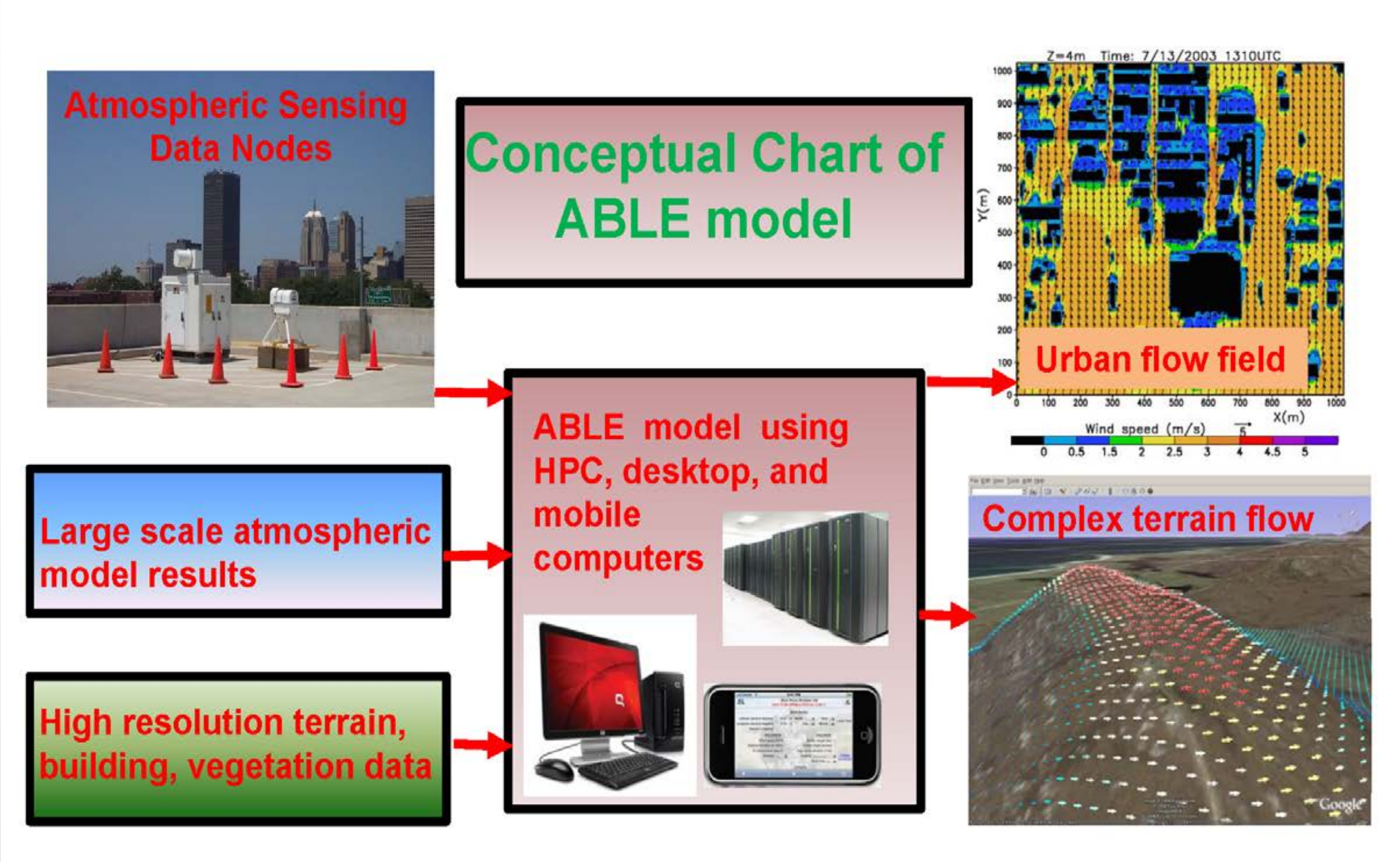
Z. Silver et al. (2017)

Outline

- Business/Laboratory Overview
- Meteorological Sensor Array Progress
- **Atmospheric Transport Modeling**
  - 3 Dimensional Wind Field (3DWF) Model
  - Atmospheric Boundary Layer Environment (ABLE) Model(s)
- Other Research of Community Interest

Objectives for Atmospheric Transport Modeling

Develop microscale (Spatial:1-50m, Temporal: minute) Atmospheric Boundary Layer Environment (ABLE) models to predict mean wind, temperature, moisture, and turbulence over urban and complex terrain in near-real-time.



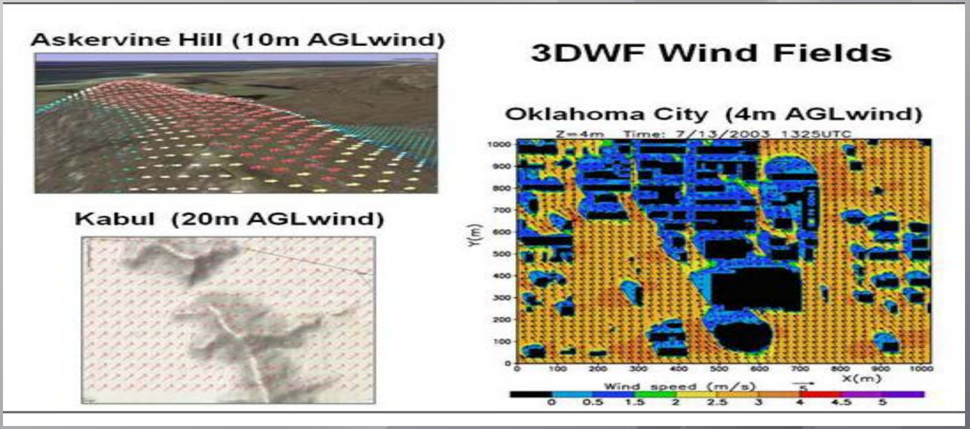
Three-Dimensional Wind Field (3DWF) Model

Background

- Objective: Develop a high resolution (1~50m in space, 1~5 min in time), mass consistent Atmospheric Boundary Layer Environment (ABLE) model for applications in urban and complex terrain.
- Method: Employ a mass consistent potential flow solver augmented with lee side wake vortex parameterization (Röckle, 1990). Essentially solve the following functional given a set of observations:

$$E(u,v,w,\lambda) = \int_V \left[\beta_1^2 \; (u-u^0)^2 + \beta_1^2 \; (v-v^0)^2 + \beta_2^2 \; (w-w^0)^2 + \lambda\left(\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z}\right) \right] dxdydz$$

- Advantages: Computationally efficient implementations available, fast turnaround to solution, etc.
- Disadvantages: Only a mean flow solver (i.e. no turbulence), hence the need for wake parameterizations. Primarily limited to neutrally stratified flow regimes (irrotational).
- Recent Developments (Huynh et al.)
  - GIS Integration – Visualization of model output using Google ® Maps/Earth APIs.
  - Porting of Fortran codebase to Java -> Implementation on handheld devices



1. Sasaki, *Mon. Wea. Rev.*, **98** (1970), pp. 875-883.
2. Röckle, Ph.D. thesis, om Fachbereich Mechanik, der Technischen Hochschule Darmstadt, Germany.
3. Wang, *et al.*, *J. Appl. Meteorol.*, **44** (2005), pp. 1078-1089.
4. Wang, *et al.*, *Comp. & Geosci.*, **61** (2013), pp. 23-31

Atmospheric Boundary Layer Environment: Lattice Boltzmann Method (ABLE-LBM)

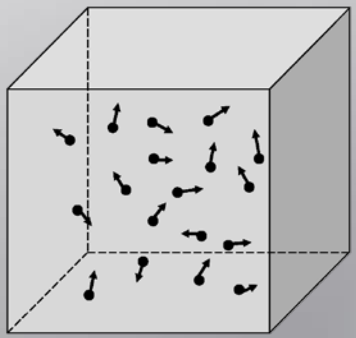
Background

- Objectives: Develop a high resolution (1~50m in space, 1~5 min in time) Atmospheric Boundary Layer Environment (ABLE) model for applications in urban and complex terrain.
- Method: Lattice Boltzmann Method (LBM) is based on statistical mechanics. A kinetic based particle method was developed last two decades. A Multi-Relaxation-time (MRT) LBM is used.
- Advantages: Effective for very complex boundary conditions; Easy generation of computation grids; Intrinsically parallel of LBM for faster computing; Better in turbulence modeling.
- Based on statistical mechanics, solves Boltzmann equations in lattice directions

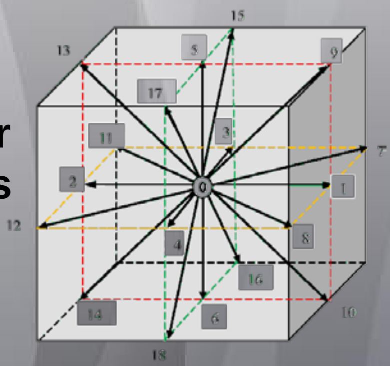
$$\boldsymbol{f}(\vec{x}+\boldsymbol{c}_\alpha dt, t+dt) - \boldsymbol{f}(\vec{x},t) = -M^{-1}S[\boldsymbol{m}(\vec{x},t) - \boldsymbol{m}^{eq}(\vec{x},t)] + M^{-1}\boldsymbol{F}(\vec{x},t)dt$$

- Flow density and velocity computed by integration of particle velocity moments:

$$\rho' = \sum_{\alpha=0}^{18} f_a \quad , \quad \rho'\vec{u} = \sum_{\alpha=0}^{18} c_\alpha f_a + \frac{dt}{2} F_\alpha$$



From Molecular Dynamics to LBM

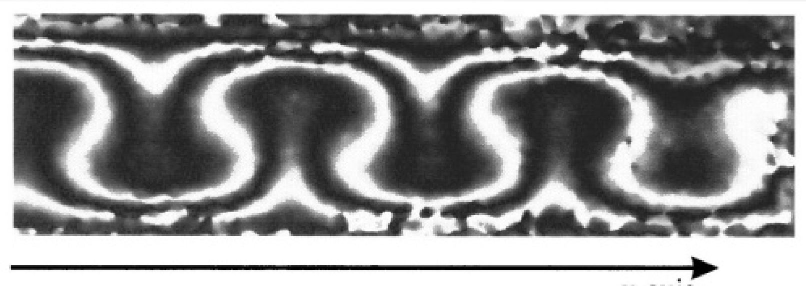


1. D'Humieres *et al., Phil. Trans. R. Soc. Lond. A,* **360** (2002), pp. 437-451
2. Lallemand and Luo, *2000, Phys. Rev.* **E61** (2000), pp. 6546-6562
3. Wang, Y., *et a*l. *Environ Fluid Mech* (2018). https://doi.org/10.1007/s10652-018-9599-3

ABLE-LBM: Thermally Driven Flow

Natural convection generated from heated ground surface

Pattern Interferometry, Ra= 3220, Doupont et al. (1995), Opt. Letters 20:1824-1826



Ra>10^6; Sparrow et al, (1970) JFM 41:793-800

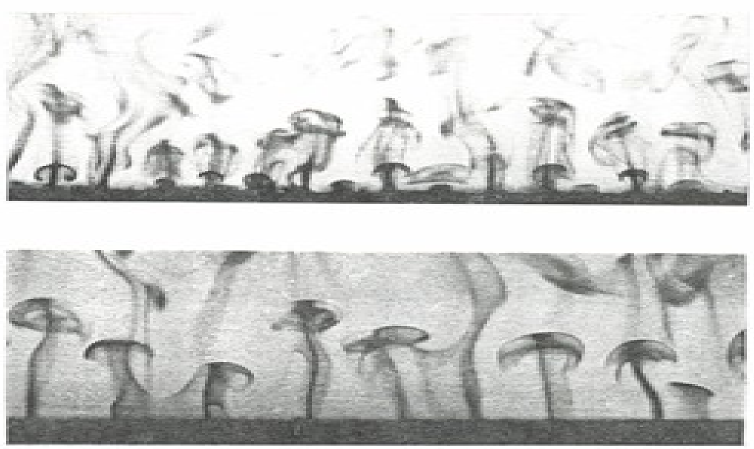
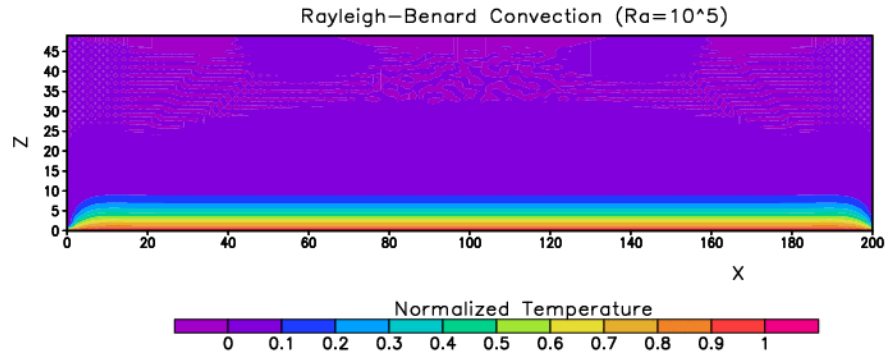
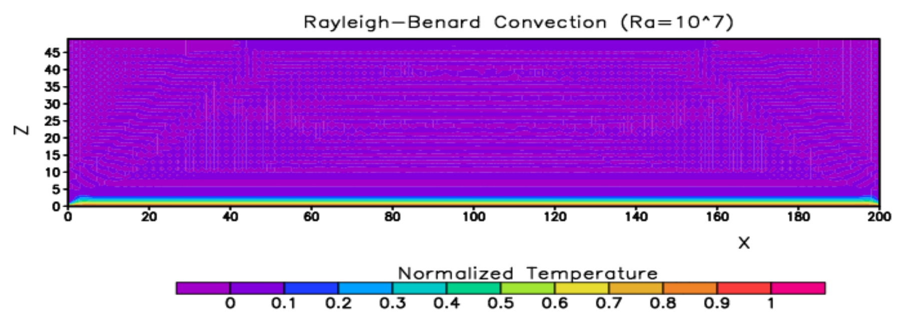


FIGURE 1. Photographs of thermals rising from a heated horizontal surface.

Low Ra = 10^5



High Ra = 10^7



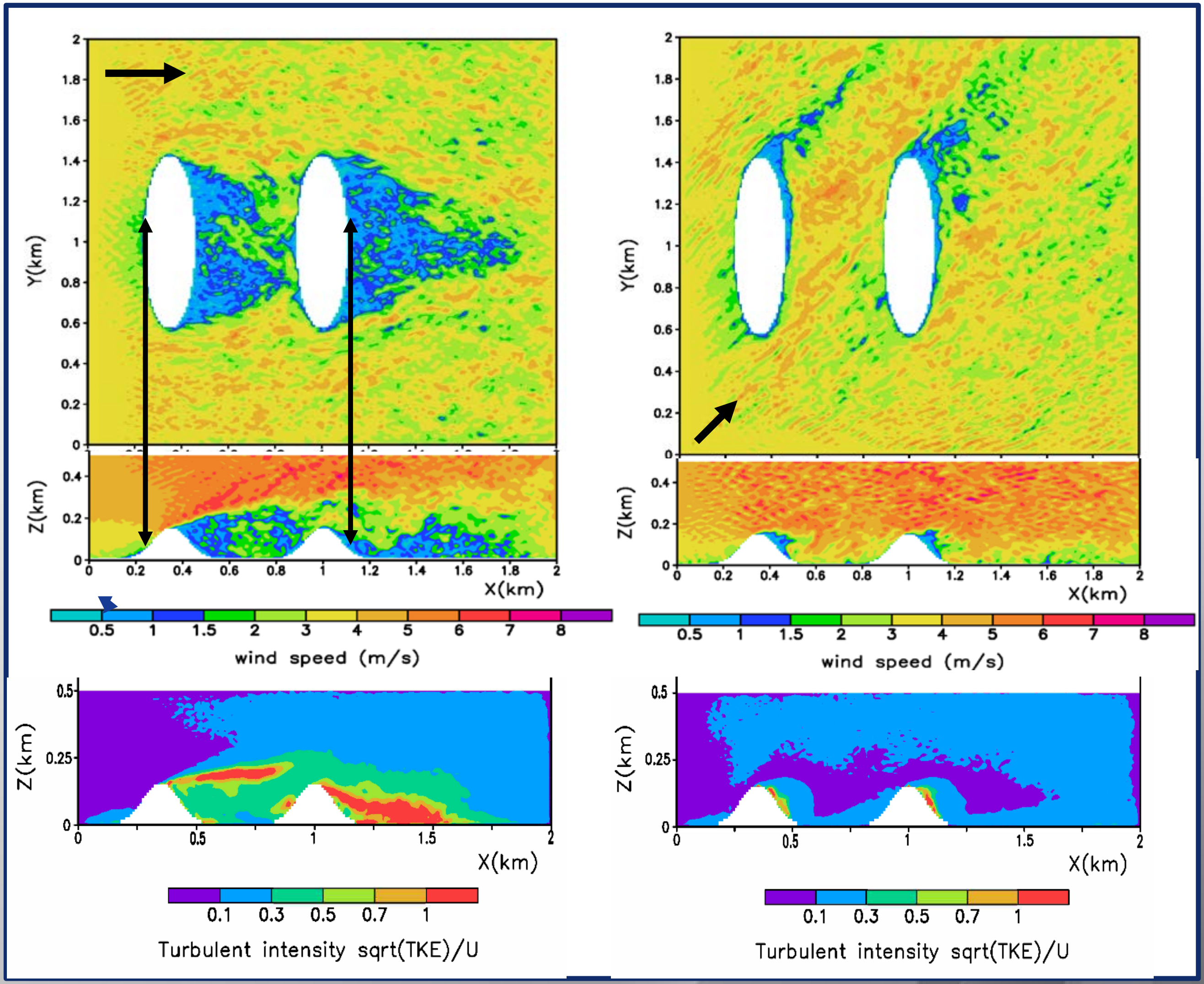
ABLE-LBM: Neutrally Stratified Double Hill

Model setup:

NX=NY=201
NZ=101

DX=DY=DZ=10m

Prescribed lateral BC, Inflow logarithmic wind profile



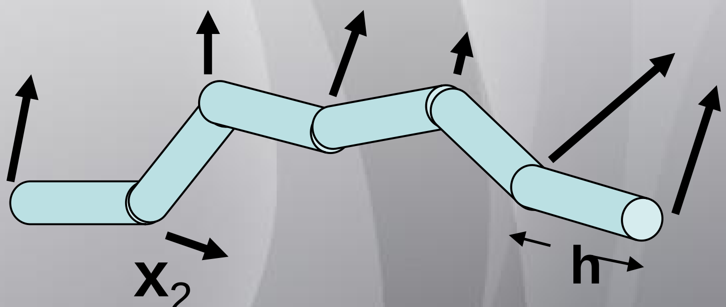
Atmospheric Boundary Layer Environment: Vortex Filament Method (ABLE-VFM)

Background

- Objective: To better understand the dynamics and turbulent structures in the atmospheric boundary layer.
- Method: Vortex Filament Method (VFM) is Lagrangian method that solves the vorticity equation:

$$\frac{D\boldsymbol{\omega}}{Dt} = (\nabla \boldsymbol{u})\boldsymbol{\omega} - \nabla \times \left(\frac{1}{\rho}\nabla p\right)$$

- Computational elements: straight vortex tubes linked end-to-end forming filaments.
- Convect tubes via their endpoints.
- Circulation Γ on filaments is constant (Kelvin's Theorem)
- Tubes subdivide when stretched beyond length h.
- Bound Γ h
- Extend original VFM formulation to include thermal characteristics



Note: This is a grid-free scheme

1. Chorin, A.J., *Commun. Math. Phys.*, **83** (1982), pp. 517-535
2. Bernard, P.S., *et al.*, *AIAA J.*, **48** (2010), pp. 1757-1771
3. Collins, J.P., *et al.*, *J. Of Comp. Phys.*, **369** (2018), pp.209-224

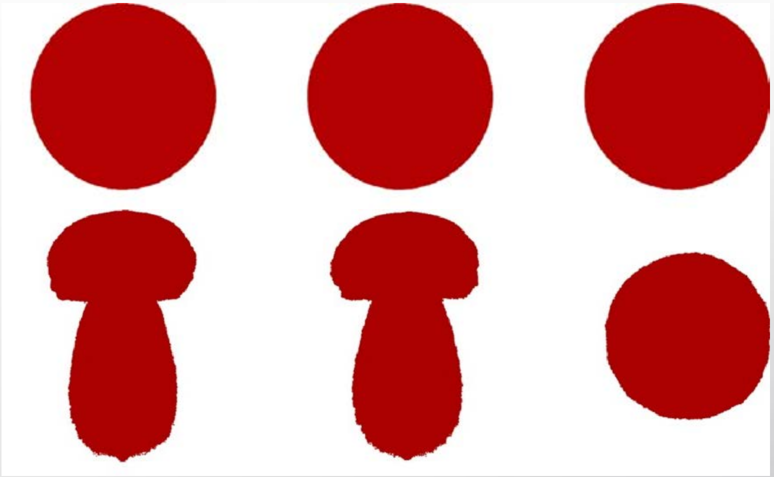
ABLE-VFM: Thermal Bubble Simulation

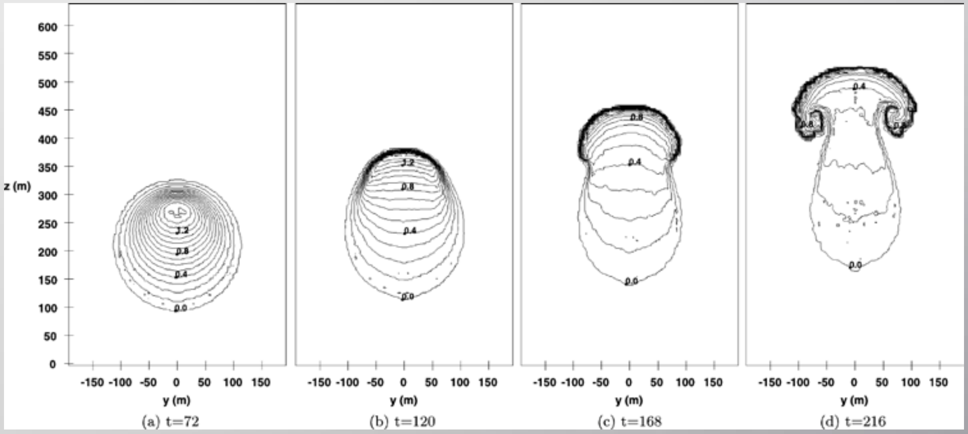
Cloud of energy particle profiles at the initial time (t=0) and at time t=216 (see Figs. Collins *et al.*)

x-profile | **Y-profile** | **Z-profile**

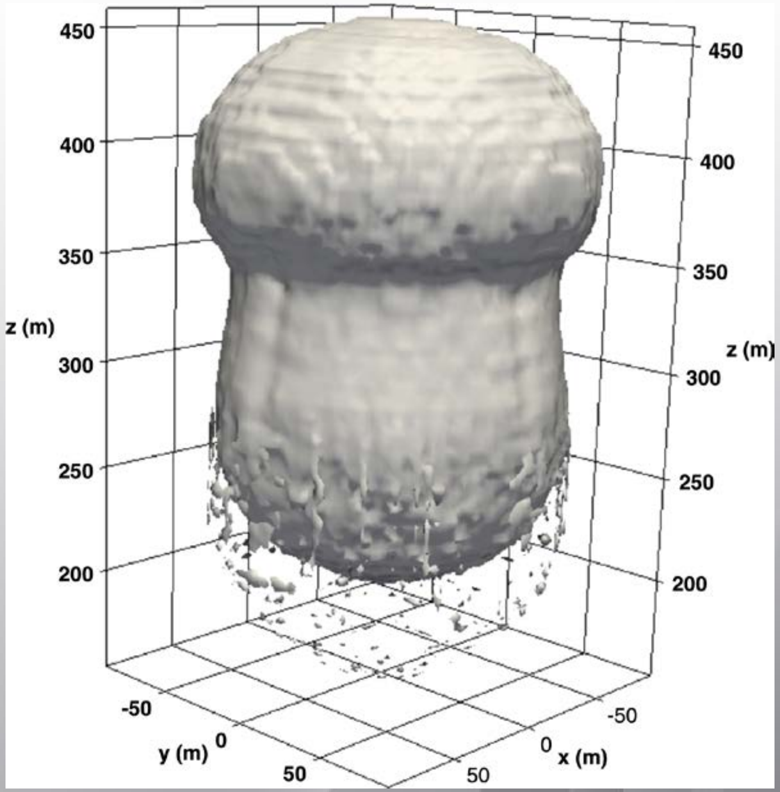
Initial (t=0)

Developed (t=216)





Time dependent temperature contours of developing thermal bubble (see Fig. 13 Collins *et al.*)



3D rendered temperature iso-surface at t=216of developing thermal bubble (see Fig. 7 Collins *et al.*)

1. Collins, J.P., *et al.*, *J. Of Comp. Phys.*, **369** (2018), pp.209-224

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- **Other Research of Community Interest**
  - Perdigão Field Campaign – Data becoming available (15 June 2018)
  - Long Island Sound Tropospheric Ozone Study (LISTOS)
  - Atmospheric Aerosols Research

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Perdigão Field Campaign

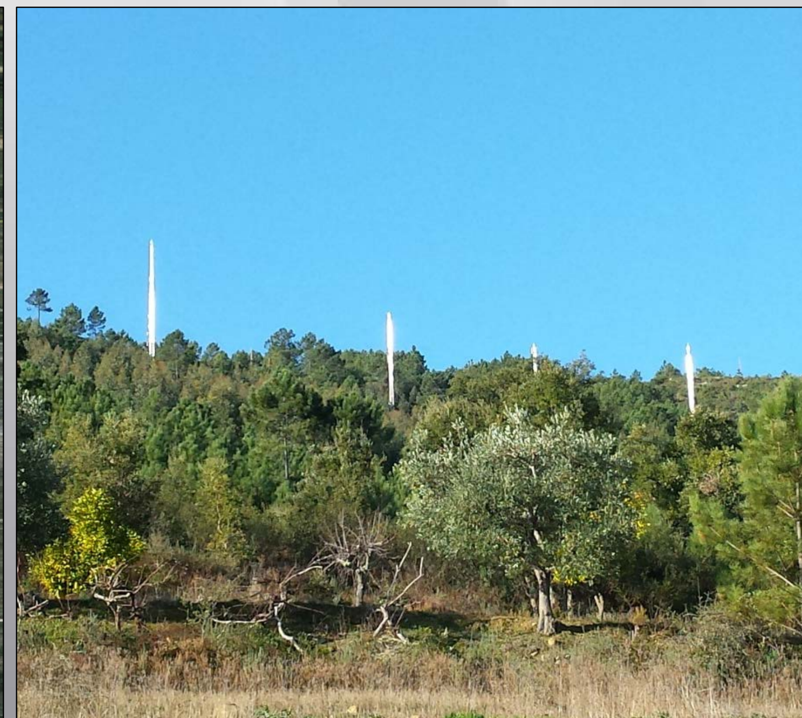
ARL

Perdigão, Portugal: 1 May – 15 June 2017

Collaborators: **EU - DTU, Porto U., Inegi, DLR**
US - UND, NCAR, CU, Cornell, U.C. Berkley,
Boise State, NOAA

Designed to study fundamental atmospheric dynamics in complex terrain with applications to wind energy harvesting, alpine warfare, air pollution in urban basins, aviation and firefighting.

PERDIGÃO
Field experiment



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Perdigão Field Campaign

ARL

PERDIGÃO

Field experiment

Dr. Ragu Krishnamurthy, UND

Long Island Sound Tropospheric Ozone Study (LISTOS)

Purpose

- Investigate evolving nature of ozone formation and transport in NYC region and downwind

Instrumentation and Resources

- Satellite, aircraft, balloon (ozone sondes), marine and ground-based data collection
- **Wind sensing (Scanning Doppler LiDAR)**

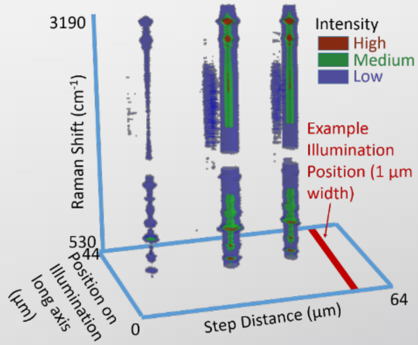
Participants (State, Federal, Academia)

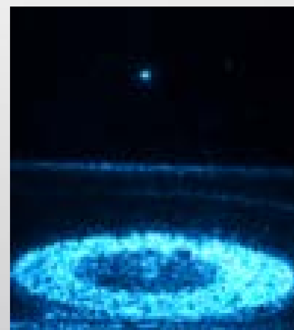
- Connecticut Department of Energy and Environmental Protection
- Maine Department of Environmental Protection
- National Oceanic and Atmospheric Administration Air Resources Laboratory
- New Jersey Department of Environmental Protection
- New York State Department of Environmental Conservation
- Northeast States for Coordinated Air Use Management (NESCAUM)
- Stony Brook University School of Marine and Atmospheric Sciences
- University of Albany Atmospheric Sciences Research Center
- University of Maryland, College Park RAMMP
- U.S. Environmental Protection Agency Office of Research and Development
- U.S. Environmental Protection Agency Region 1 (New England)
- Yale University Department of Chemical & Environmental Engineering and Peabody Museum

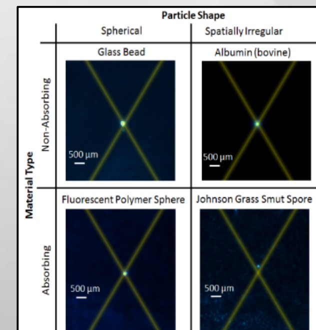
http://www.nescaum.org/documents/listos/listos-page/

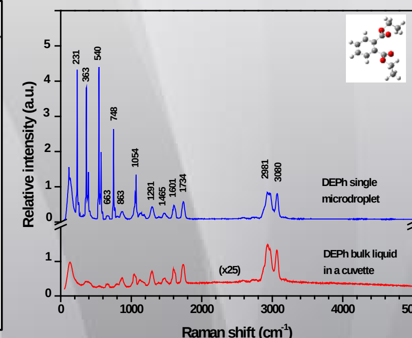
Aerosol Characterization: Raman Spectroscopy

- Automated Aerosol Raman Spectrometer (ARS) – Optical Characterization of Atmospheric Background Aerosol Particles using Raman Scattering
- Optical Trap Raman Spectrometer – Raman Spectra of Single Aerosol Particles Optically Trapped in Air: Laboratory Studies



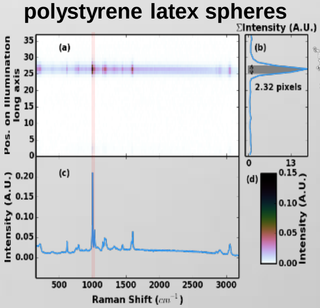


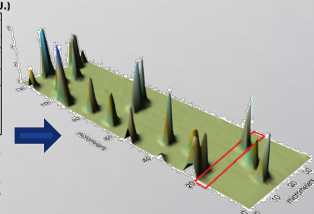


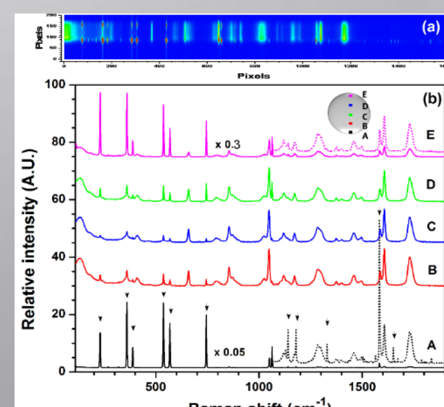


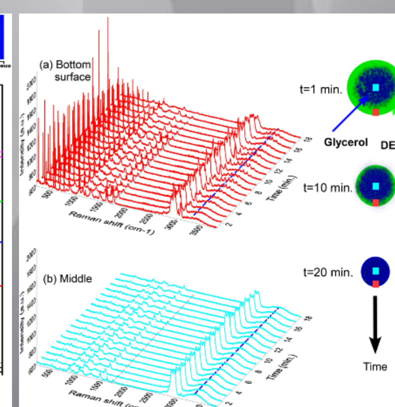
Example of one line-scanned image for 2 micron polystyrene latex spheres

Summed up scans over one 15 minute collection period









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  - Mr. Ed Creegan
  - Mr. Sean D’Arcy
  - Mr. Jeff Swanson
- ARL Atmospheric Science Center
  - Dr. Robb Randall – ASC-Lead
  - Dr. Jeffrey Smith
  - Dr. Ben MacCall

Questions?