MEASUREMENTS AND SIMULATIONS OF THE DISPERSION OF A PASSIVE TRACER IN A MOUNTAINOUS AREA

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INTRODUCTION

Measured air concentrations of the field tracer experiments are compared to the atmospheric dispersion code, MERCURE.

- field tracer experiments done around Akagi Testing Center located at the mountain slope
- To apply atmospheric dispersion model in different meteorological conditions

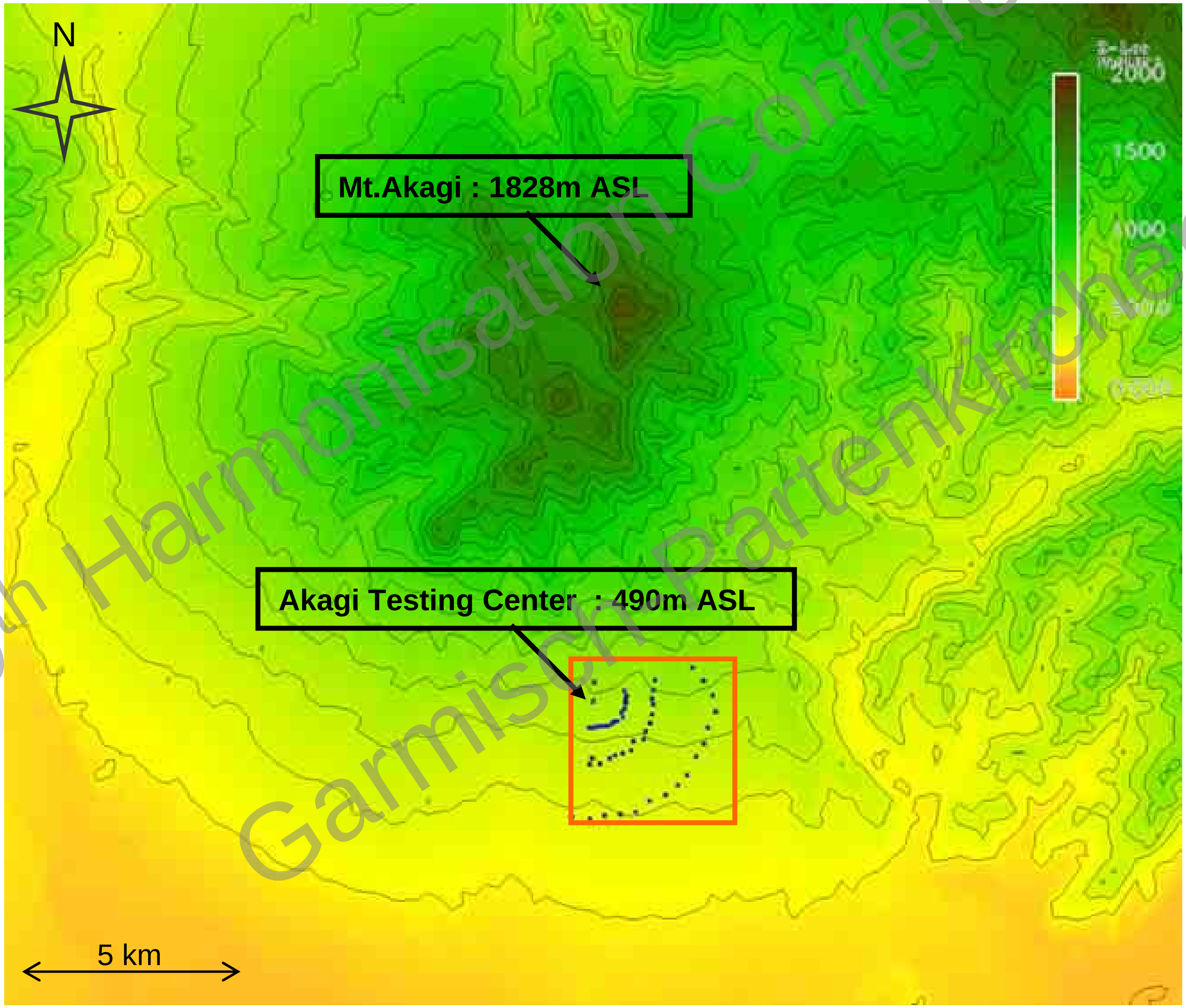
FIELD EXPERIMENTS

1. Outline of Experiments

Site and Date	
Site	Central Research Institute of Electric Power Industry (CRIEPI), Akagi Testing Center
Date	23 and 24 January 2001, 22, 23 and 24 January 2002
Tracer Emission and Sampling	
Tracer	PMCH (C_7F_{14}: Perfluoro-Methyl Cyclohexane)
Release height	95 m ground level (GL)
Air flow rate	0.035 Nm^3 /min
Tracer's flow rate	90 g/h
Sampling time and rate	Every 30 minutes, 100 ml/min.
Meteorological Measurement	
Meteorological Conditions	Weather: no precipitation; Wind direction: north (2001), north and west (2002); Atmospheric stability: neutral
Ultrasonic anemometer	Horizontal and vertical velocities at 100 m (GL). sampled at 20Hz
Doppler-Sodar	Observation heights: 11 ground levels between 30m and 250m; Measurements of standard deviation of vertical wind velocity (2001), and standard deviation of horizontal and vertical wind velocities (2002)

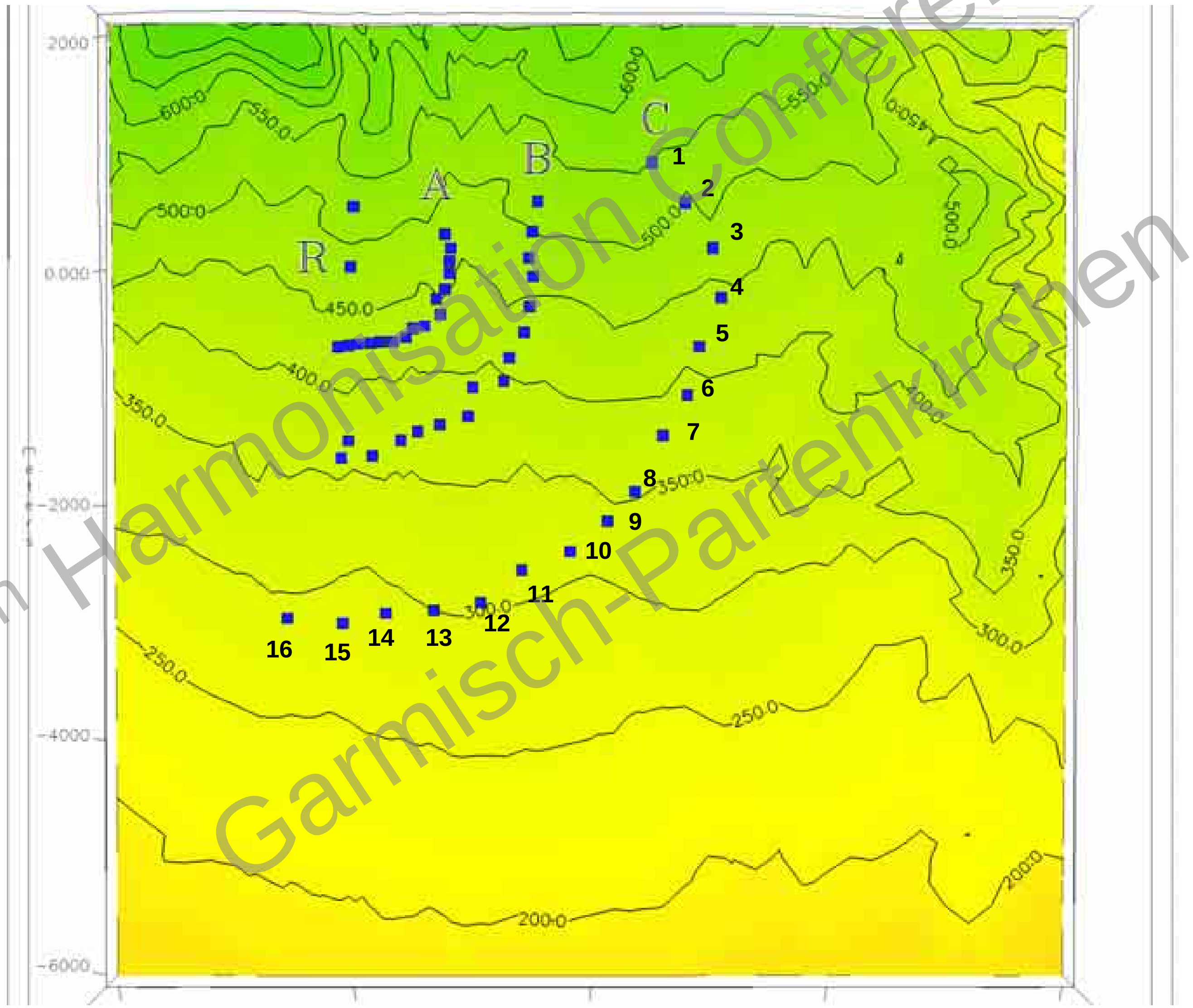
FIELD EXPERIMENTS

2. Test site & Topography



FIELD EXPERIMENTS

3. Release point & Sensors



MODELING

1. Description of MERCURE

- CFD code, adapted to the atmosphere
- Finite-difference and Finite-volume Method
- Standard k-ε closure scheme
- Terrain-following coordinate in vertical direction

Mass balance equation

$$\frac{\partial \bar{\rho}\tilde{v}_i}{\partial x_i} = 0$$

Navier-Stokes equation

$$\bar{\rho}\left(\frac{\partial \tilde{v}_i}{\partial t} + \tilde{v}_j \frac{\partial \tilde{v}_i}{\partial x_j}\right) = \frac{\partial \bar{\rho}^M}{\partial x_i} - \frac{2}{3}\frac{\partial}{\partial x_i}\left[\bar{\rho}\tilde{k} + (\mu + \mu_t)\,\mathrm{div}\,\tilde{\mathbf{v}}\right] + \frac{\partial}{\partial x_j}\left[(\mu + \mu_t)\left(\frac{\partial \tilde{v}_i}{\partial x_j} + \frac{\partial \tilde{v}_j}{\partial x_i}\right)\right] + \left(\bar{\rho} - \rho^c\right)g_i + \bar{\rho}\bar{F}_{co,i} - \rho^G F^G_{co,i}$$

Energy balance equation

$$\rho\left(\frac{\partial \theta}{\partial t} + u_j \frac{\partial \theta}{\partial x_j}\right) = T\left(\frac{p_s}{p}\right)^{\left(\frac{R^*}{C_p}\right)}\left(\frac{\partial}{\partial x_j}\left(\frac{\lambda_c}{C_p}\frac{\partial T}{\partial x_j}\right) + \Phi\right)$$

here, Potential temperature

$$\theta = T\left(\frac{p_s}{p}\right)^{\left(\frac{R^*}{C_p}\right)}$$

Passive tracer transport equation

$$\bar{\rho}\left(\frac{\partial \tilde{X}^K}{\partial t} + \tilde{v}_j \frac{\partial \tilde{X}^K}{\partial x_j}\right) = \frac{\partial}{\partial x_j}\left(\left(\frac{\lambda_c}{C_p} + \frac{\mu_t}{\sigma_t}\right)\frac{\partial \tilde{X}^K}{\partial x_j}\right) + \tilde{S}_K$$

here, Turbulent viscosity

$$\mu_t = \bar{\rho} C_\mu \frac{\tilde{k}^2}{\varepsilon} = \bar{\rho}\nu_t$$

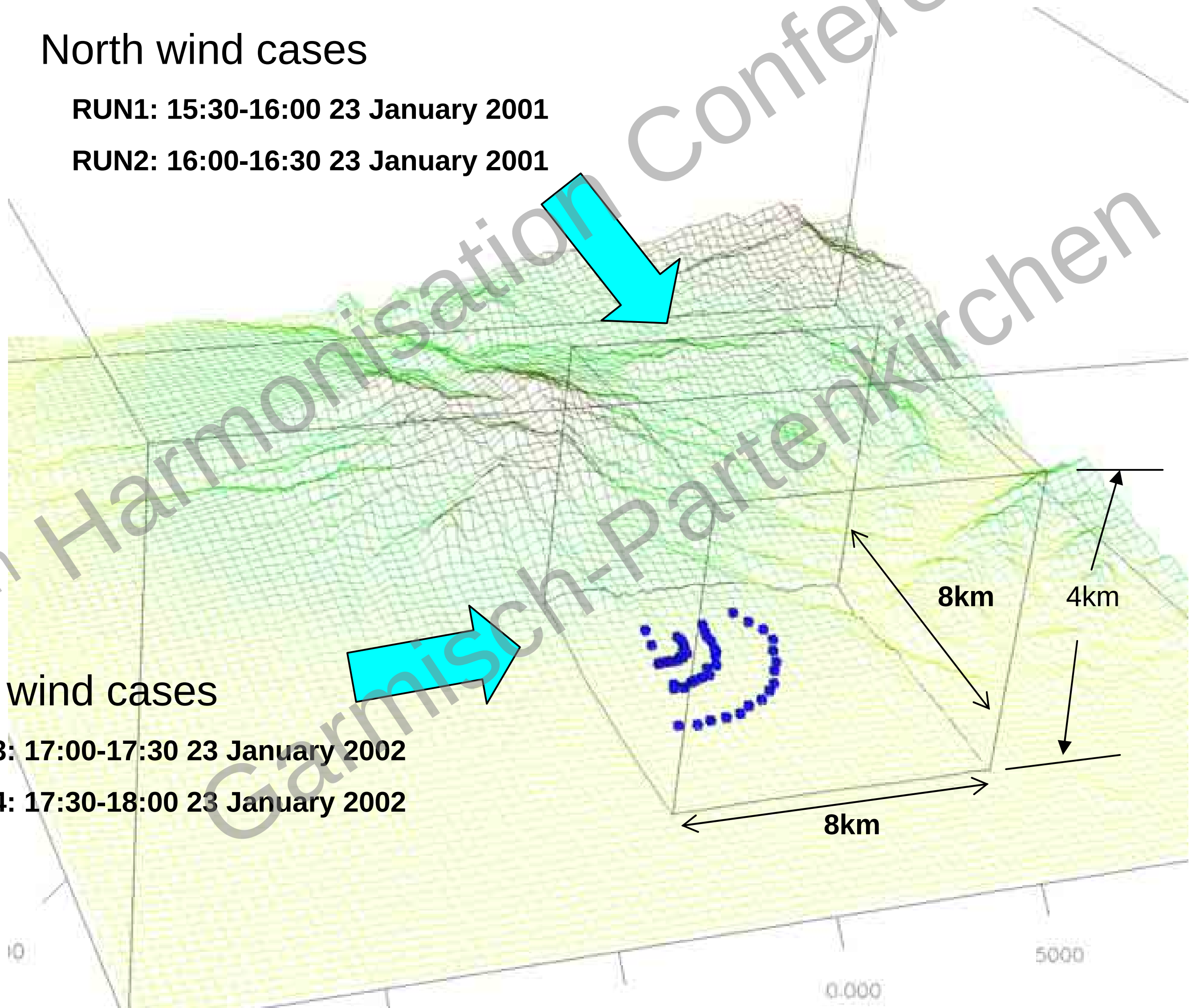
MODELING

2. Computational Domain & Simulated Cases

North wind cases

RUN1: 15:30-16:00 23 January 2001

RUN2: 16:00-16:30 23 January 2001



West wind cases

RUN3: 17:00-17:30 23 January 2002

RUN4: 17:30-18:00 23 January 2002

MODELING

4. Input data (Inlet boundary condition)

Vertical profile of following data needed at Inlet condition

- Velocities (Vx, Vy, Vz=0)
  - From the wind measurements at 100m GL

$$V(z) = V_0 (z/z_0)^p$$

- Potential temperature (derived from temperature, pressure)
  - From the measurements at ground surface (RUN1-2: 5ºC, RUN3-4: 3ºC)

$$T(z) = T_0 - z\Gamma$$

- Relative humidity
  - No measurement assumed to be constant (80%)

- Turbulent energy & Dissipation of turbulent energy
  - From the wind measurements at 100m GL

$$k(z) = U_m^2 / \sqrt{C_m}$$

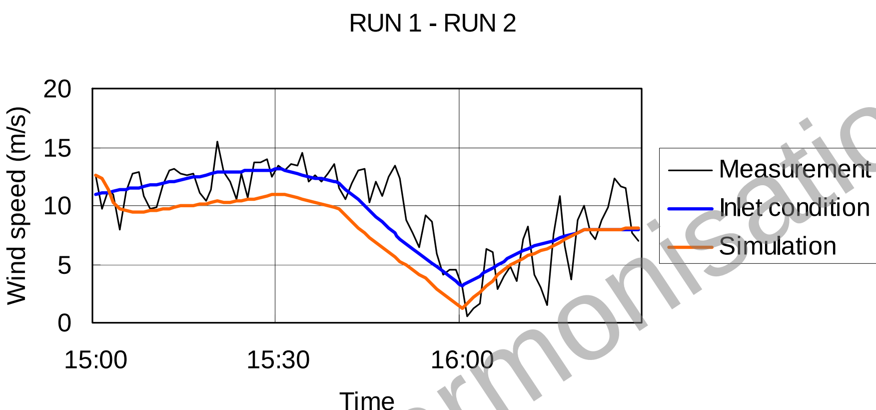
$$\varepsilon(z) = U_m^3 / (K_m z)$$

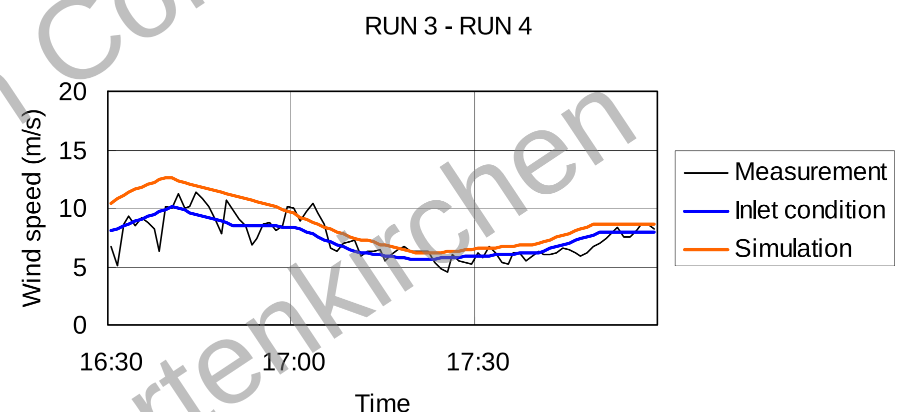
where $U_m = V_0 K_m / \log(z_0 / z_r)$

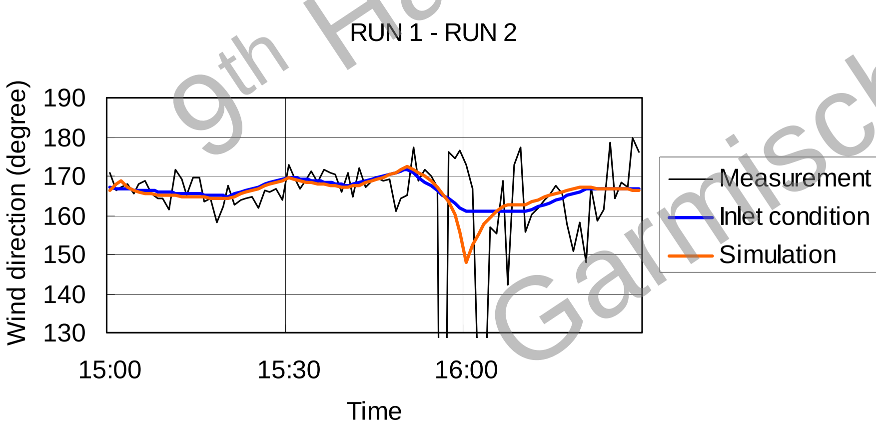
RESULT

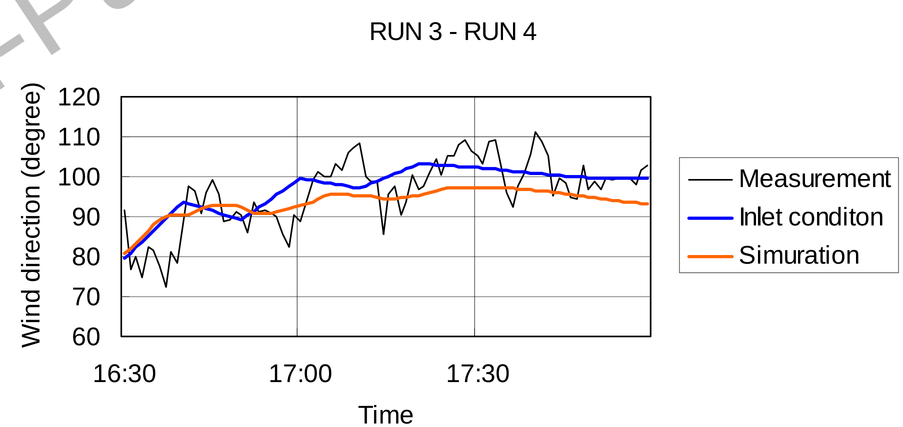
1. Wind field

Time series of wind velocity at 100m (GL) on the release point



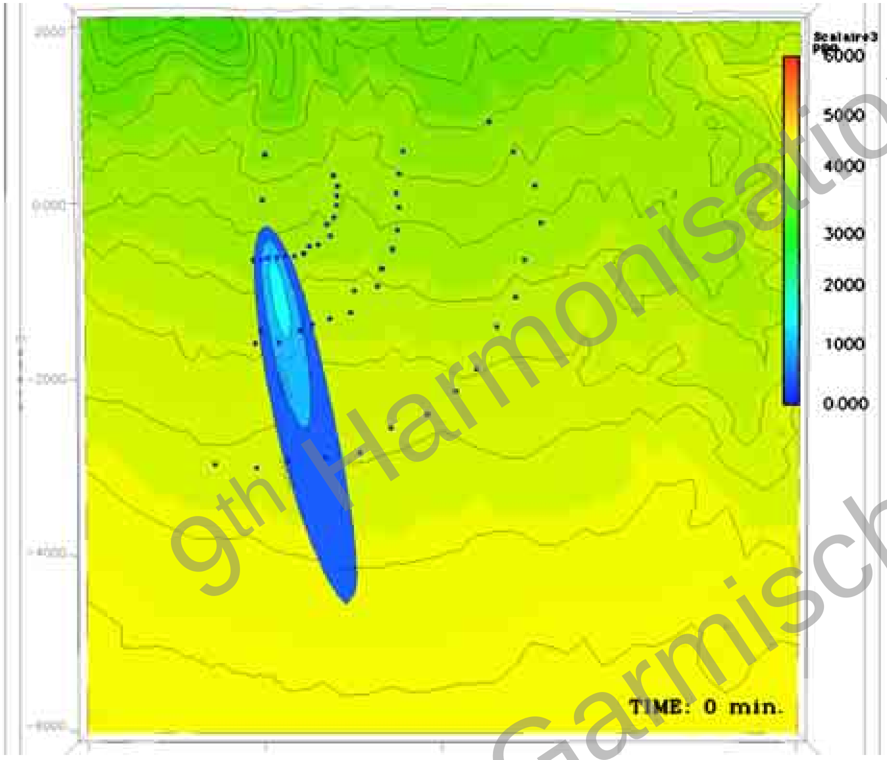




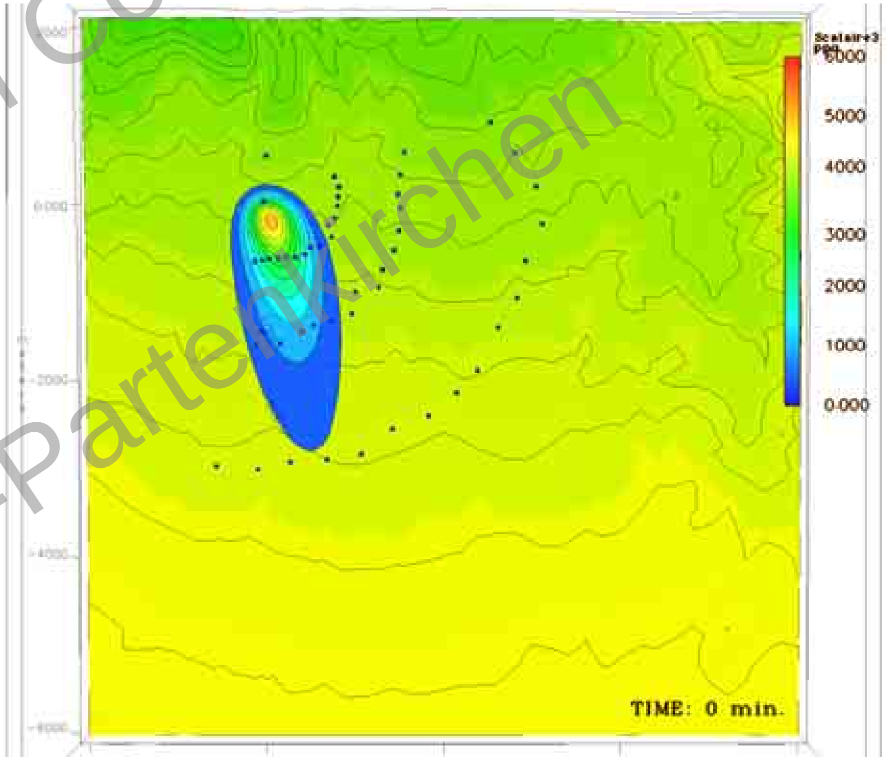


RESULT
2. Tracer concentrations

Tracer concentration on the ground surface : North wind cases



RUN1

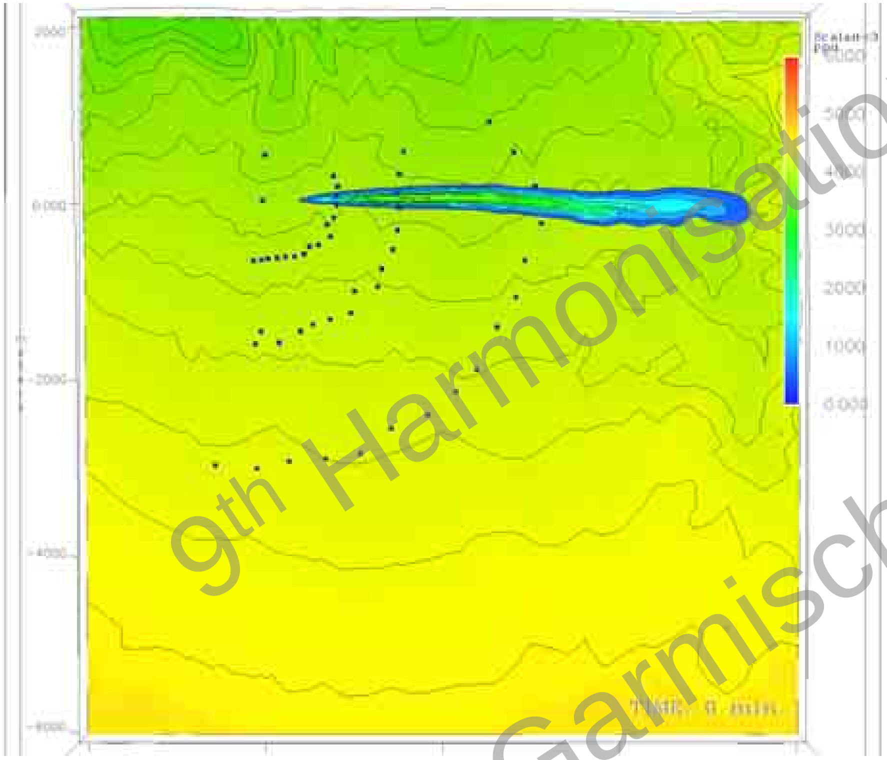


RUN2

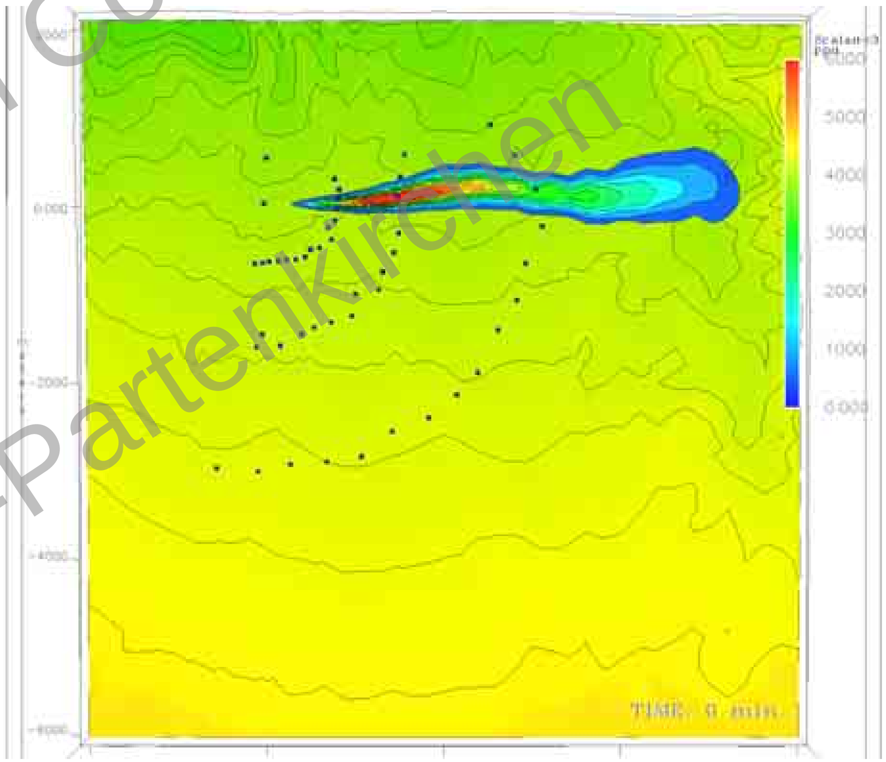
RESULT

2. Tracer concentrations

Tracer concentration on the ground surface : West wind cases



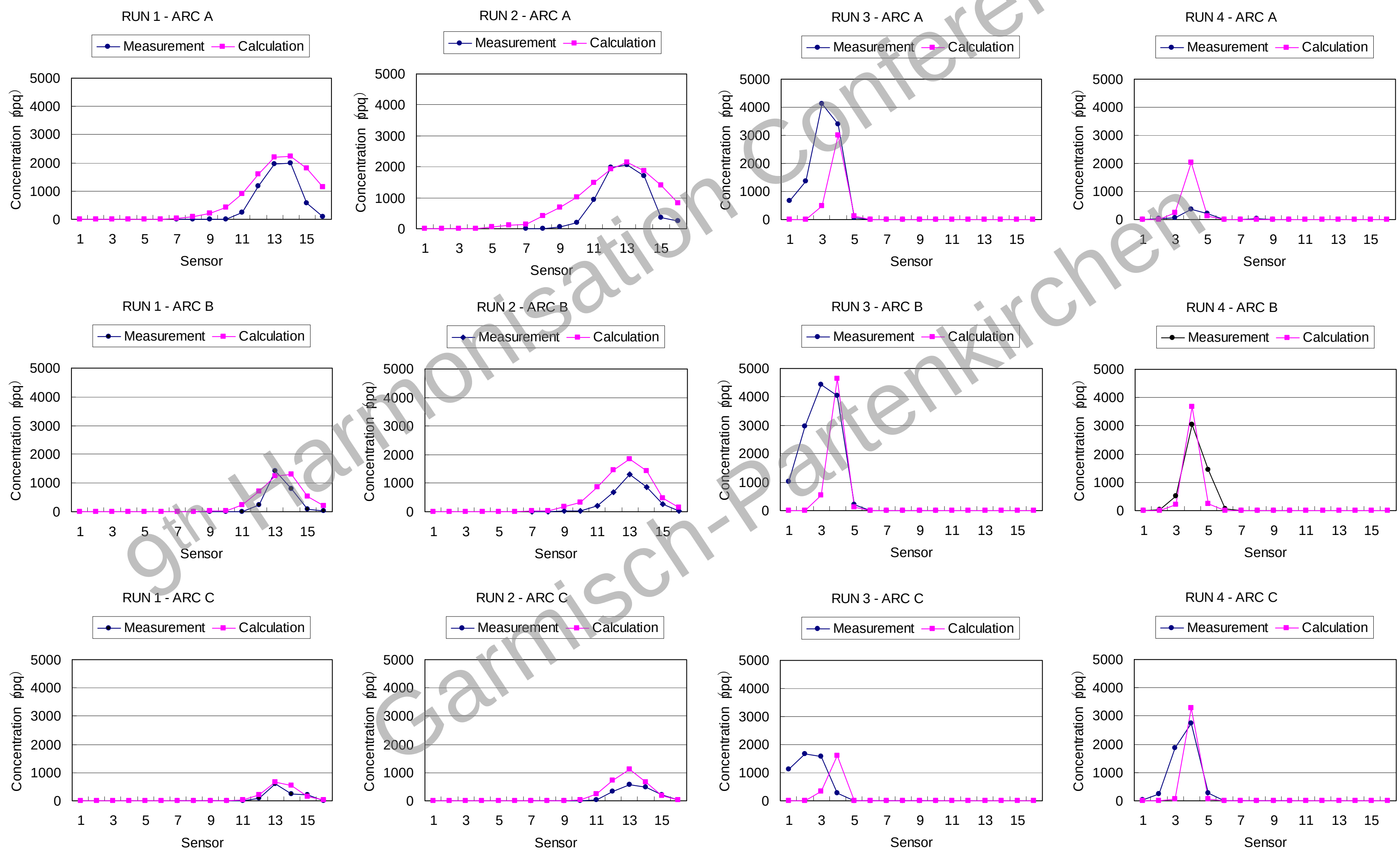
RUN3



RUN4

RESULT

2. Tracer concentrations



RESULT

2. Tracer concentrations

Quantitative Comparison

	RUN 1	RUN2	RUN3	RUN4
σ	0.54	0.71	0.85	2.31
τ	0.10	0.44	0.12	1.70

Mean-square root σ

$$\sigma^2 = \frac{1}{3}\sum_{j=1}^{3}\frac{\sum_i \left(M_{i,j} - C_{i,j}\right)^2}{\sum_i M_{i,j}^{\ 2}}$$

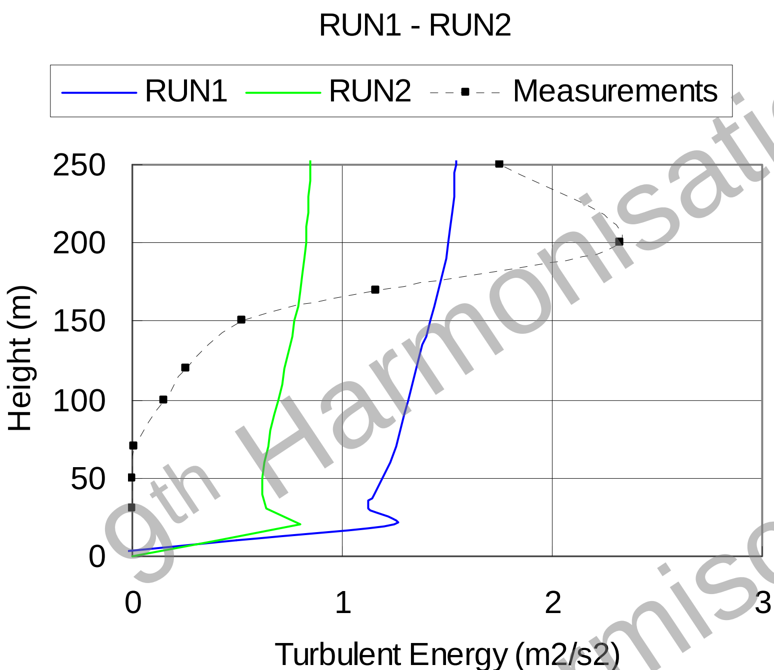
Peak accuracy prediction τ

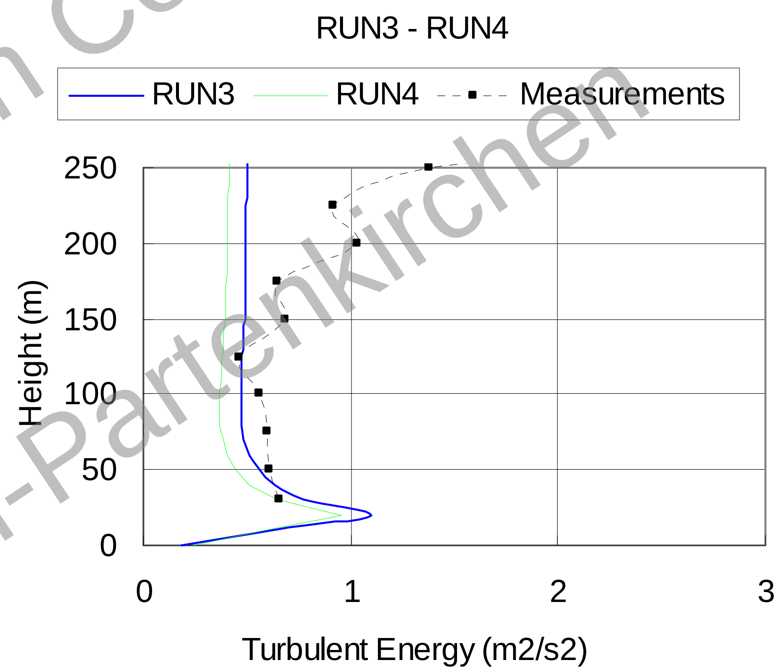
$$\tau = \frac{1}{3}\sum_{j=1}^{3}\frac{\left|Max_i M_{i,j} - Max_i C_{i,j}\right|}{Max_i M_{i,j}}$$

RESULT

3. Turbulent kinetic energy

Vertical profile of turbulent kinetic energy at the release point





Calculated turbulent kinetic energy in North wind case (RUN1-RUN2) are about 2.5 times larger than West wind case (RUN3-RUN4)

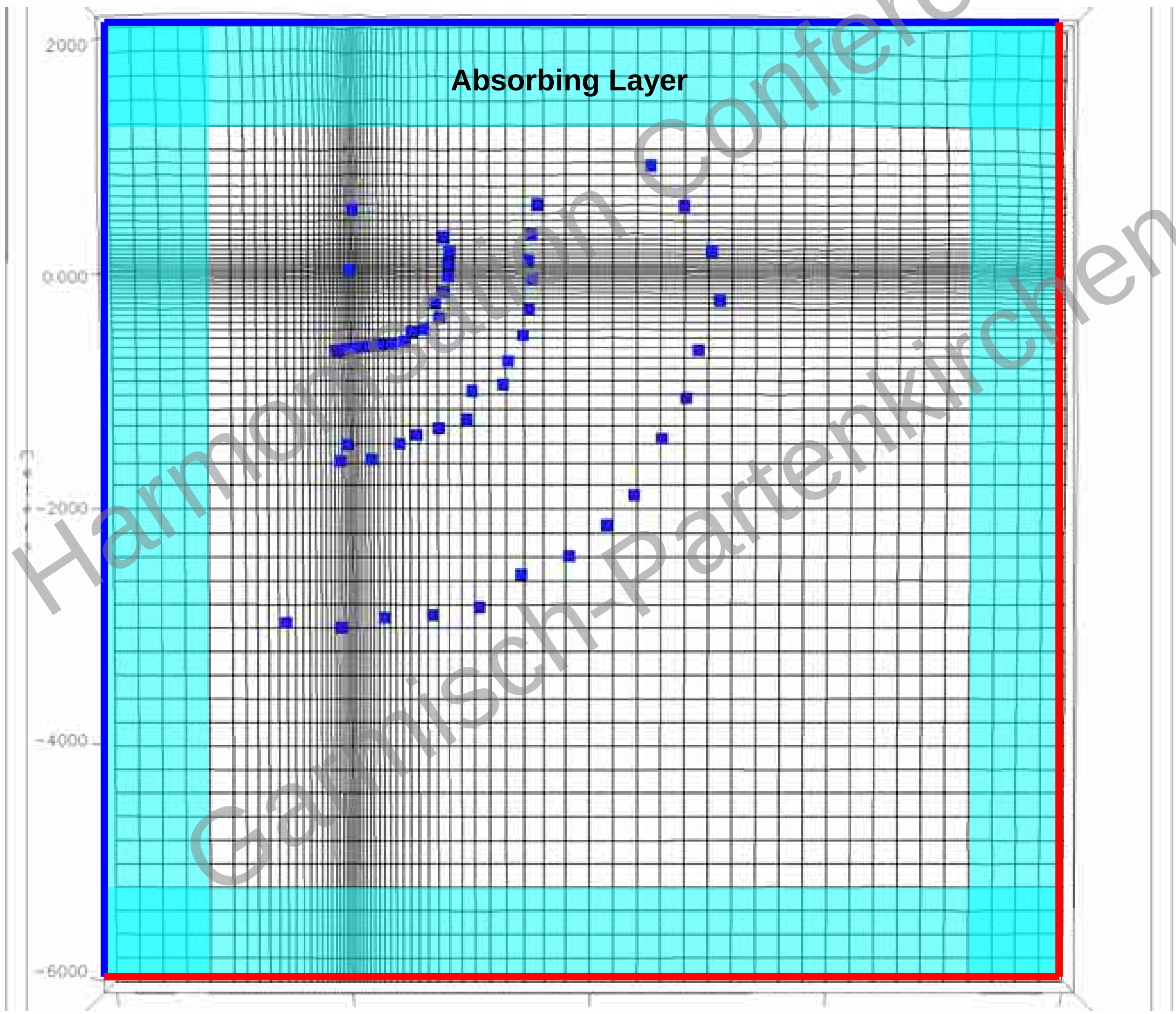
CONCLUSION

- Field experiments at Akagi Testing Center,
  - dispersion of tracer in the presence of topography
- Using a CFD code, Mercure,
  - good agreements with measured tracer concentrations
  - good agreements with measured kinetic turbulent energy in west wind case
- Further studies
  - more precise wind boundary conditions,
  - other turbulence scheme

MODELING

3. Mesh discritization & Boundary condition

Inlet



Outlet

RESULT

1. Wind field

Wind speed averaged over 30 min. at 100m (GL) on the release point

	Measured	Computed	Relative Errors
RUN1	10.7m/s	7.2m/s	-33.1%
RUN2	6.3m/s	5.9m/s	-5.6%
RUN3	6.8m/s	7.2m/s	+6.4%
RUN4	6.7m/s	7.7m/s	+15.3%

Note: wind speeds in RUN2, RUN3 and RUN4 are almost same values (differences are less than 10% in measurements, less than 15% in simulations).