JRII Special sonic anemometer study: A first comparison of building wakes measurements with simple and high resolution numerical modelling

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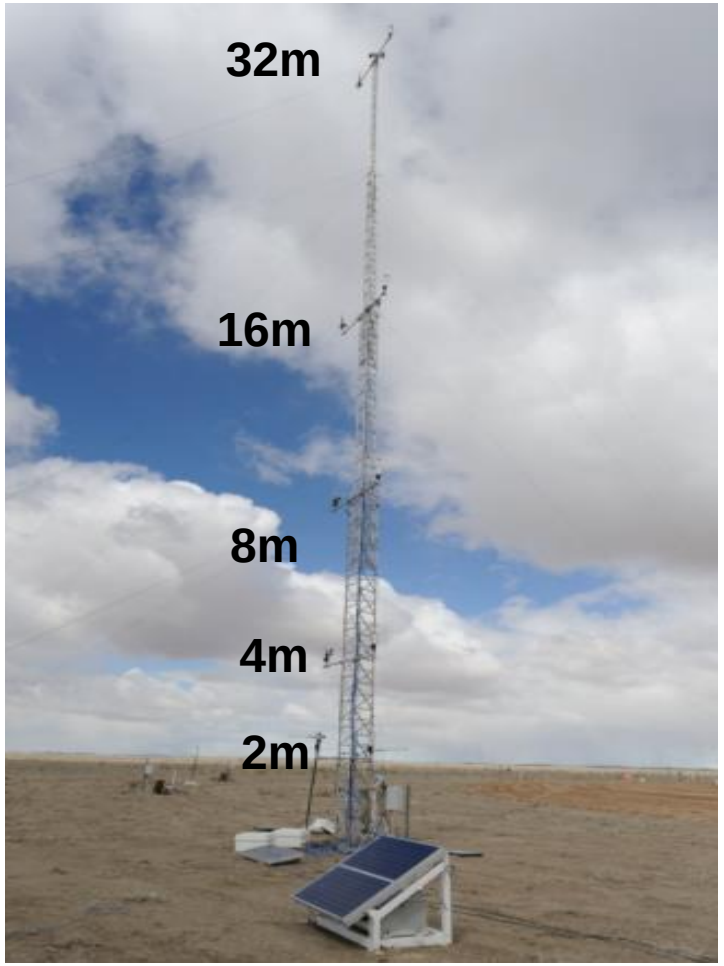
Special Sonic Anemometer Study in Fall 2015 and Spring 2016 around CONEXs

- Sonic anemometers were not used during JR II in the CONEX array because they would be destroyed by the presence of chlorine
- Still, we want to know flow and turbulence in wakes next to CONEXs
- Special studies were carried out during about 40 days in fall 2015 and spring 2016 with CONEXs in place, and no chlorine released
- 17 sonic anemometers were placed near the 2 by 3 CONEX stack and 13 near 40 ft CONEX. Sonic "towers" were located upwind and downwind of obstacles.

32m Upwind Sonic Tower

- In addition to the sonics in the CONEX array, there was a 32m tower that provided an unobstructed upwind flow profile at 5 levels
- 30-minute average mean and turbulence variables were calculated from the raw 10Hz sonic data



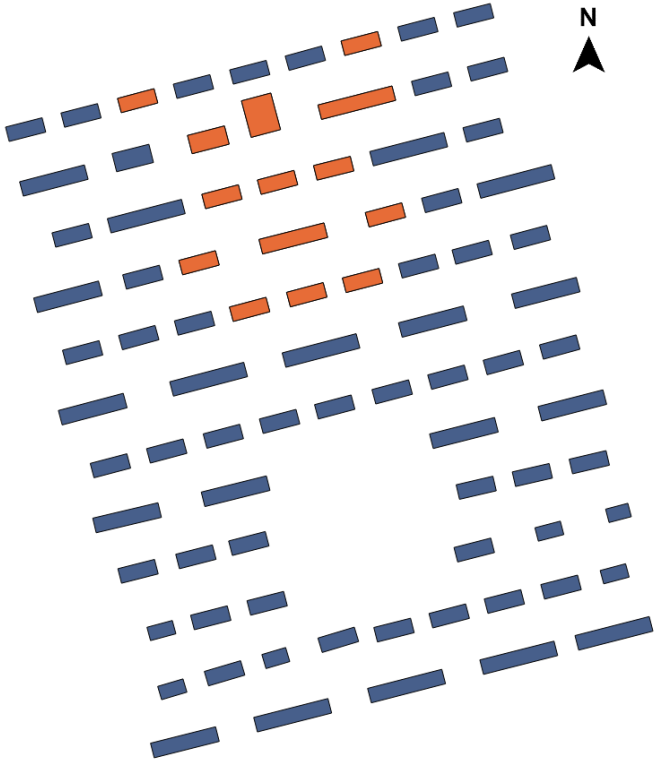
32m tall tower 100m upwind from CONEX array

Objectives

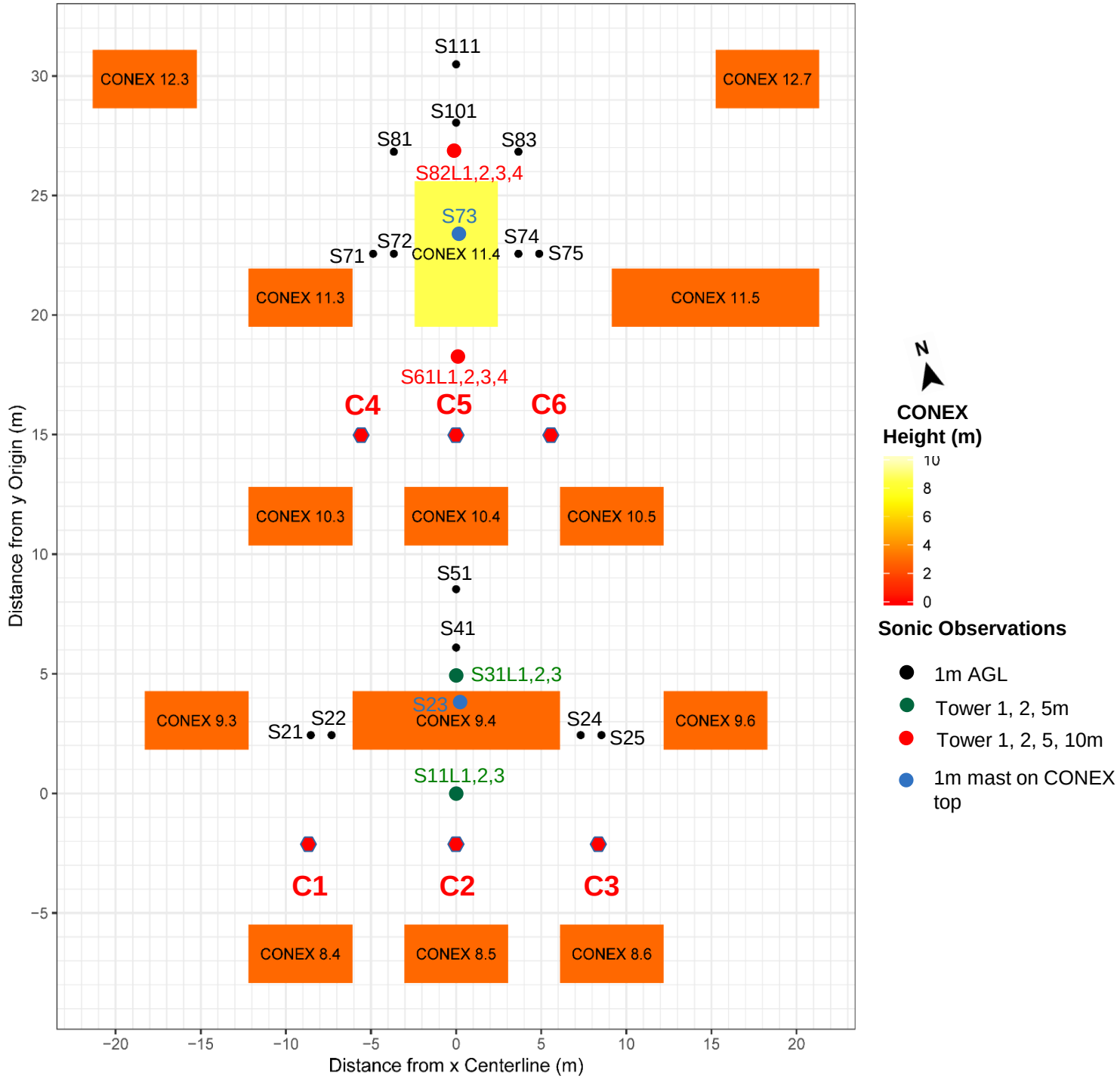
- JRII-Sonic (JRIIS) data processing and analysis
- Use JRII-Sonic for model validation, intercomparison and improvement
- Validation of complex models with detailed sonic measurements
- Intercomparison with simpler operational models
- Improvements of all models
- Test impact of wake prediction and differences on the simulated concentration (no measurements)

Where is Dugway?

Actual (real world) CONEX array was aligned 165 - 345 degrees (special sonic study in orange)



Inner <u>subset</u> of the array around sonics



JRIIS Data Analysis

- Time periods informed by 32m tower were selected for further analysis for sonics within array
- Filtered 30-min periods with relatively moderate winds speeds characteristic of more neutral PBL flow
  - ≥ 2.5 m/s
  - ±15º perpendicular to CONEX face
- for further analysis of wakes and recirculation zones

Candidate Periods Informed by 32m Upwind Tower

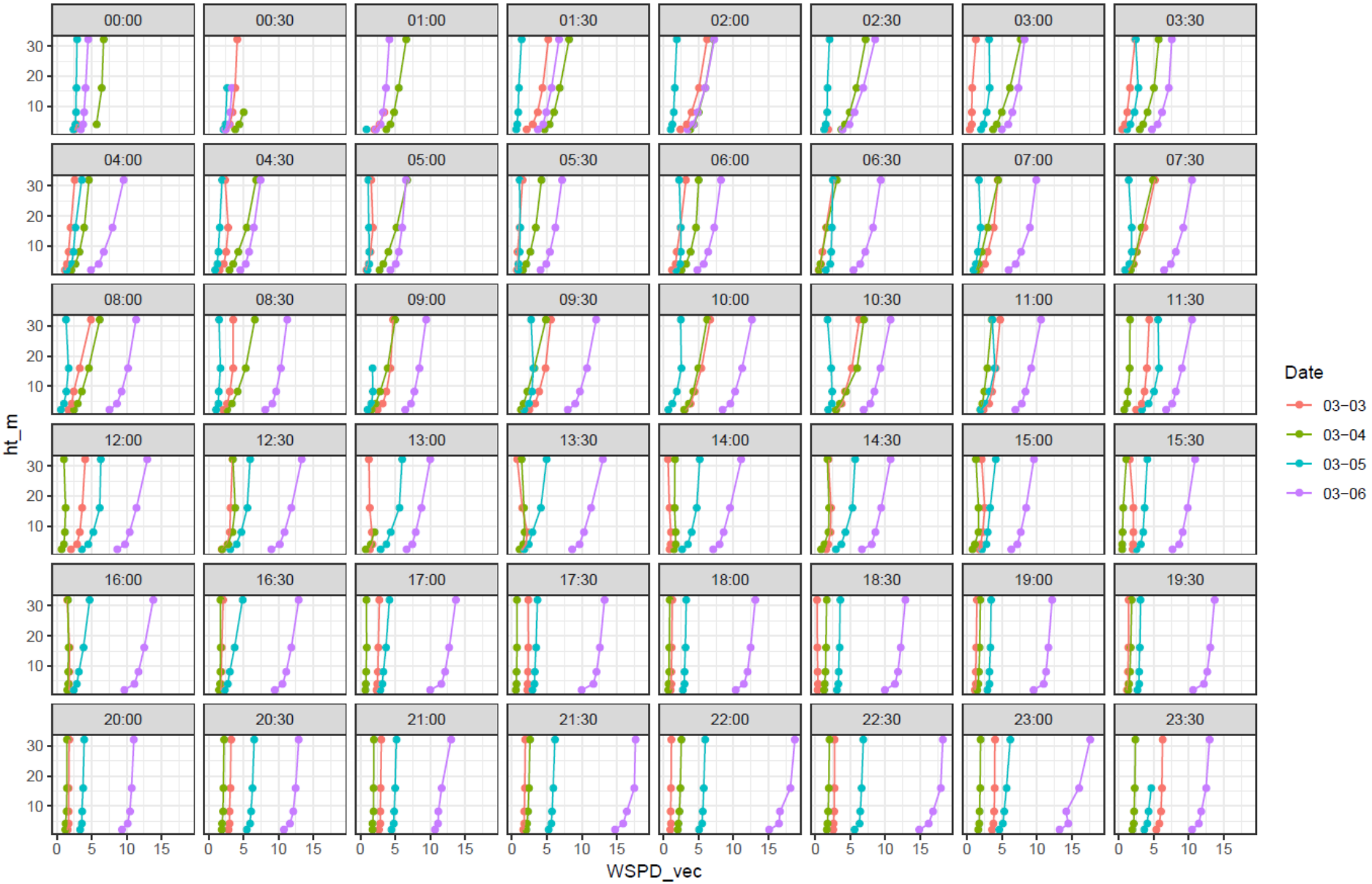
Northerly flow:

- **March 19, 0200-1300 UTC**
- **March 20, 0600-0930 UTC**
- March 26, 1600-2000 UTC

Southerly flow:

- March 5, 1630-2330; 0000-1300 UTC (March 6) (frontal shift)
- March 10, 0500-0700 UTC; 1200-0000 UTC
- March 15, 1430-1930 UTC
- **March 16, 1330-1800 UTC**
- **March 24, 0730-2100 UTC**

Examples of vertical wind profiles at the 32 reference tower (+ temperature and Obukhov length)



Wake simulation :

continuity : 1

$$\frac{\partial \bar{u}_i}{\partial x_i} = 0$$

momentum : 2

$$\frac{\partial \bar{u}_i}{\partial t} + \bar{u}_j \frac{\partial \bar{u}_i}{\partial x_j} = -\frac{1}{\rho} \frac{\partial \bar{p}}{x_i} + \frac{\partial}{\partial x_j} \left[\upsilon \left(\frac{\partial \bar{u}_i}{\partial x_j} + \frac{\partial \bar{u}_j}{\partial x_i} \right) - \overline{u'_i \, u'_j} \right]$$

turbulence fluxes : 3

+ similar for scalars

➔ **Exact equations (N.S.) but need turbulent fluxes**

Wake simulation with different models:

- **L.E.S : u = resolved velocity, u' : subgrid**

  solve : 1 2 **closure :** 3

- **RANS : u = average velocity, u' : turbulent fluctuation**

  solve : 1 2 **closure :** 3

- **Mass consistent (PMSS, Quic…)**

  solve : 1 **parameterize :** 2 3

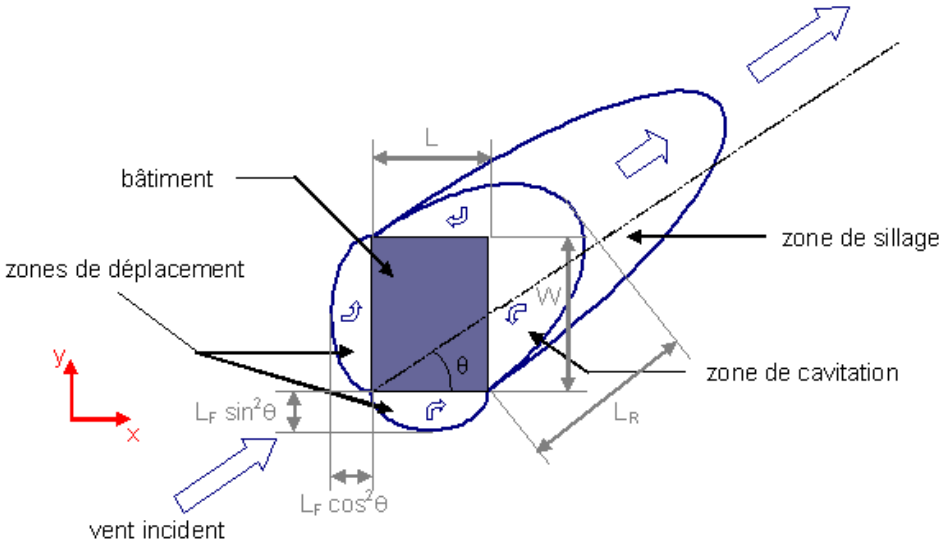
- **Empirical : parameterize :** 1 2 3

Discussed here

RANS model turbulence closure : 3

- **Eddy viscosity models :**
  - **(constant)**
  - **mixing length**
  - **k-eps , 2 equations**
- **Second order closure :**
  - **Rij-eps (7 equations)**

Schematics of wakes in mass-consistent models (« Rockle »)



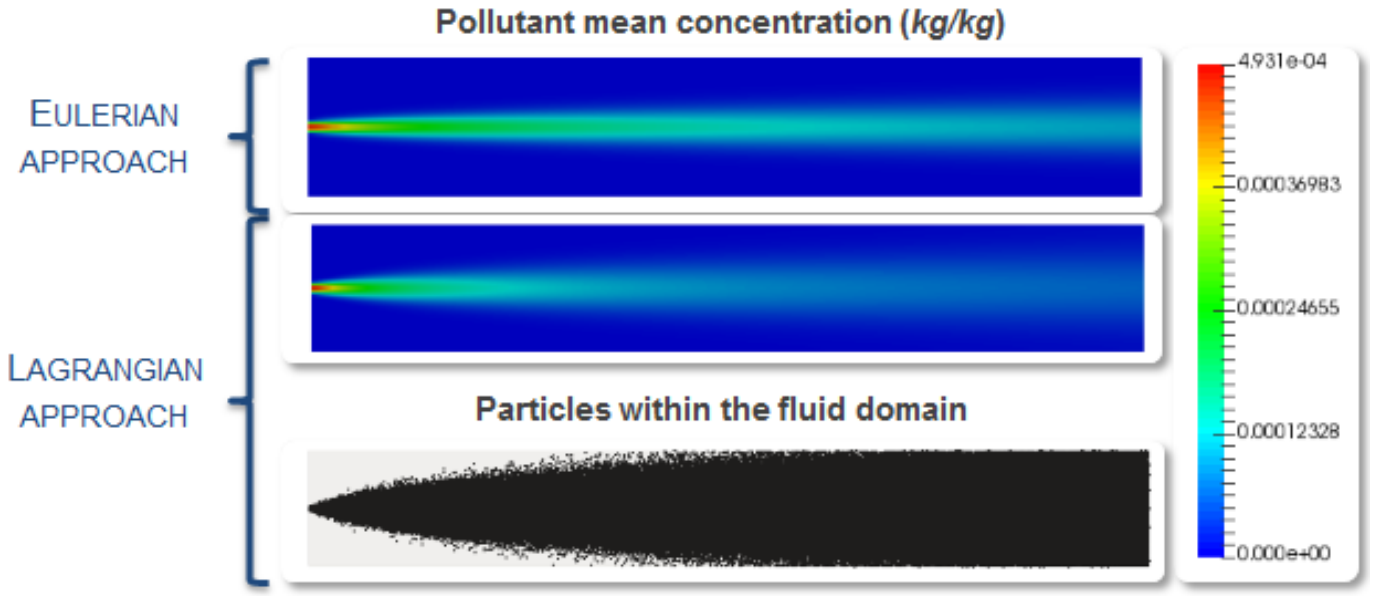
2 Parameterize wake

Exact continuity

3 Parameterize turbulence

NB : Momentum added in recent PMSS and QUIC

EULERIAN AND LAGRANGIAN APPROACHES



EULERIAN APPROACH

- Mean advection-diffusion equation for a scalar *c*:

$$\frac{\partial \bar{c}}{\partial t} + \bar{u}_j \frac{\partial \bar{c}}{\partial x_j} = \frac{\partial}{\partial x_j}\left(D \frac{\partial \bar{c}}{\partial x_j} - \overline{u_j' c} \right) + \bar{S} + \bar{R}$$

- Velocity and turbulence fields → solved by the CFD code *Code_Saturne* using RANS models with classical k-ε or R_{ij}-ε closures adapted to the atmosphere and complex geometries

LAGRANGIAN APPROACH

- Particle's equation of motion:

$$\rho_p \frac{\pi D_p^3}{6} \frac{d\mathbf{U}_p}{dt} = \rho_p \frac{\pi D_p^3}{6} \frac{\mathbf{U}_s - \mathbf{U}_p}{\tau_p} + \frac{\pi D_p^3}{6}(\rho_p - \rho)\mathbf{g} + \mathbf{F}_{ma} + \mathbf{F}_{gp} + \mathbf{F}_h$$

Drag force — *Buoyancy force* — *Added mass force* — *Pressure-gradient force* — *History (or Basset) term*

where: $\mathbf{U}_s(t) = \mathbf{U}_f(\mathbf{X}(t),t)$ is the velocity of the fluid sampled through the trajectory of the particle

Intercomparions

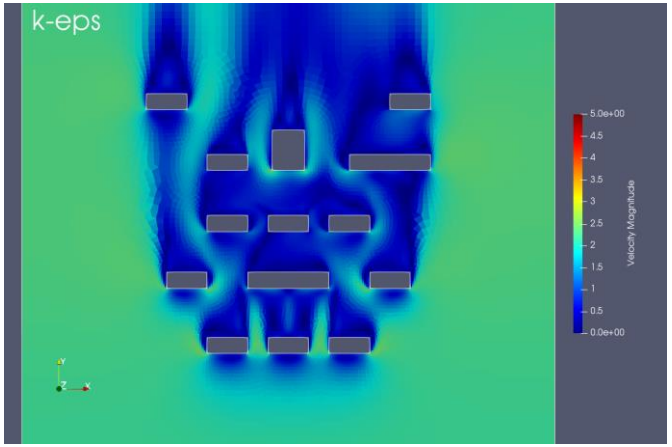
- Here : preliminary comparisons on cross sections at z=1m
- Future : pointwise comparisons and statistics with the sonics (velocity and turbulence)

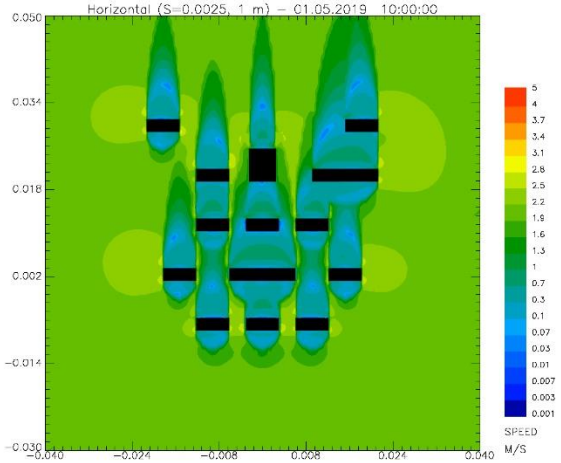
3 models so far in intercomparison:

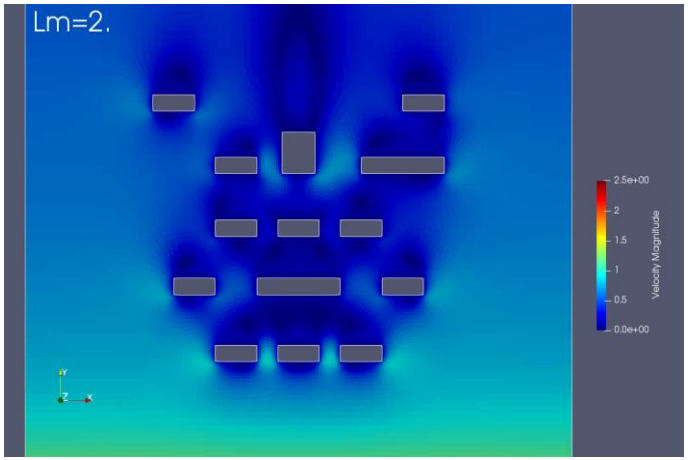
- *Code_Saturne* + Mixing Length (Lm=2 and 5 m) (Eulerian)
- *Code_Saturne* + k-eps (Eulerian)
- PMSS : Micro Swift Spray (Eulerian+Lagrangian)

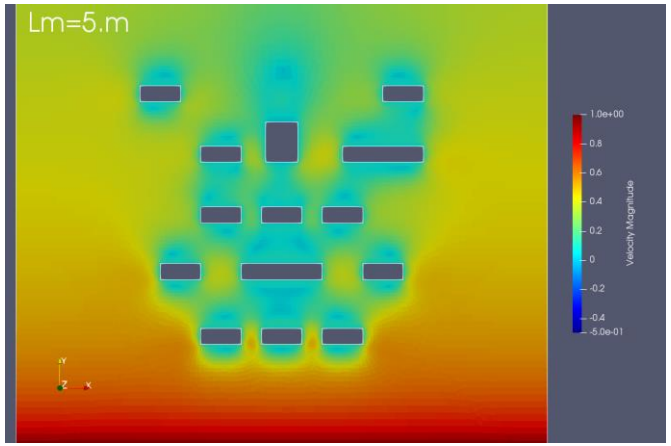
Preliminary wake comparisons 180° wind:

(idealized profile from highest sonic)

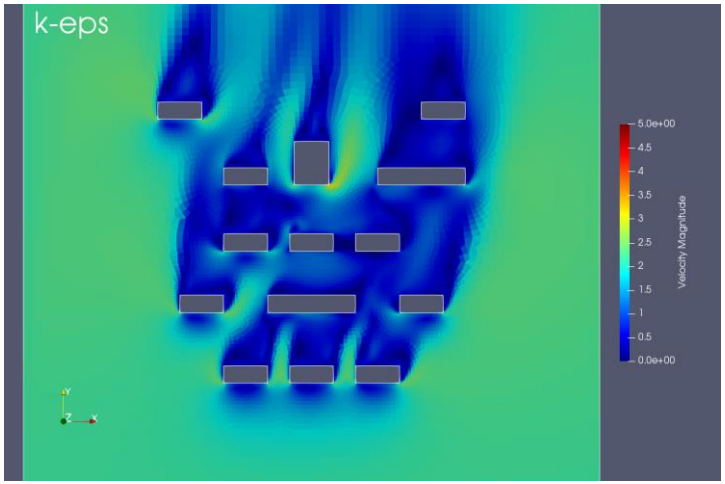


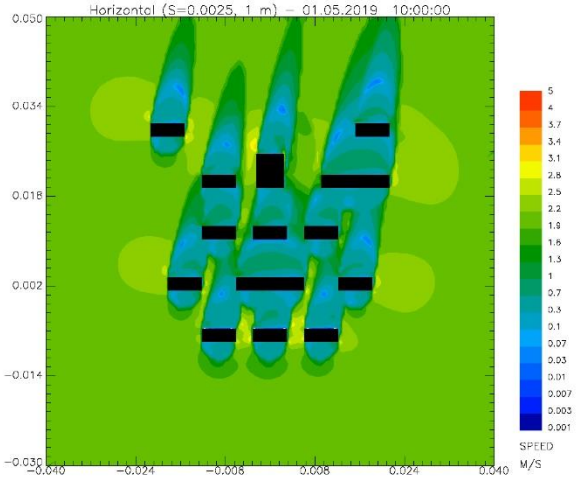


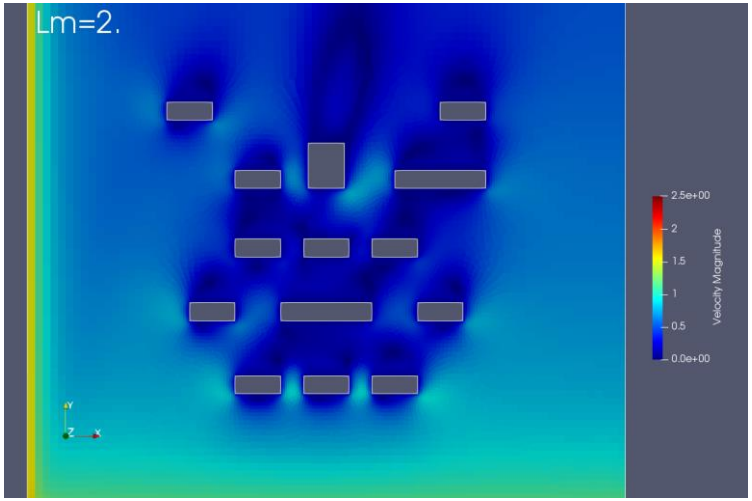


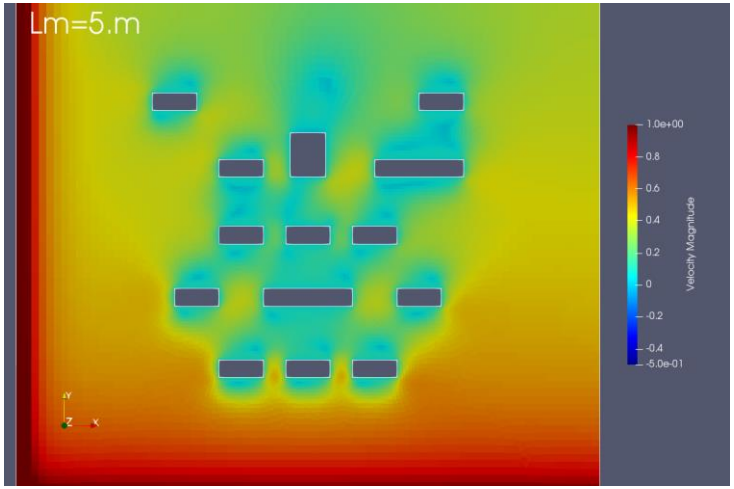


Preliminary wake comparisons 190° wind:

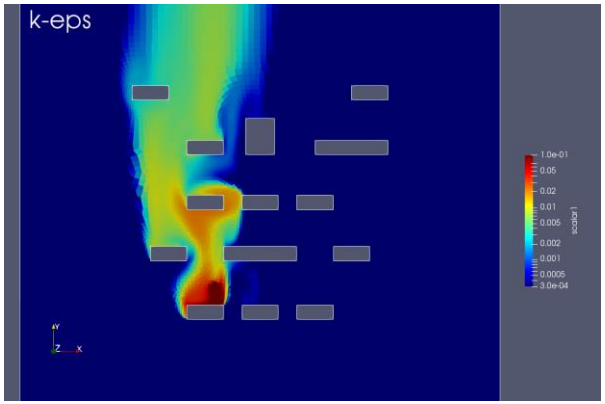


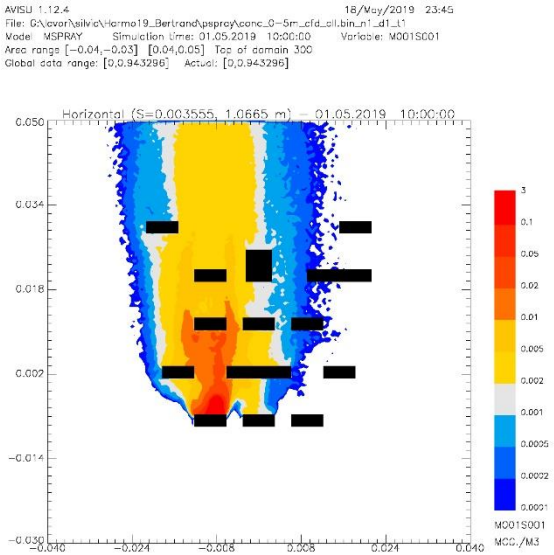


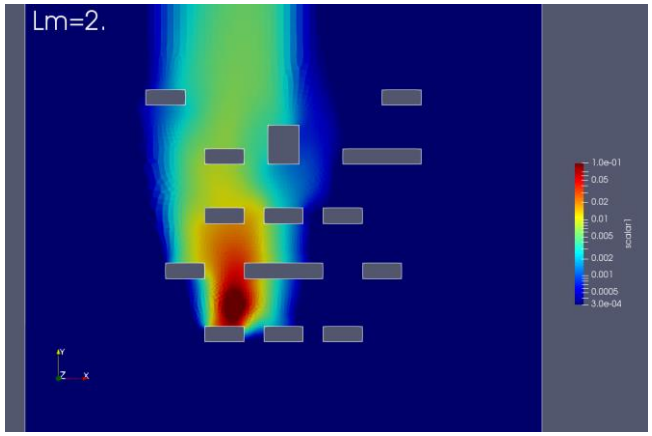


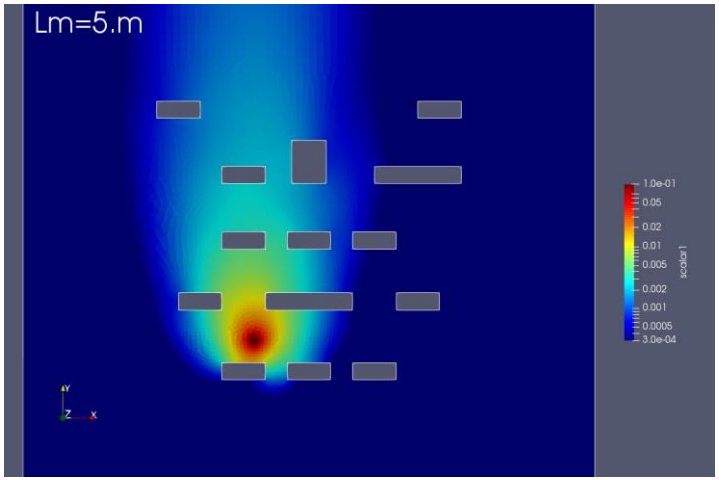


Source C1 180° wind

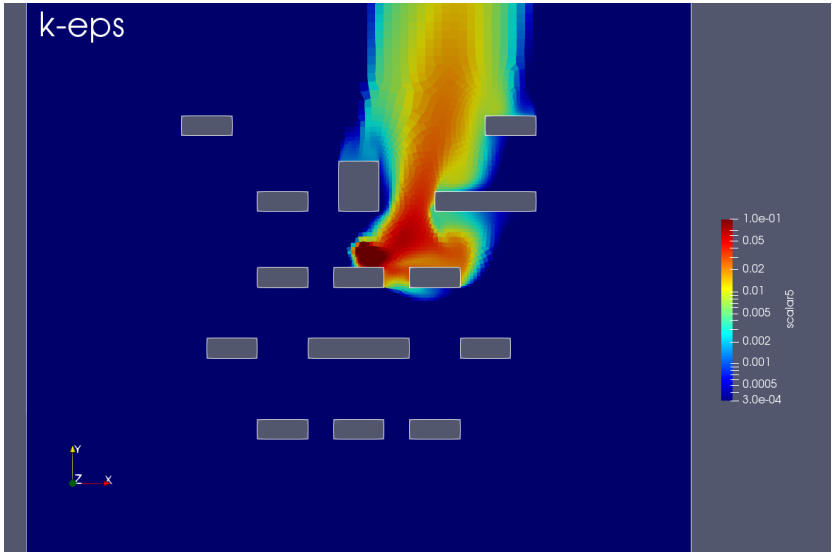


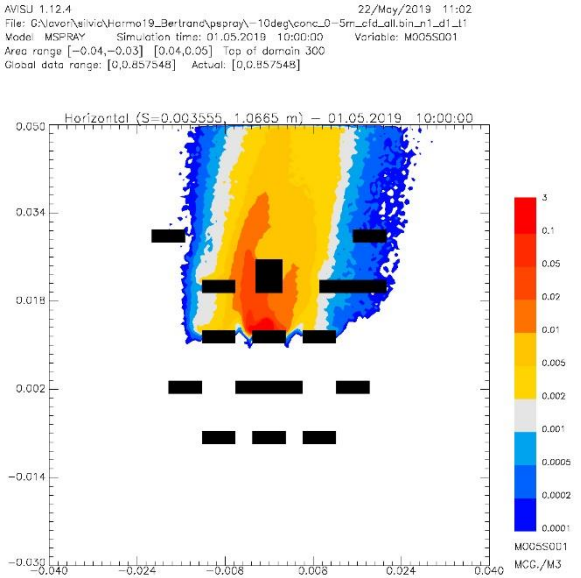


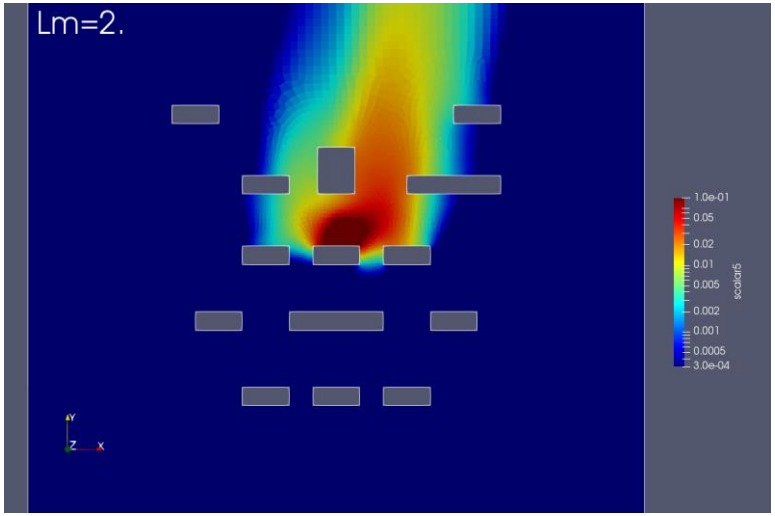


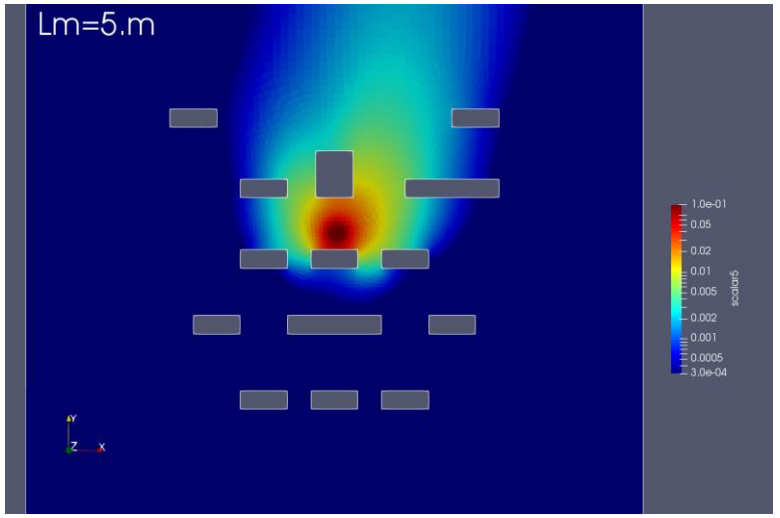


Source C5, 190° wind







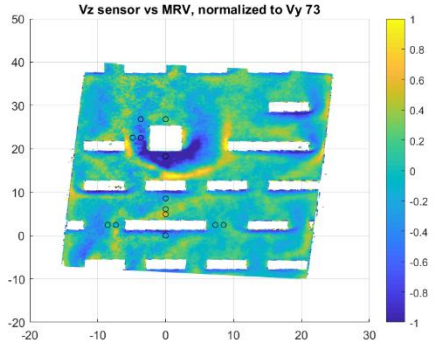


JRIIS EPA Wind Tunnel Study

- Complementary wind tunnel study is planned at the US EPA to examine the flow and dispersion of neutrally buoyant releases within the CONEX array
- Tracer gas releases for comparison with virtual releases in the models involved in the comparison

US EPA Meteorological Wind Tunnel

- +University of Arkansas (T. Spicer) and USMA (M. Benson) also doing laboratory scale modeling



Conclusions

- Ongoing analysis of JRII-Sonic dataset
- Preliminary simulation results presented (academic meteo profile)
- 6 (virtual) passive sources added to test model sensitivity to wake modeling
- Important sensitivity to type of wake modeling and turbulence closure

- ***Future:***
  - Select most appropriate periods for comparison
  - Pointwise comparison statistics on velocity, turbulence with sonic measurements and with the different models
  - Diagnose model shortcomings and improve
  - Comparison with EPA and U of Arkansas laboratory scale releases
  - Invitation to other modelers to join

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