MINISTERIO DE EDUCACION Y CIENCIA

Ciemat Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas.

STREET CANYON SIMULATION COMPARISON WITH WIND TUNNEL EXPERIMENT

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OVERVIEW

- Introduction
- Model description
- Simulation and experimental set up
- Comparison numerical and wind tunnel results
- 3D Analysis of flow

INTRODUCTION (1)

- Urban Air Pollution: one of most important problem. Why?:
  - Many people live in cities
  - High pollution levels (traffic emissions)
  - Protect human health

INTRODUCTION (2)

- Investigate air flow inside Urban Canopy:
  - Interaction Atmospheric Flow ⇔ Urban Geometry
  - Complex structures
  - Important tool: CFD models (buildings explicitly resolved)
- ***OBJECTIVE:***
  - Validate CFD model with wind tunnel measurements
  - In a future work, use CFD simulations of street canyon to obtain mean flow properties and parameterizations for mesoscale models

MODEL DESCRIPTION

- FLUENT CFD is used
- Simulations for steady state based on Reynolds-Averaged Navier-Stokes equations (RANS)
- Turbulence model: k-ε standard
- Governing equations solved by means of a collocated grid system using finite volume method
- Pressure-velocity coupling : SIMPLE
- Advection-differencing scheme: QUICK

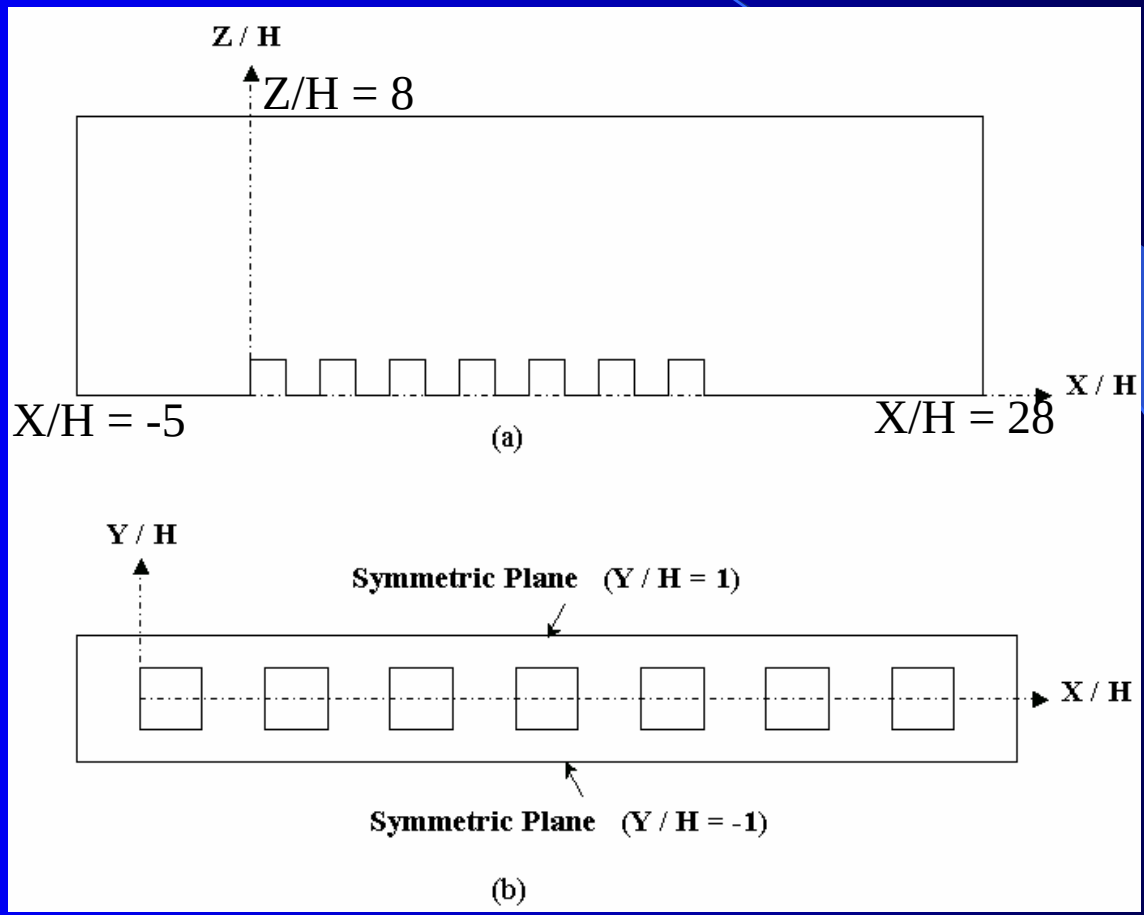
WIND TUNNEL EXPERIMENT

- U.S. Environmental Protection Agency's Fluid Modelling Facility wind tunnel (Brown et al. 2001).
- Test section: 18.3m x 3.7m x 2.1m
- Roughness length = 0.001m. Horizontal velocity as power-law profile (3 m/s at z = H).
- Reynolds number ≈ 3 x 10^4

GEOMETRICAL DESCRIPTION

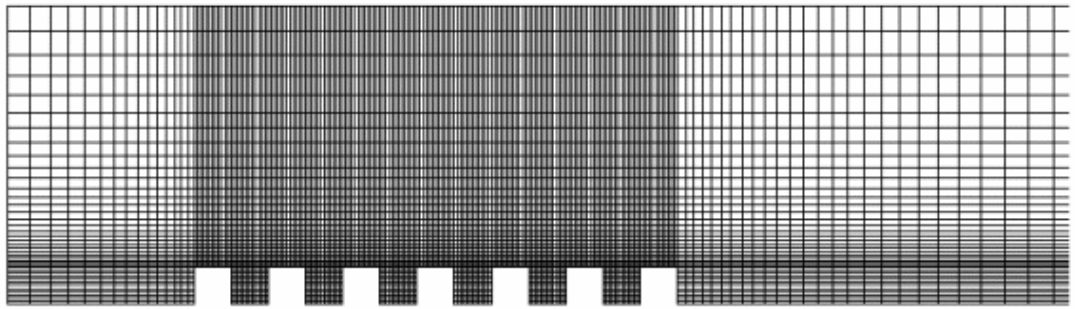
- Building Array:
  - 7 buildings (X-direction) x 11 buildings (Y-direction)
- Building dimensions:
  - 0.15m x 0.15m x 0.15m
- Face to face spacing:
  - 0.15 m in streamwise direction
  - 0.15 m in spanwise direction

SIMULATION SET UP: DOMAIN

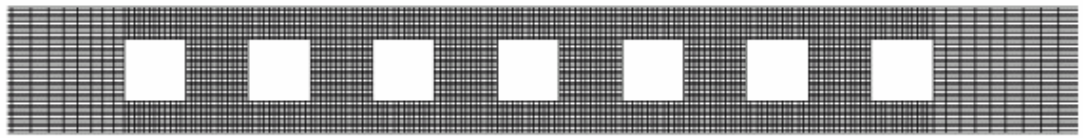


SIMULATION SET UP: GRID

- Cartesian Grid:
  - 202 x 44 x 40 cells
- Grid Size:
  - 0.0125m in X and Z directions near buildings

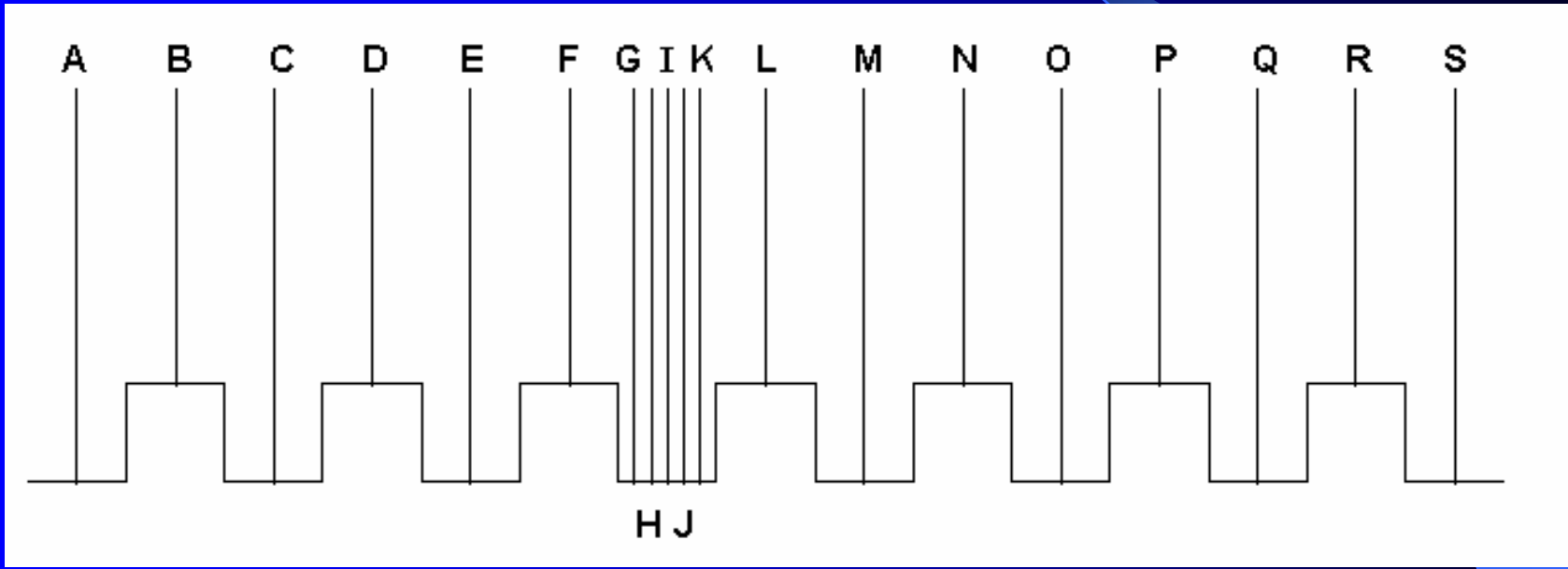


(a)



(b)

LOCATION OF MEASUREMENTS



STATISTICAL ANALYSIS (1)

- "Hit Rate" Test (Schlünzen et al., 2004)

$$q = \frac{N}{n} = \frac{1}{n}\sum_{i=1}^{n} N_i \qquad \text{with} \qquad N_i = \begin{cases} 1 \text{ if } \left|\frac{P_i - O_i}{O_i}\right| \le RD \text{ or } |P_i - O_i| \le AD \\ 0 \quad else \end{cases}$$

n : total number of points compared
O_i and P_i : wind tunnel (reference) data and model results, respectively.
RD :relative deviation allowed.
AD : absolute deviation allowed of model results from reference data
Comparison computed results with wind tunnel data a hit rate of $q > 66\%$ is demanded (Schlünzen et al. (2004)).

- Statistics

$$NMSE = \frac{\sum_{i=1}^{n}(O_i - P_i)^2}{\sum_{i=1}^{n}(O_i \cdot P_i)}$$

$$FB = \frac{\overline{O} - \overline{P}}{0.5 \cdot (\overline{O} + \overline{P})}$$

$$R = \frac{\sum_{i=1}^{n}\left[(O_i - \overline{O})(P_i - \overline{P})\right]}{\left[\sum_{i=1}^{n}(O_i - \overline{O})^2\right]^{1/2}\left[\sum_{i=1}^{n}(P_i - \overline{P})^2\right]^{1/2}}$$

STATISTICAL ANALYSIS (2)

- "Hit Rate" Test

	Number of Points	*Number of Hits*	*Hit Rate (q)*
U	248	235	95%
W	248	190	77%
TKE	248	201	81%

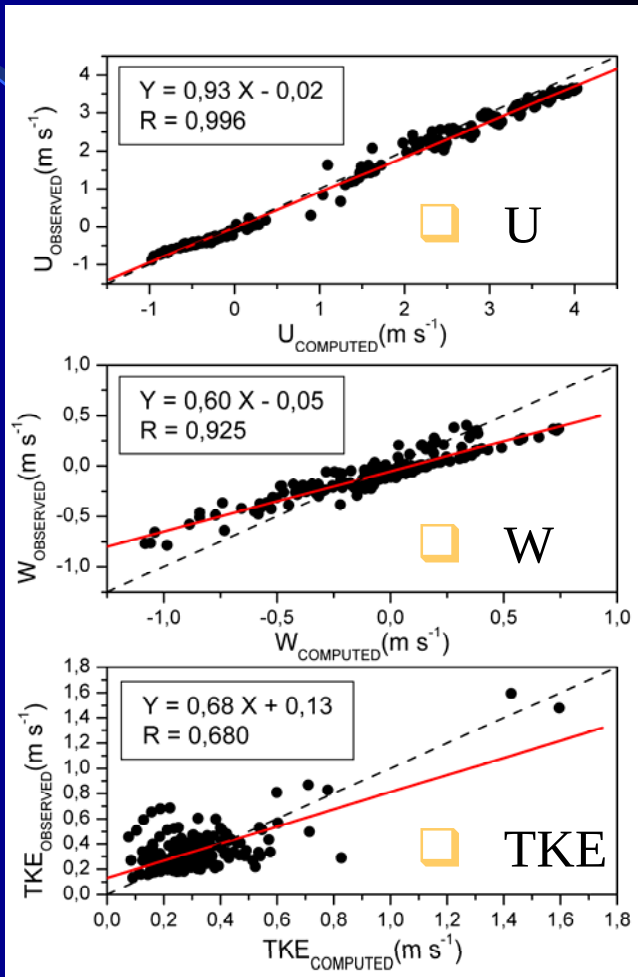
Table 1. Results of hit rate validation procedure outlined in Schlünzen et al. (2004) for mean streamwise velocity, mean vertical velocity and turbulent kinetic energy. A relative deviation of $RD = 0.25$ for all variables and an absolute deviation of $AD = 0.15$ m s^{-1} for mean streamwise velocity and mean vertical velocity and $AD = 0.15$ m^2 s^{-2} for turbulent kinetic energy are used.

q > 66 % for comparison with wind tunnel data

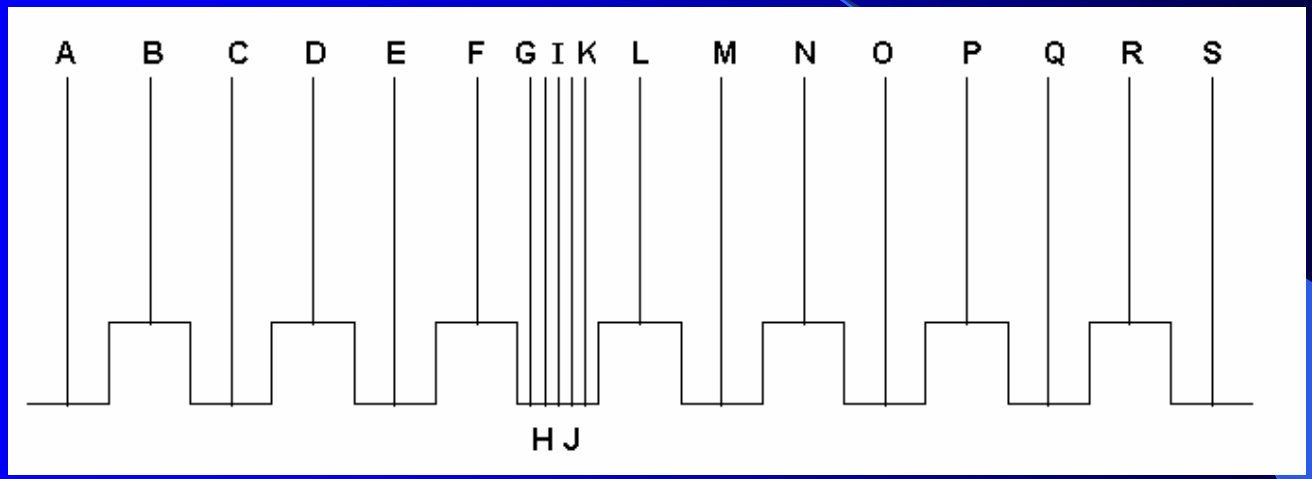
- Statistics

	NMSE	*FB*	*R*
U	0.009	-0.082	0.997
W	0.352	0.396	0.926
TKE	0.159	0.122	0.680

Table 2. Values of normalised mean square error (*NMSE*), fractional BIAS (*FB*) and correlation coefficient (*R*) for mean streamwise velocity, mean vertical velocity and turbulent kinetic energy.



COMPARISON OF VERTICAL PROFILES

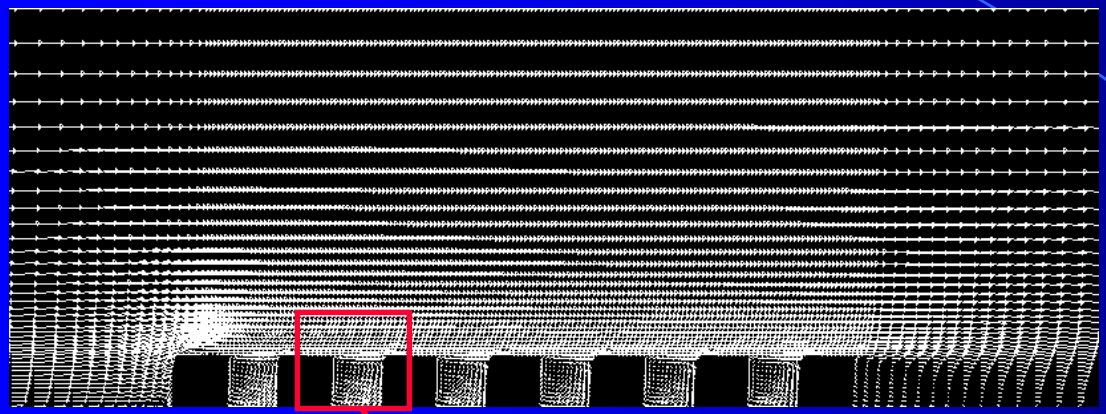


A B C D E F G H

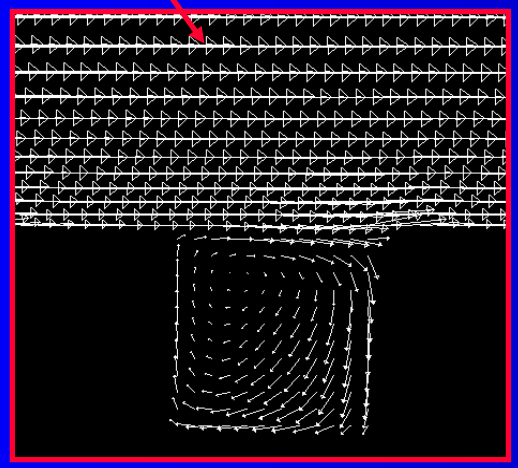
I J K L M N O P

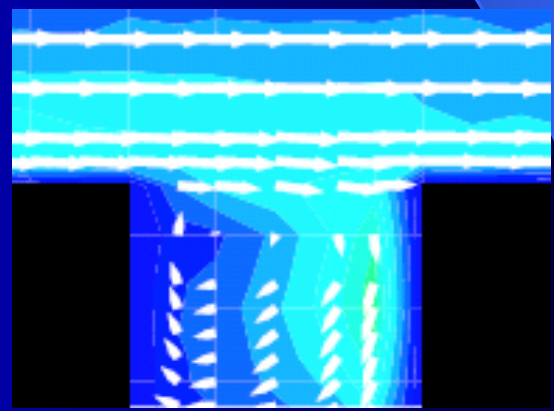
Q R S

ANALYSIS OF FLOW (1)



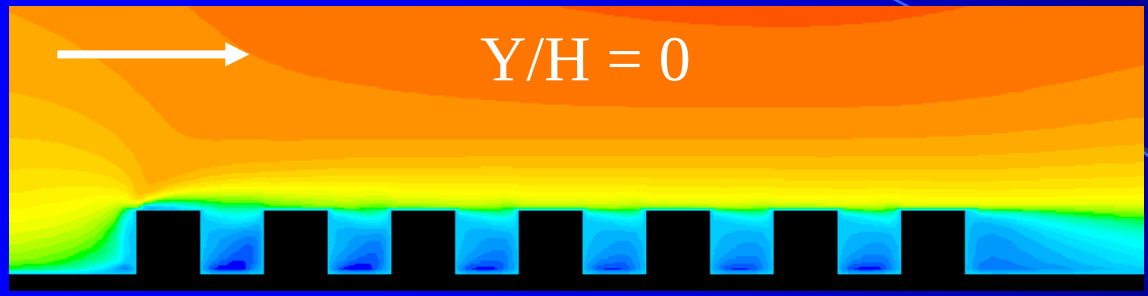
WIND FLOW AT $Y/H = 0$



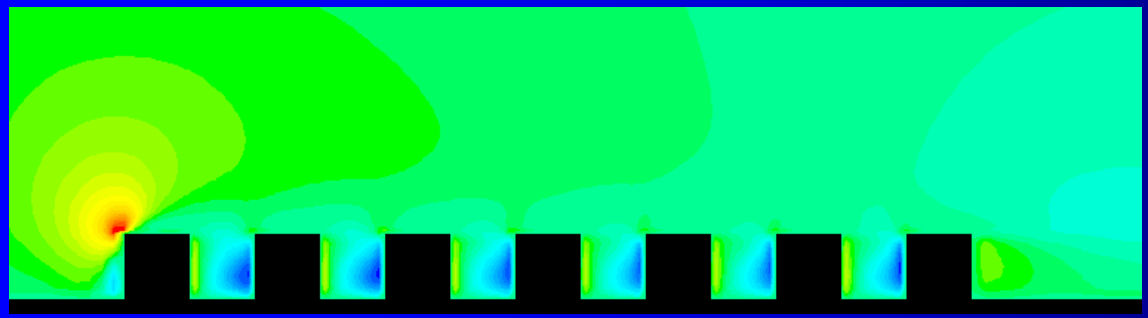


- CFD
- Wind tunnel

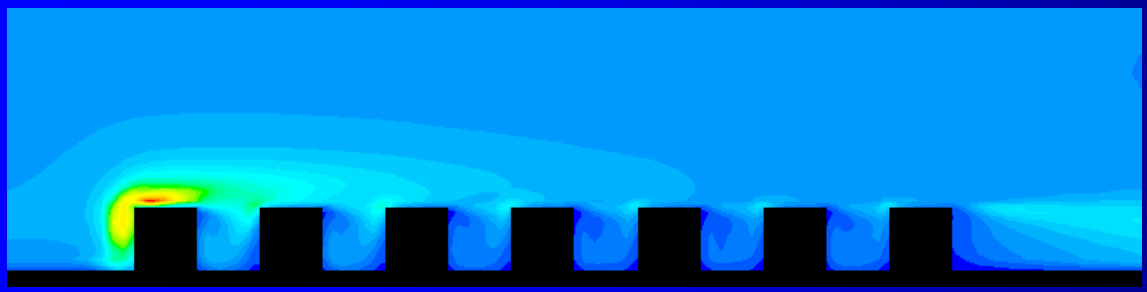
ANALYSIS OF FLOW (2)



- U

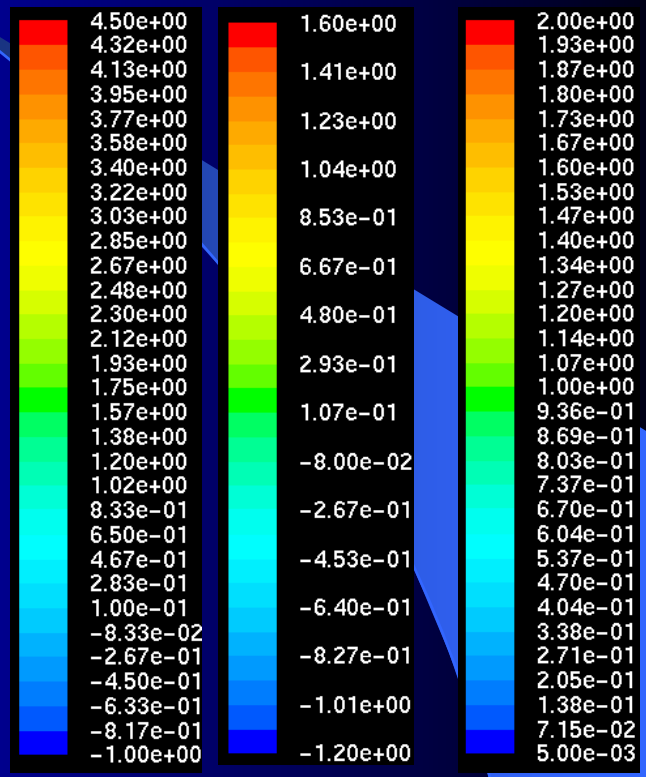


- W



- TKE

- U
- W
- TKE



ANALYSIS OF FLOW (3)

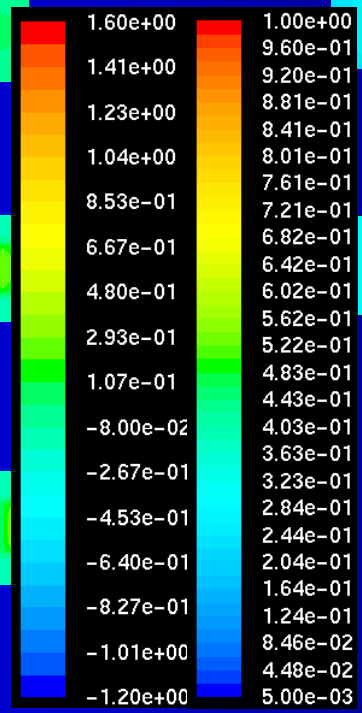
- W

Z/H = 0.25

Z/H = 0.5

Z/H = 0.75

Z/H = 1.0



- TKE

Z/H = 0.25

Z/H = 0.5

Z/H = 0.75

Z/H = 1.0

CONCLUSIONS (1)

- FLUENT reproduces quite well flow structure observed in wind tunnel experiment.
- Comparison methodology (U, W, TKE):
  - "Hit rate" Test (Schlünzen et al., 2004)
  - Statistics (NMSE, FB, R)
  - Profile comparisons

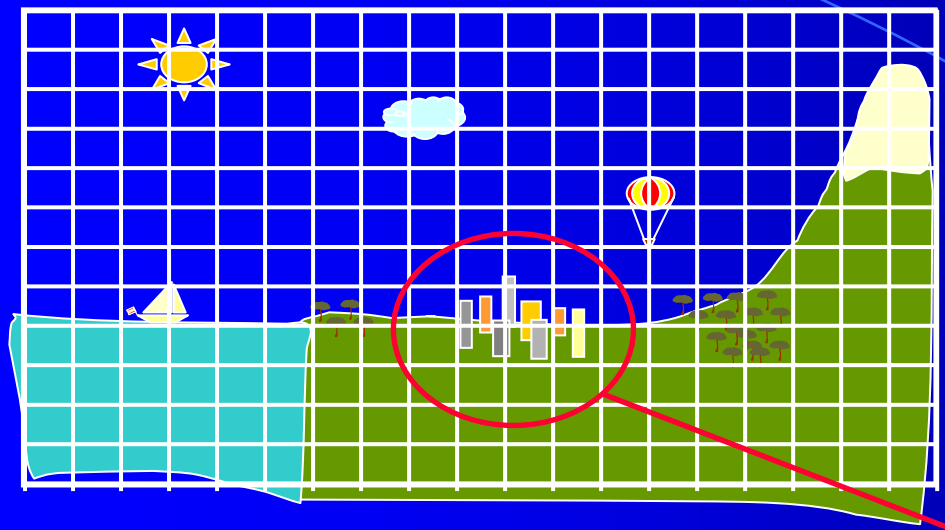
CONCLUSIONS (2)

- General good agreement.
  - Excellent agreement for U
  - W intensity is overestimated
  - TKE is underestimates inside canyons
- Complex flow inside canyons

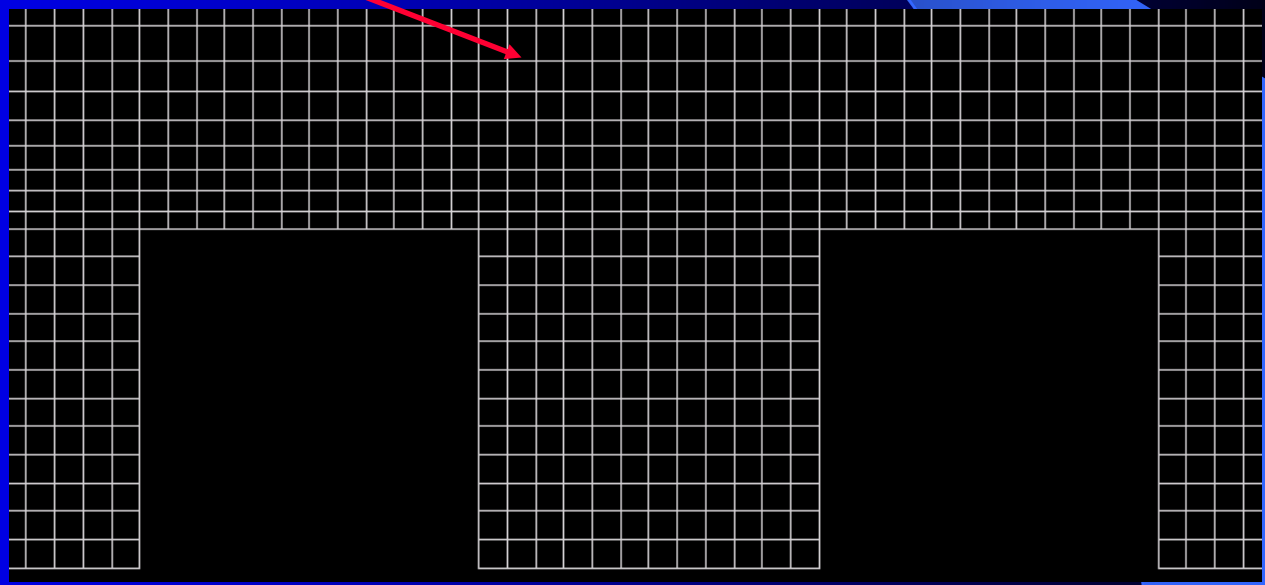
ACKNOWLEDGEMENTS

- The authors would like to thanks:
  - CIEMAT for doctoral fellowship hold by Jose Luis Santiago.
  - Dr. Michael J. Brown for providing data of wind tunnel experiments.

Thank you for your attention



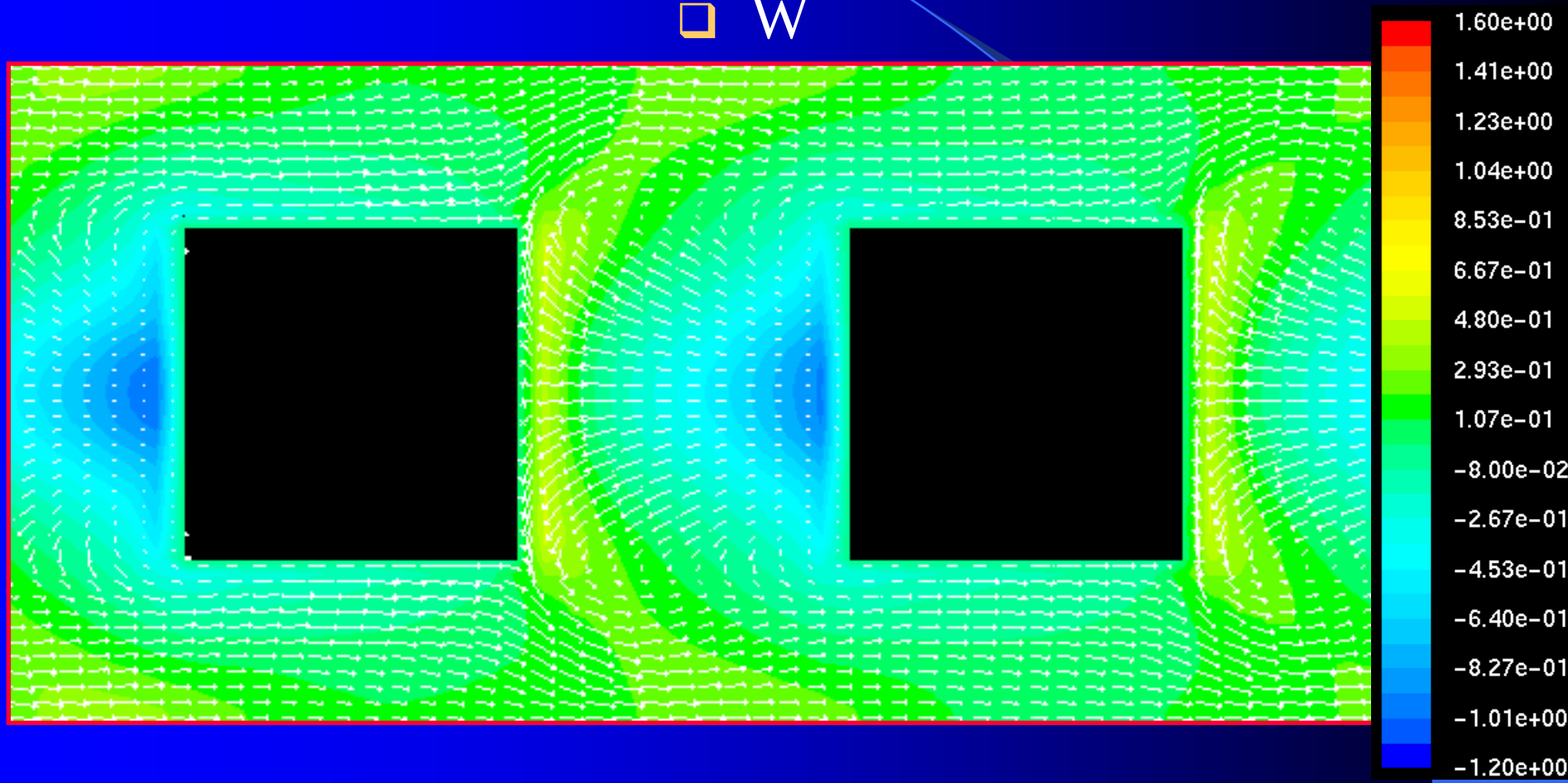
- MESOSCALE MODELS



- CFD MODELS

Z/H = 0.25

- W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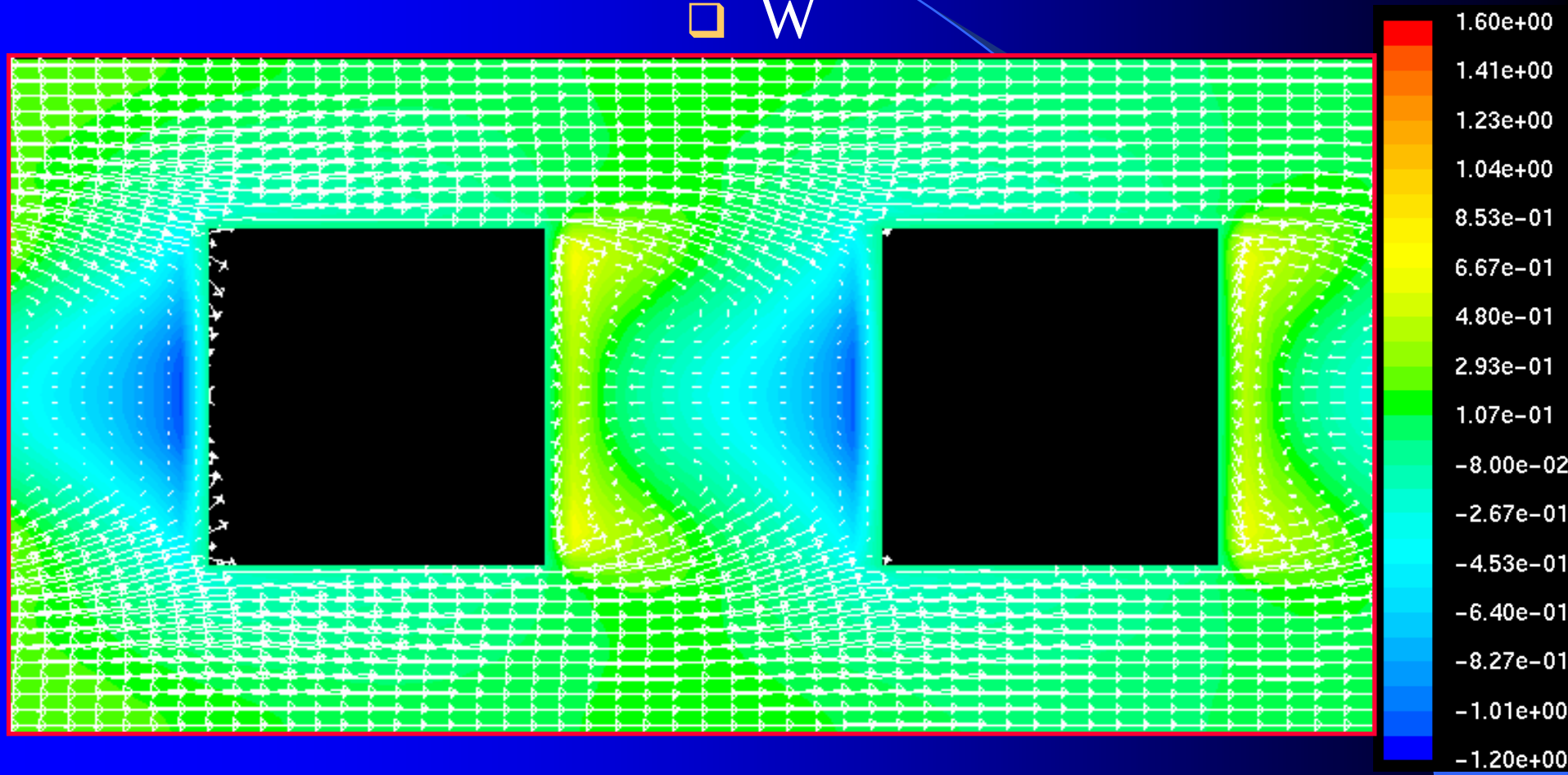
Z/H = 0.5

- W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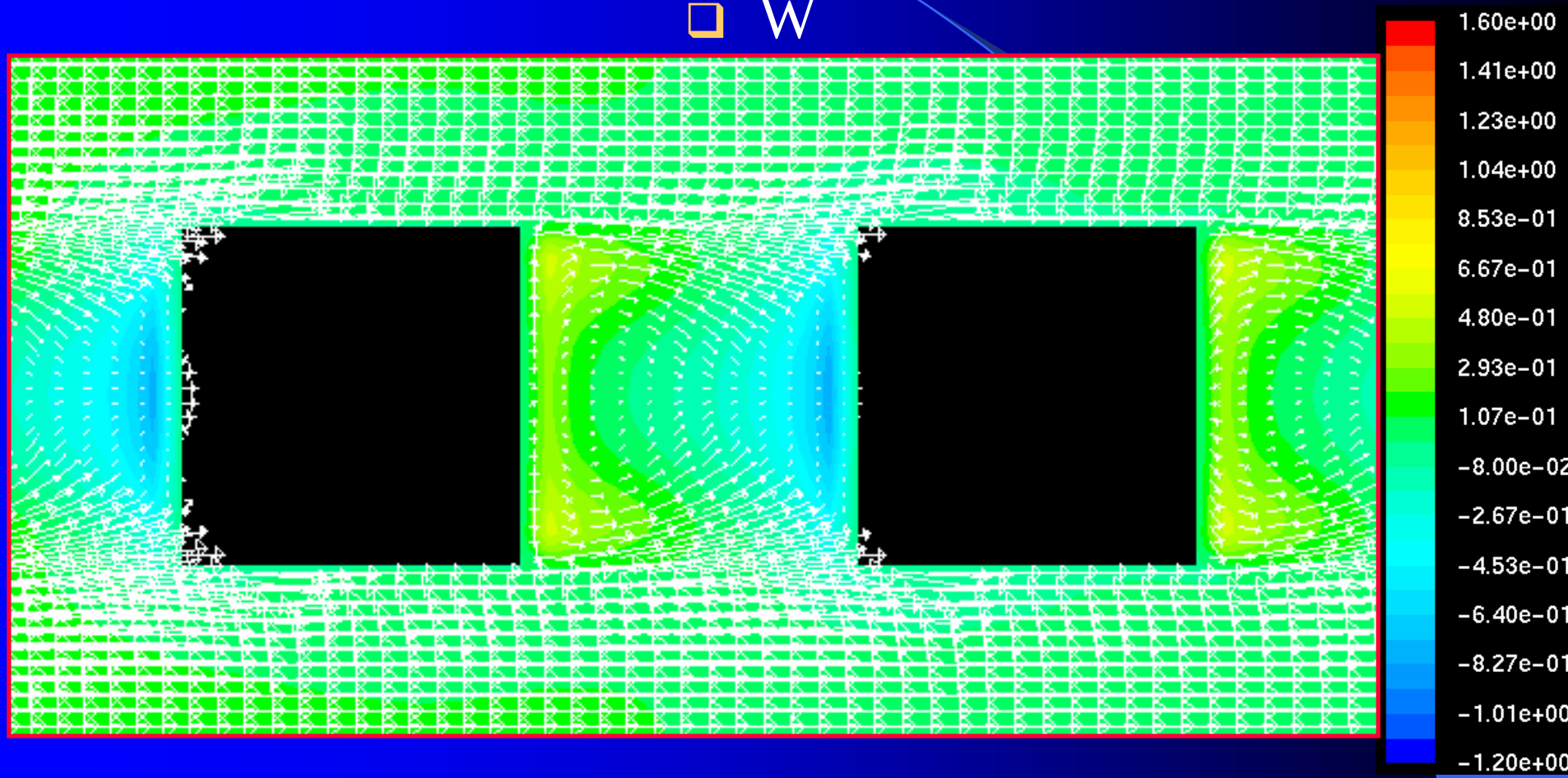
-1.20e+00

Z/H = 0.75

- W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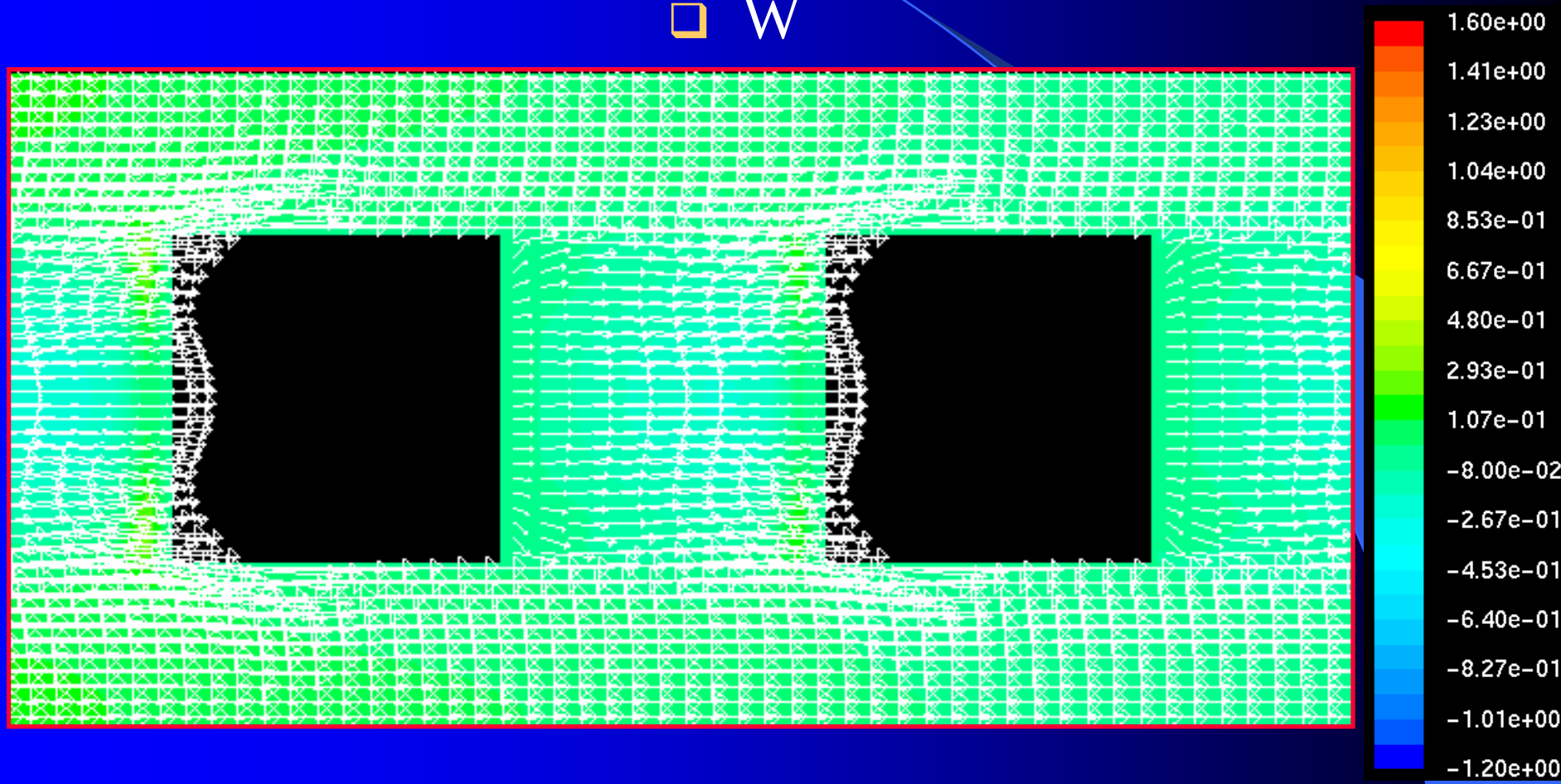
Z/H = 1.0

- W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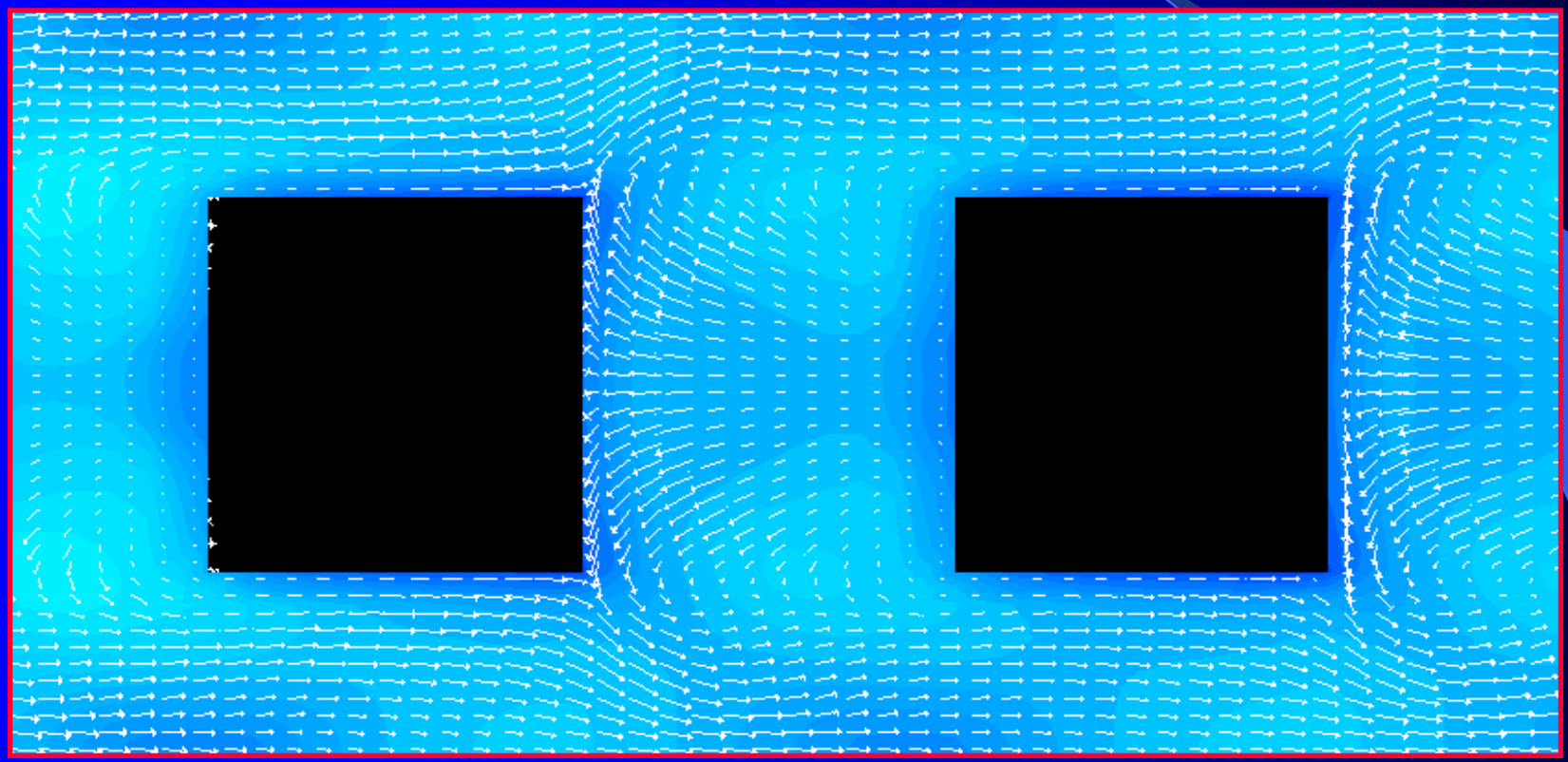
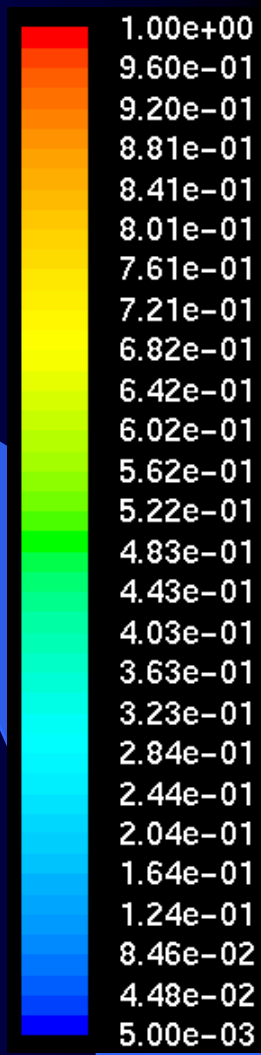
Z/H = 0.25

- TKE

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2.44e-01
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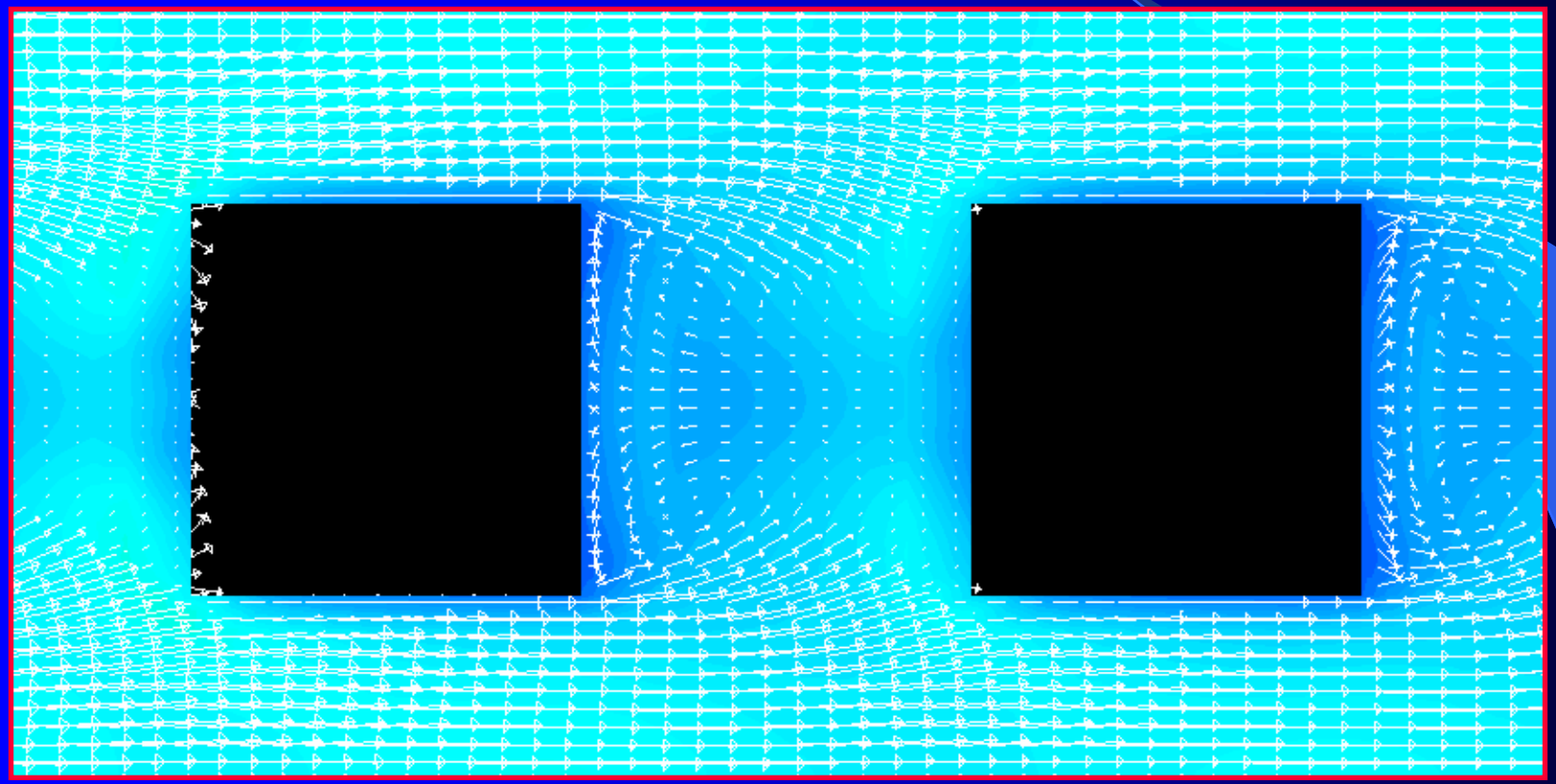
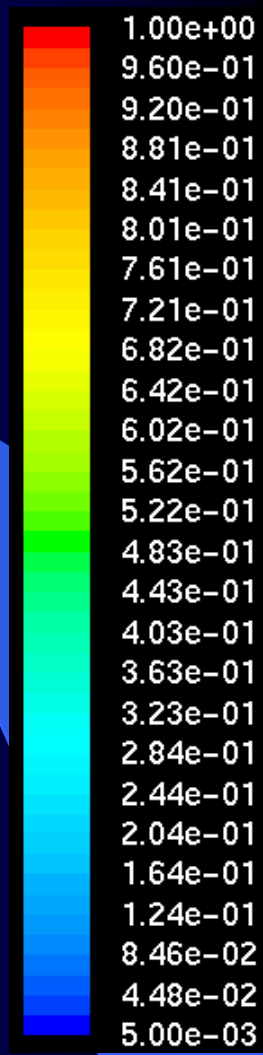
Z/H = 0.5

- TKE

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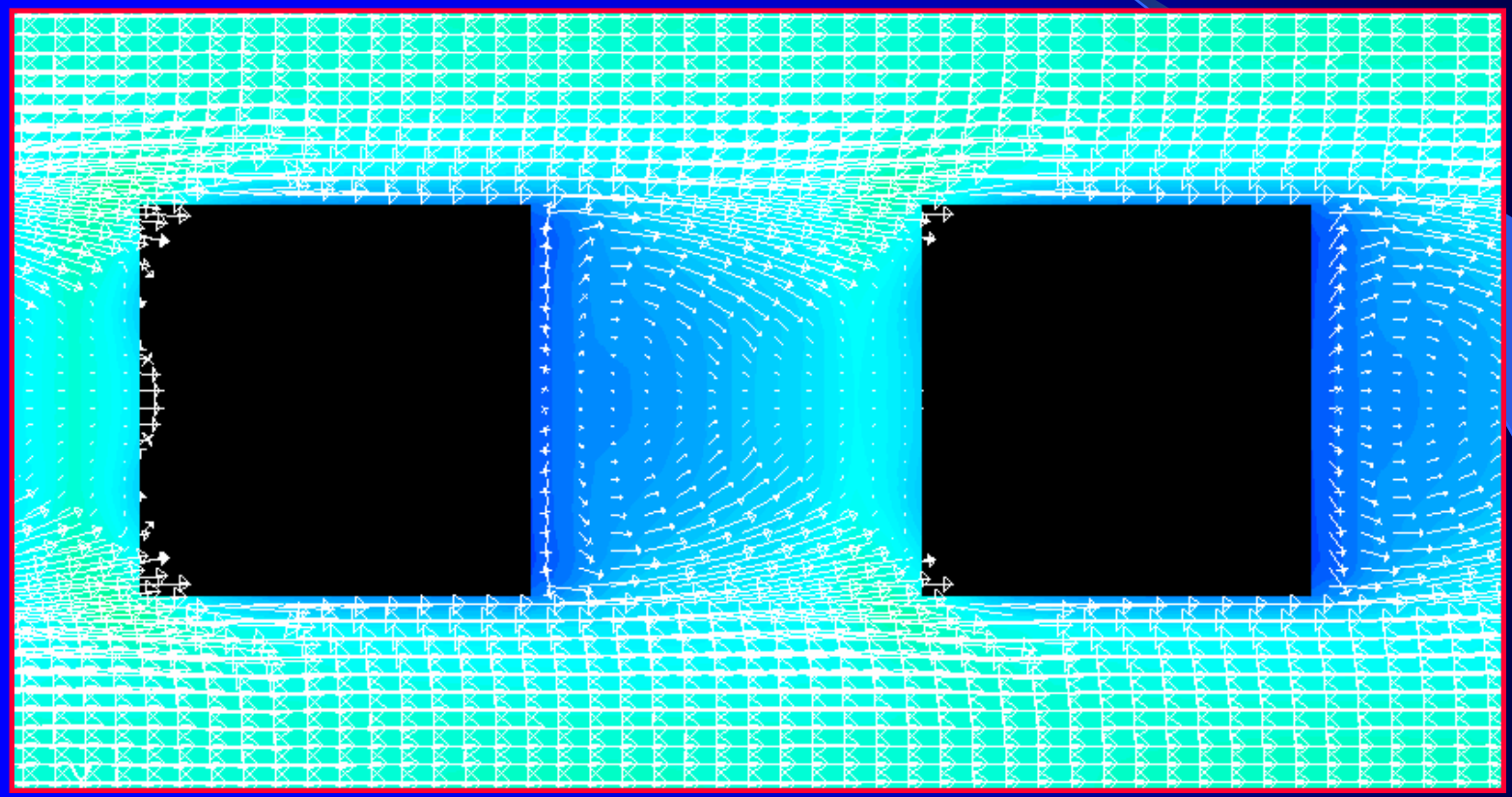
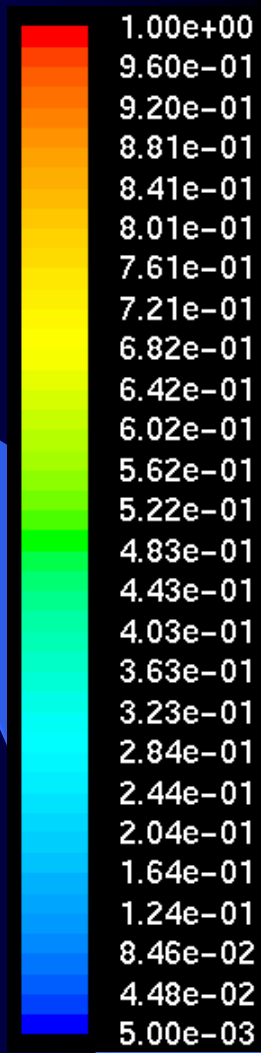
Z/H = 0.75

- TKE

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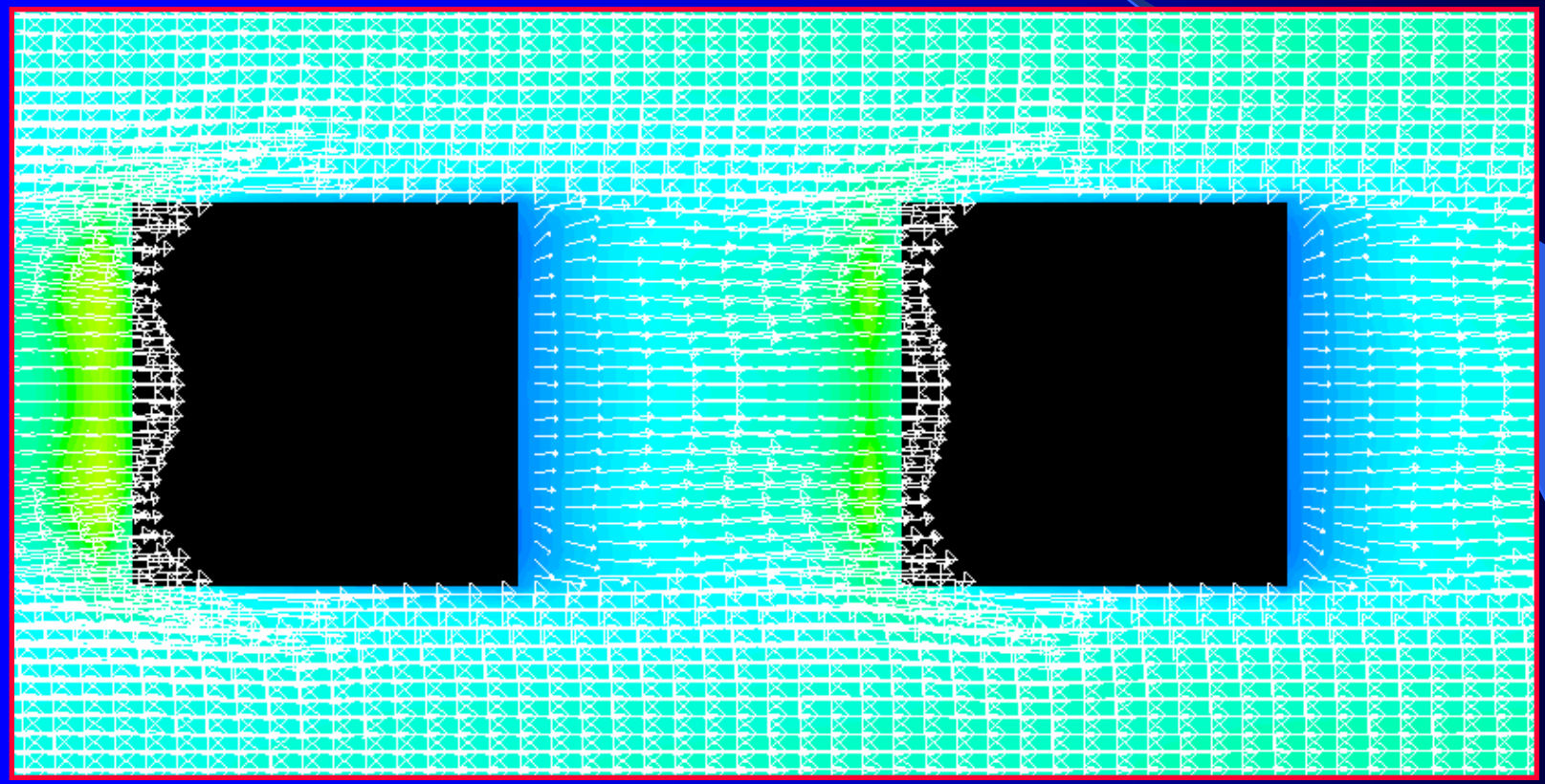
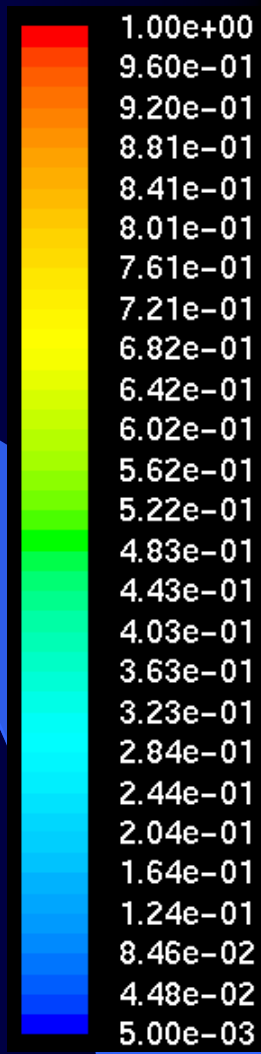
Z/H = 1.0

- TKE

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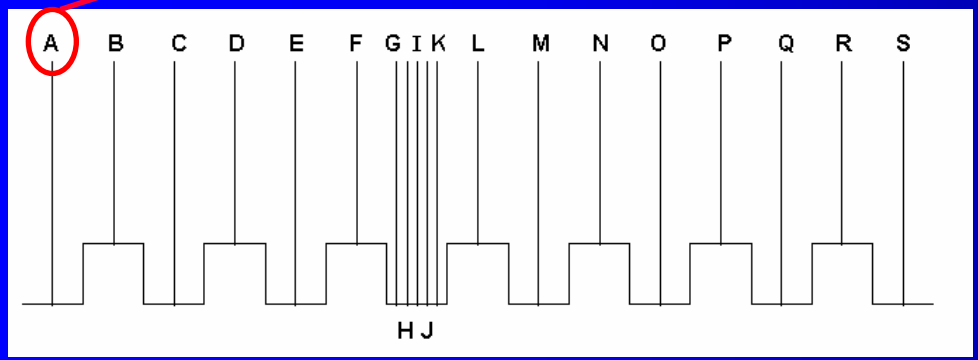
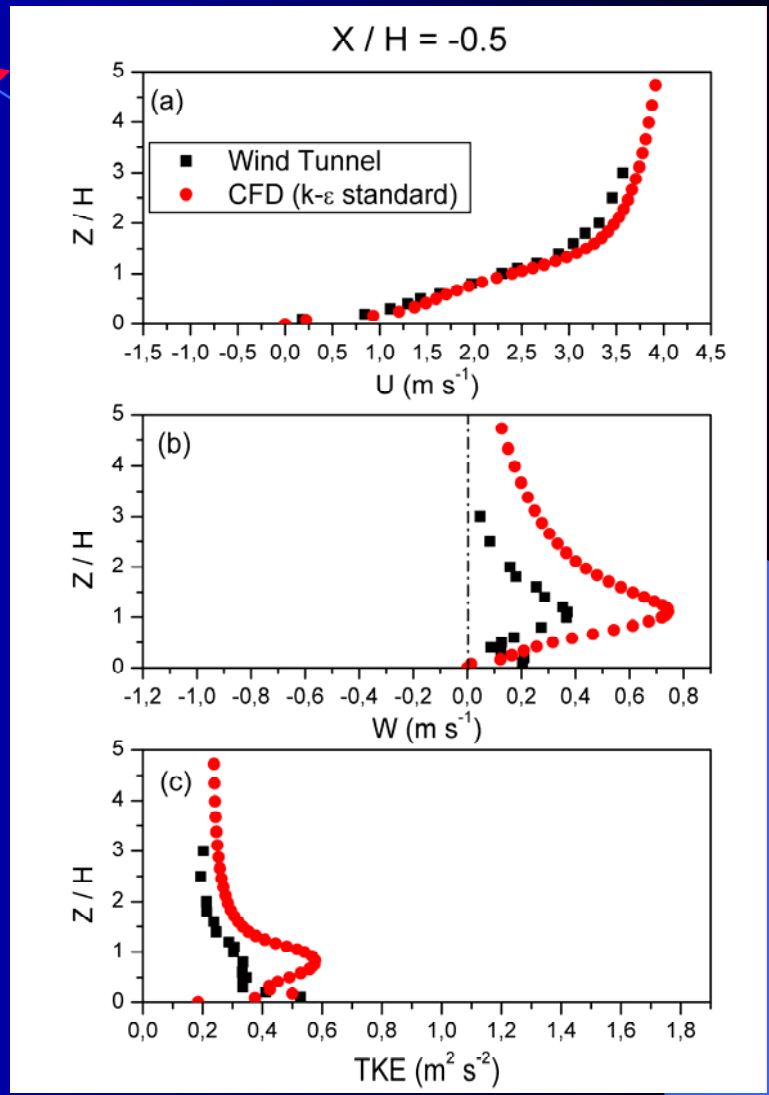
COMPARISON OF VERTICAL PROFILES





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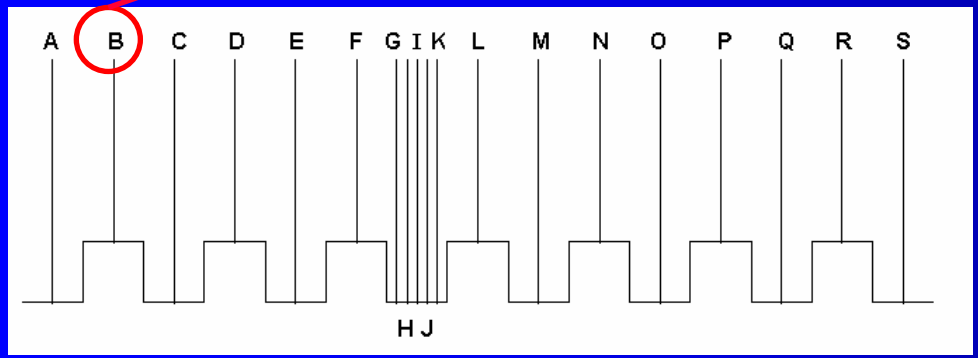

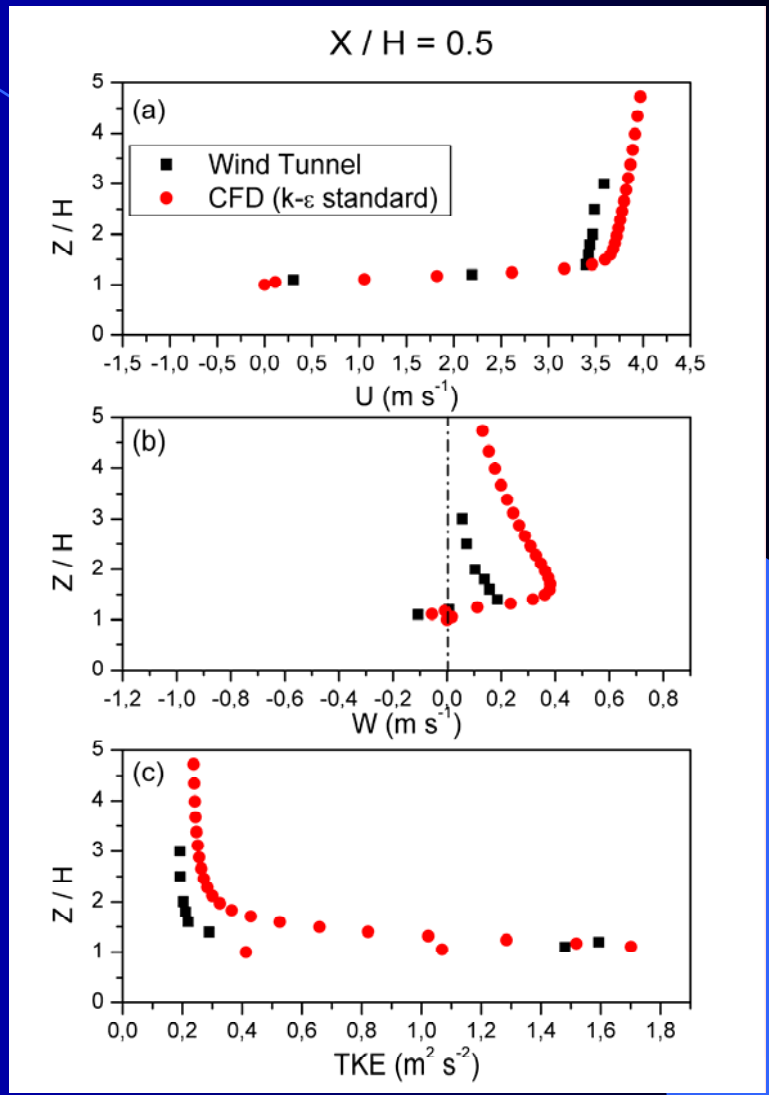

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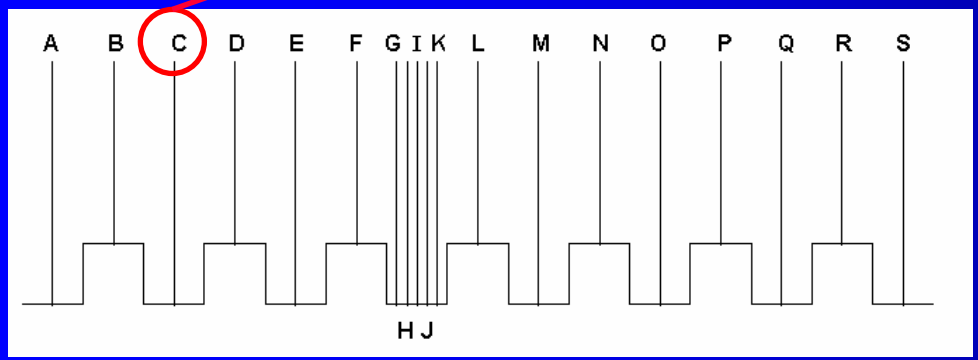
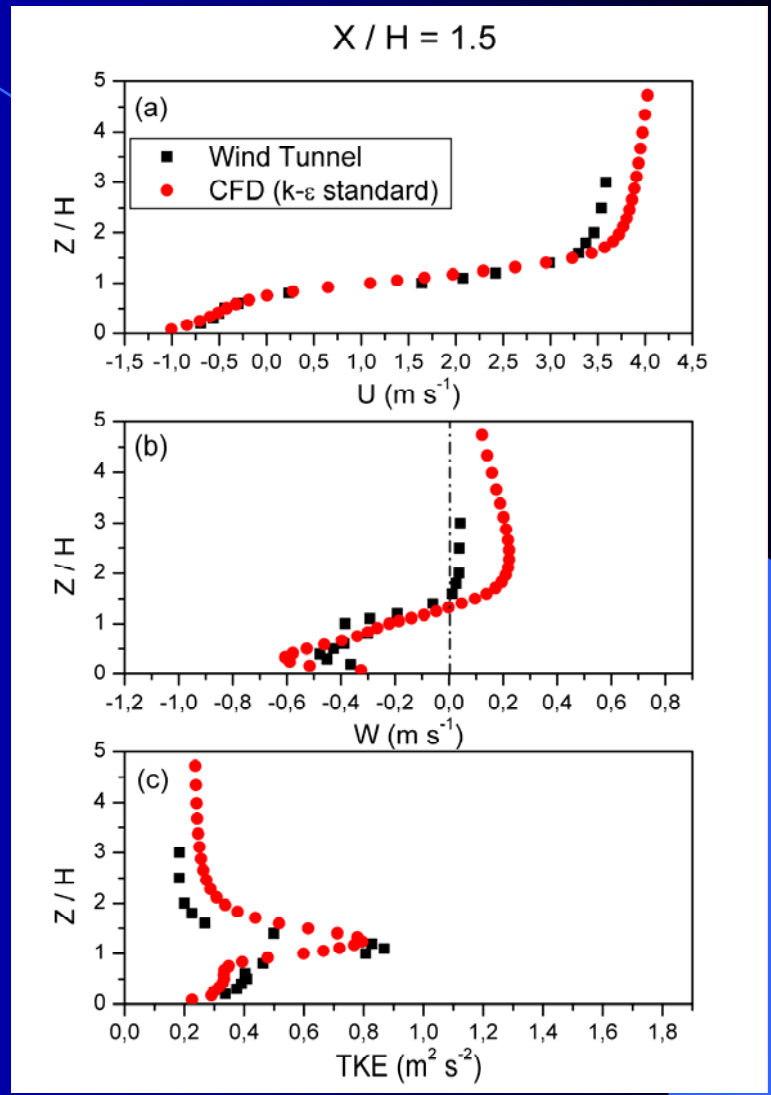
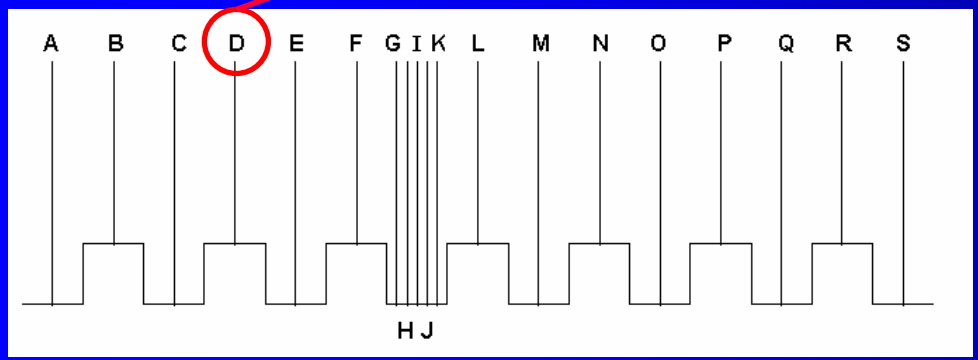
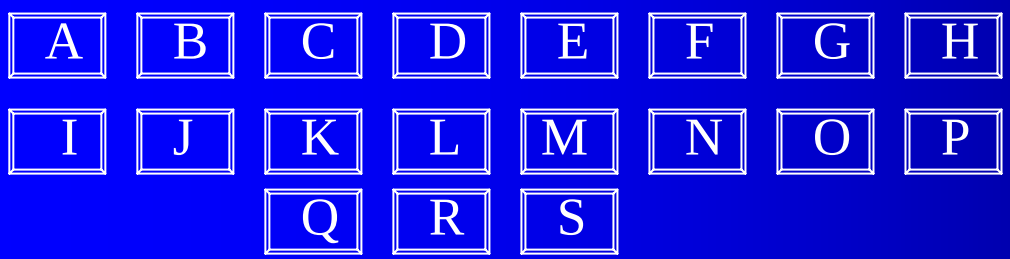
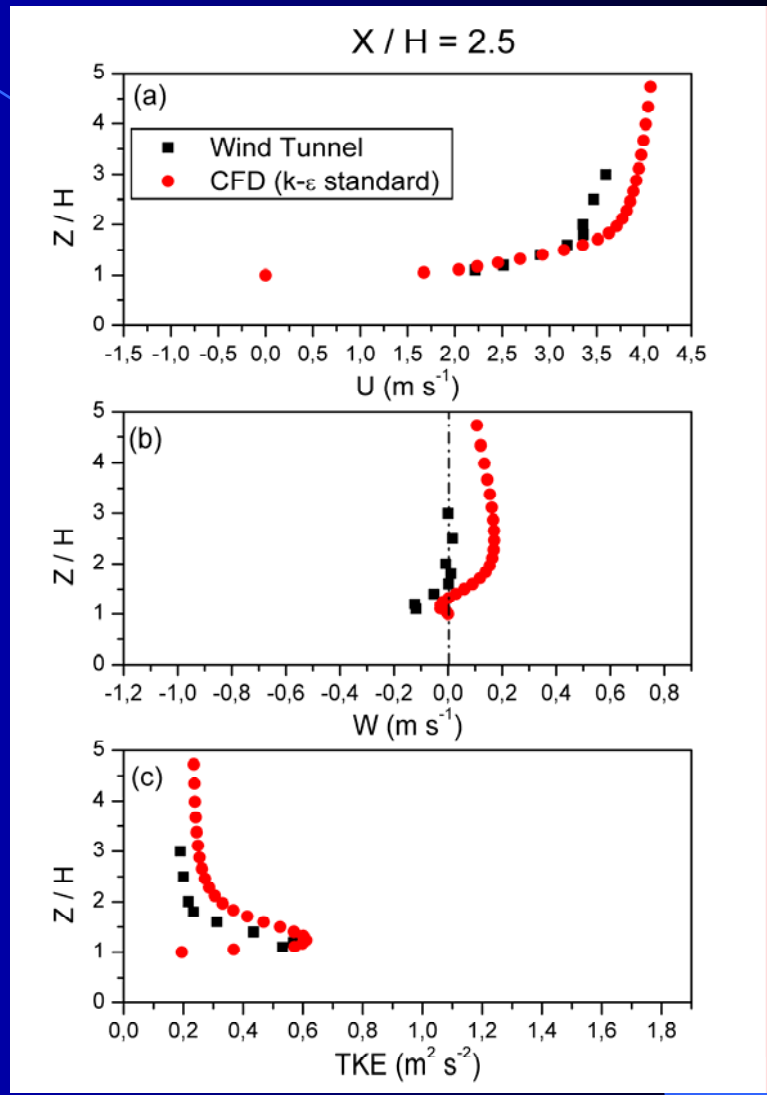




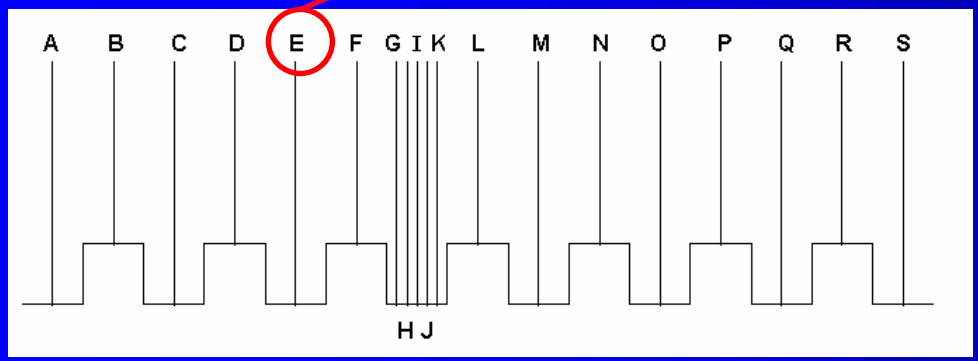
COMPARISON OF VERTICAL PROFILES

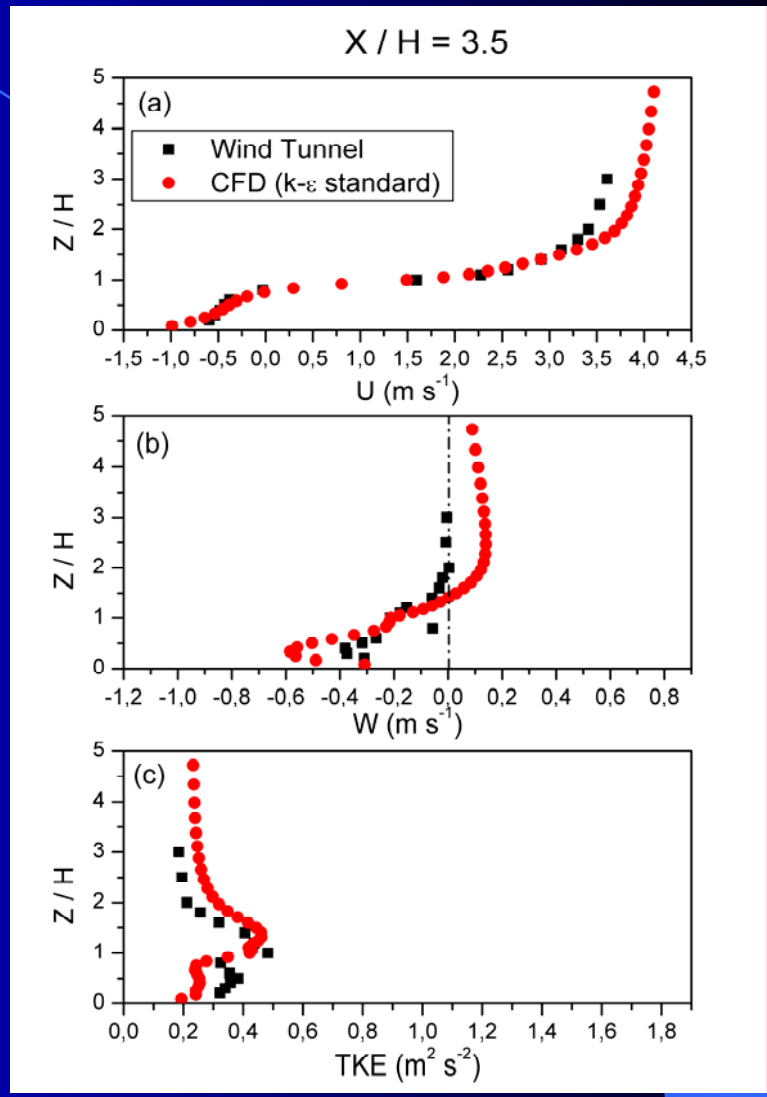




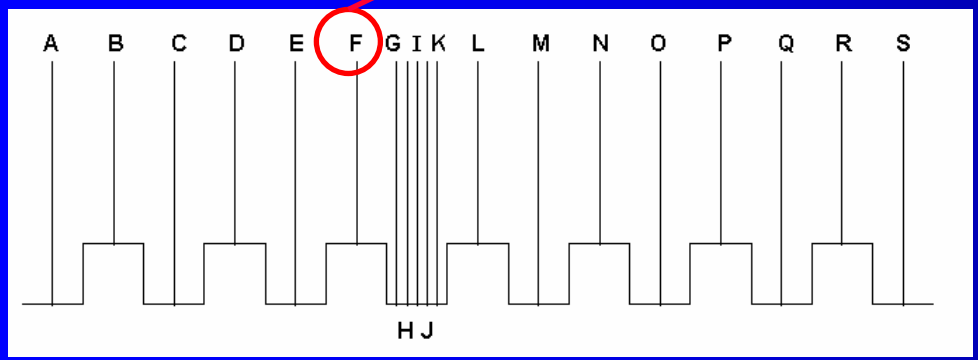


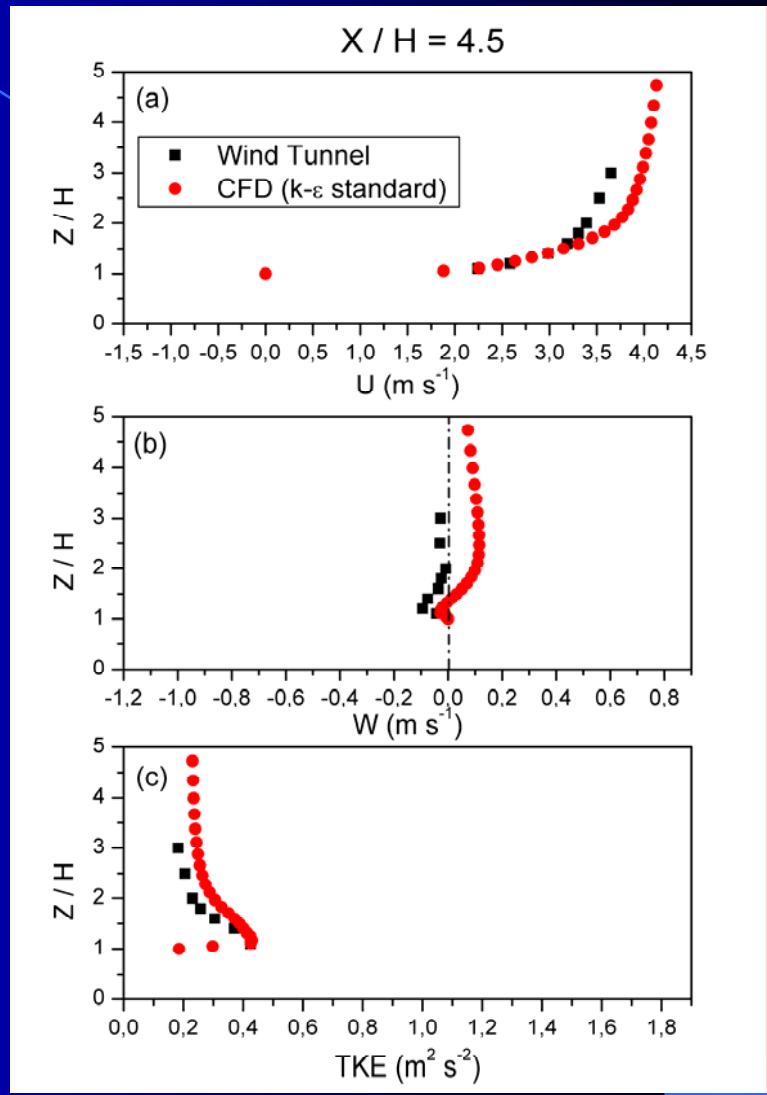
COMPARISON OF VERTICAL PROFILES



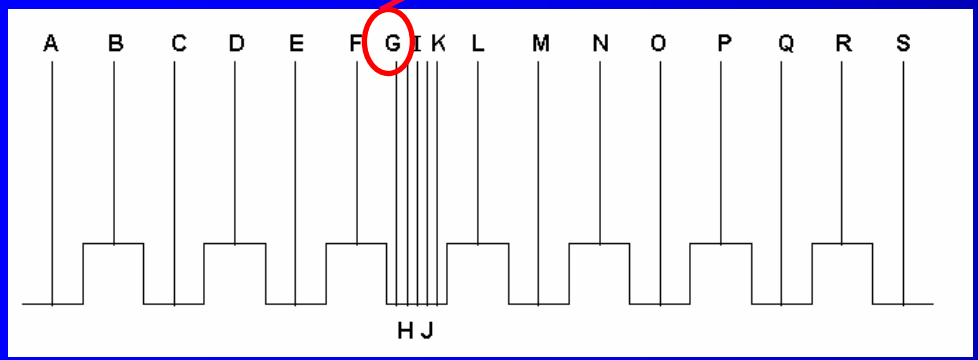


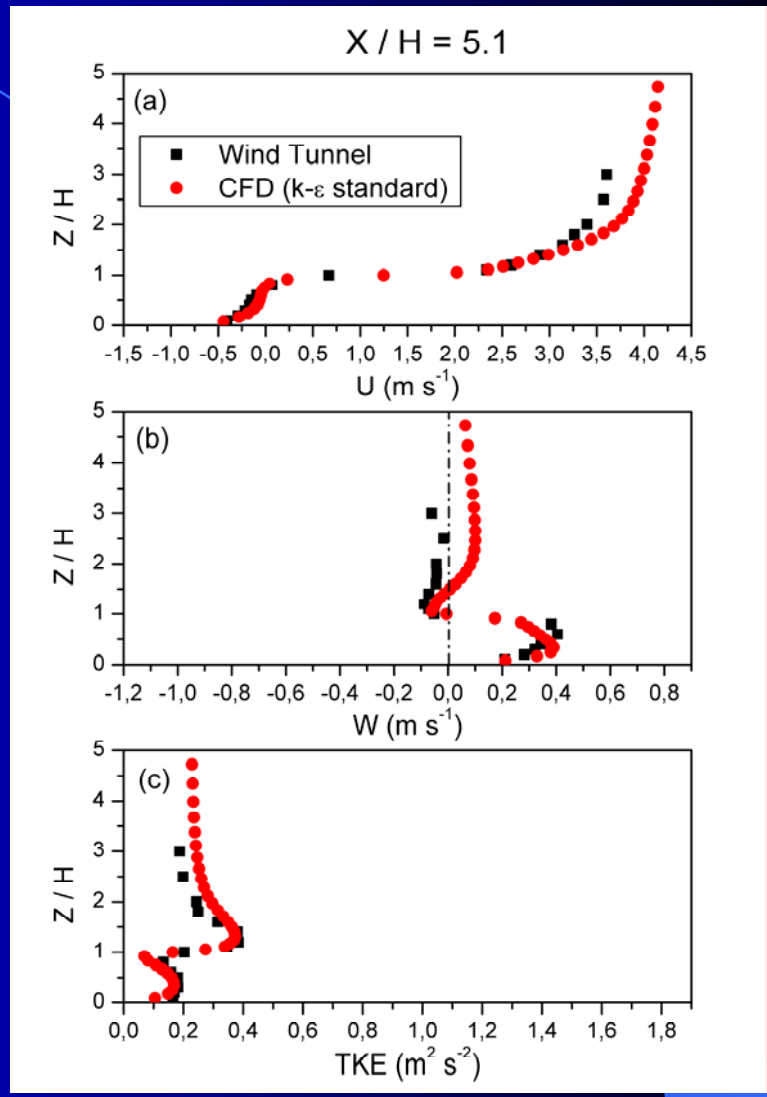
COMPARISON OF VERTICAL PROFILES



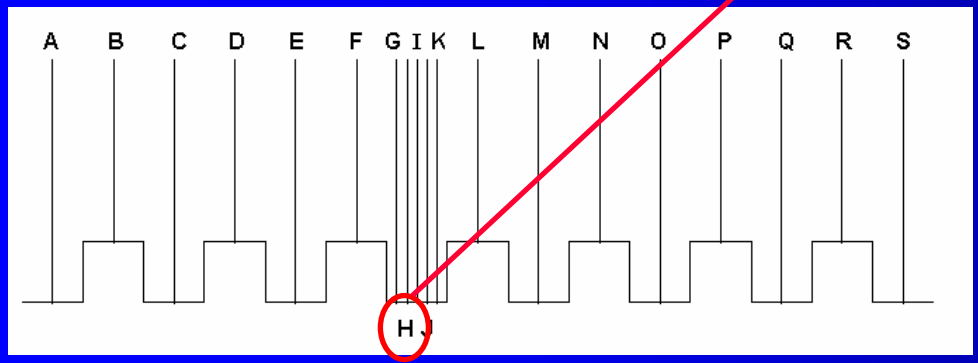


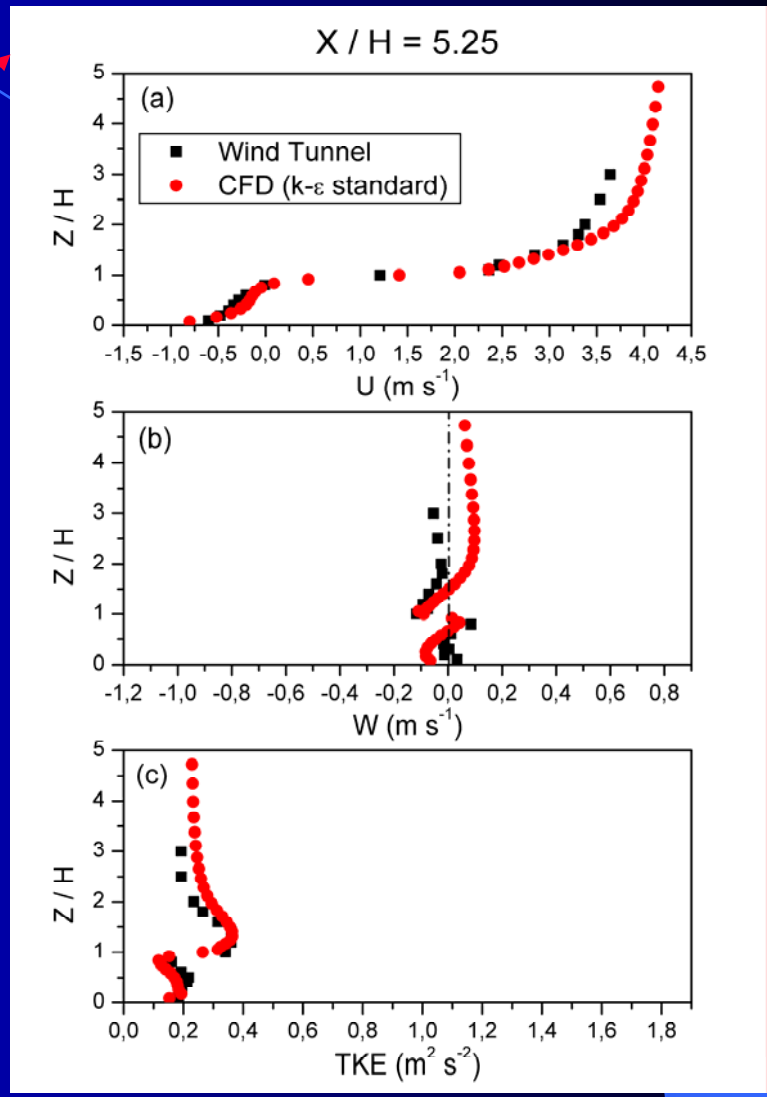
COMPARISON OF VERTICAL PROFILES





COMPARISON OF VERTICAL PROFILES





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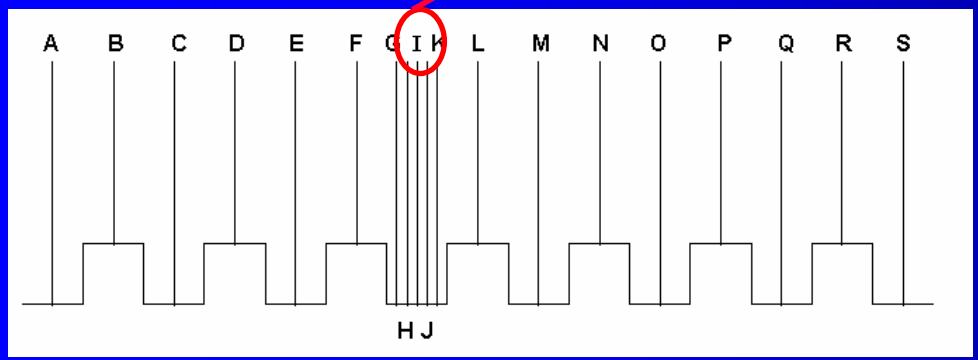

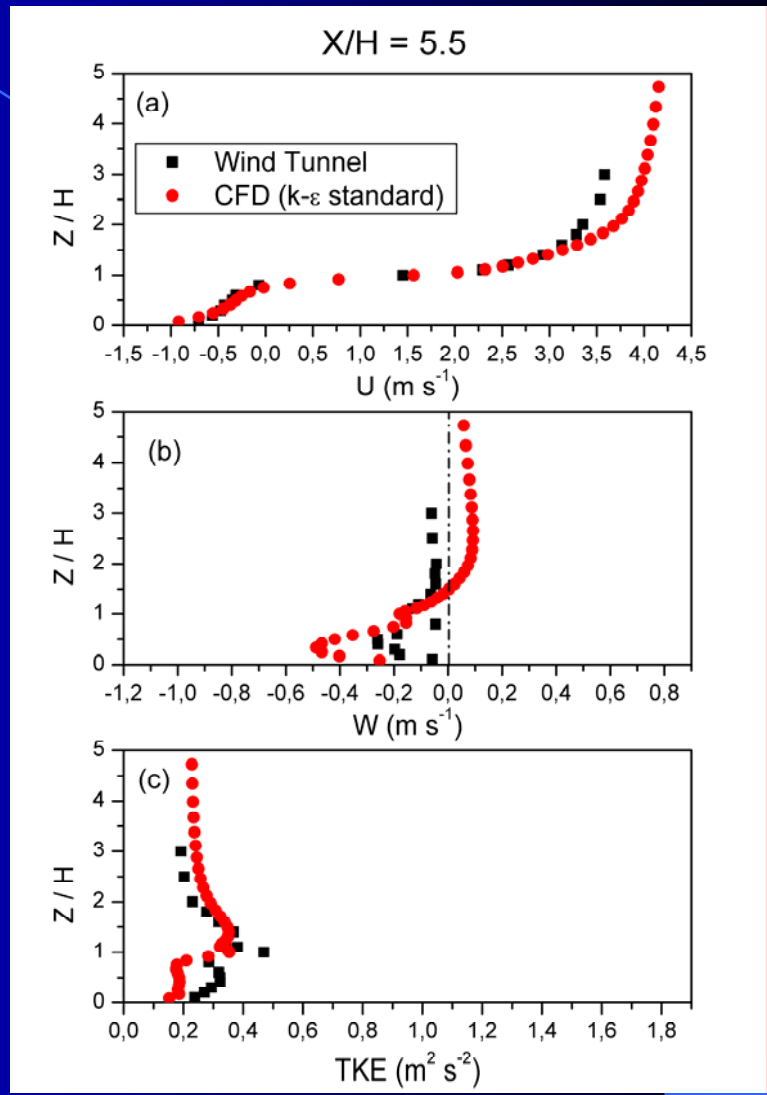

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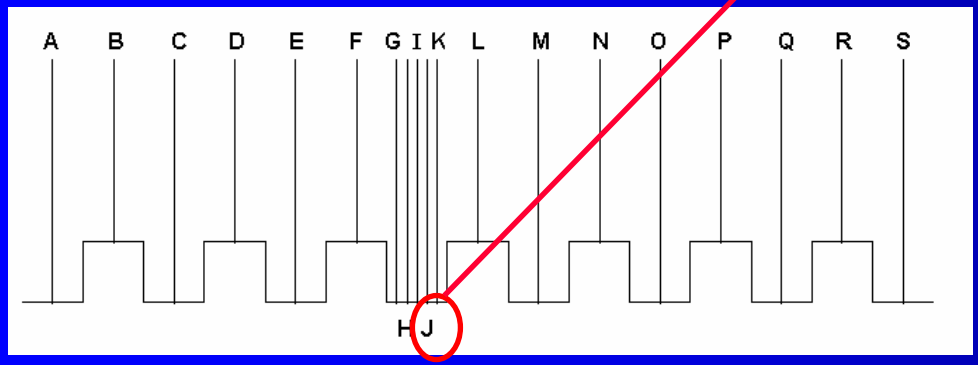

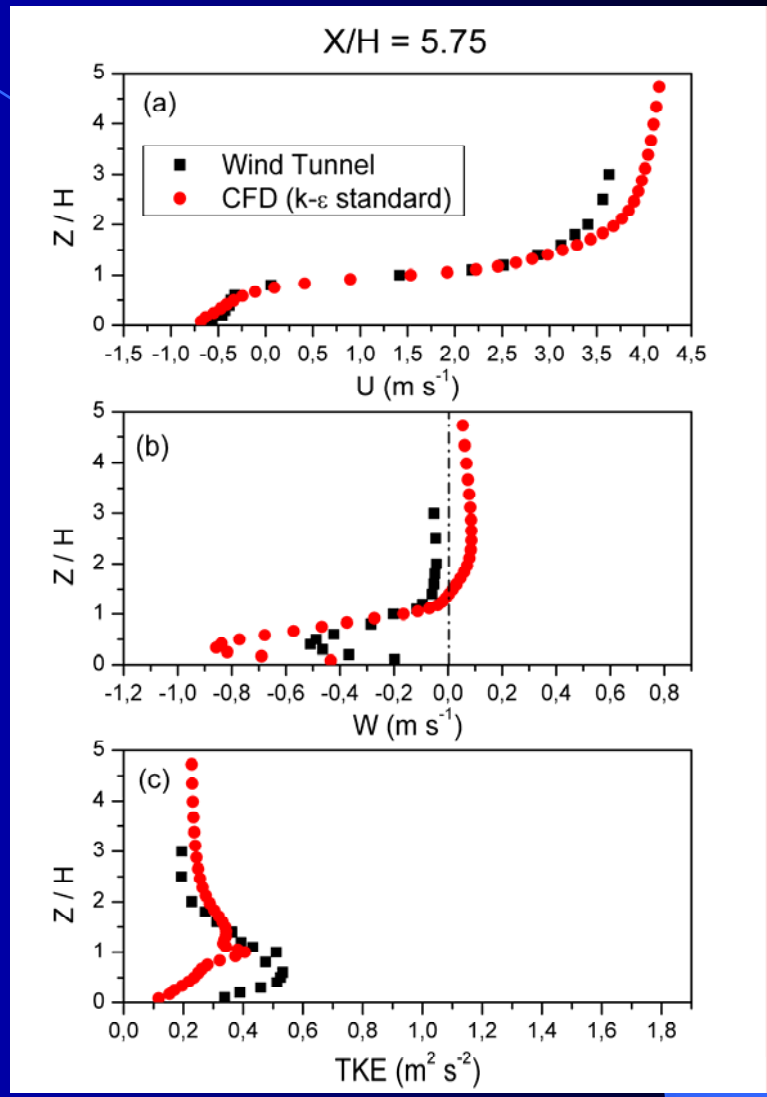

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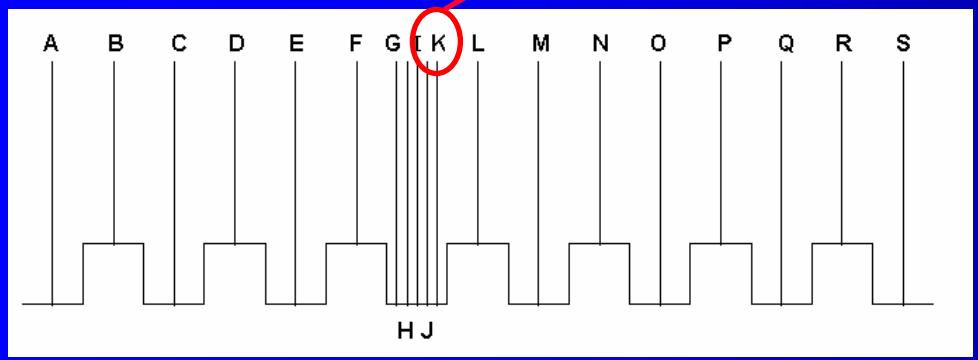

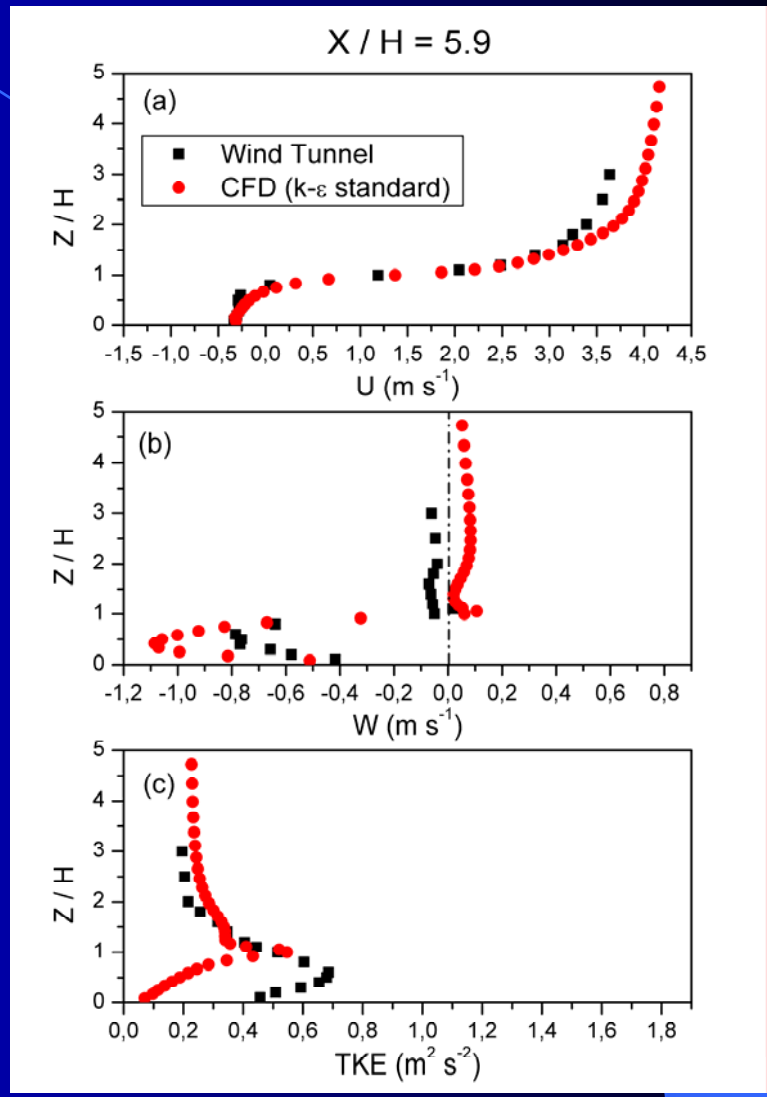

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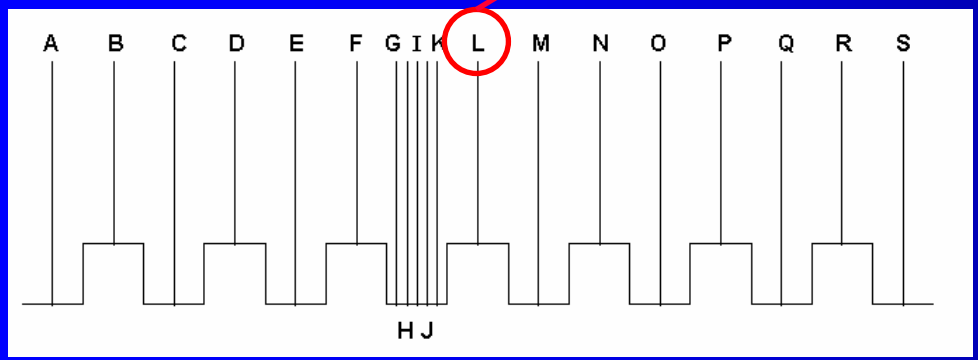

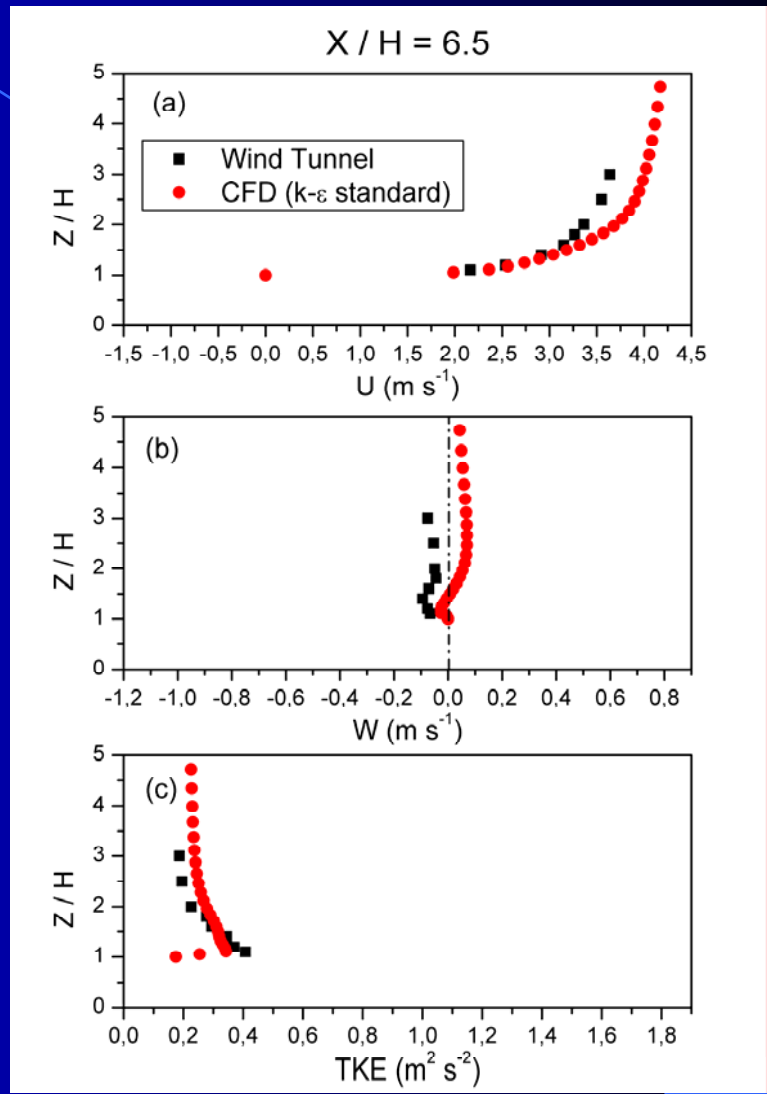

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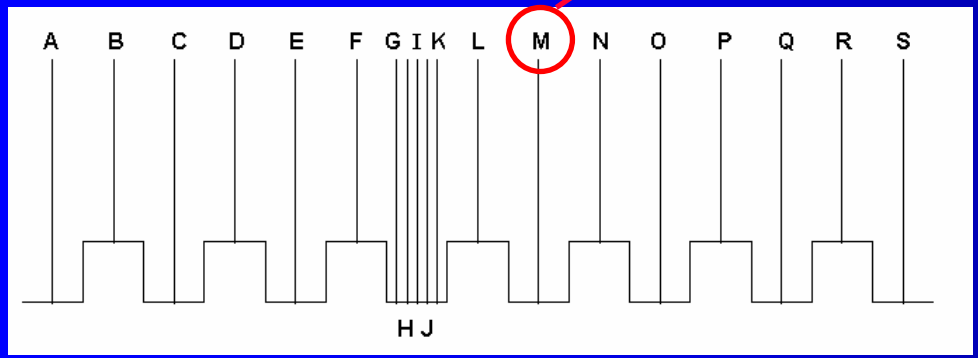

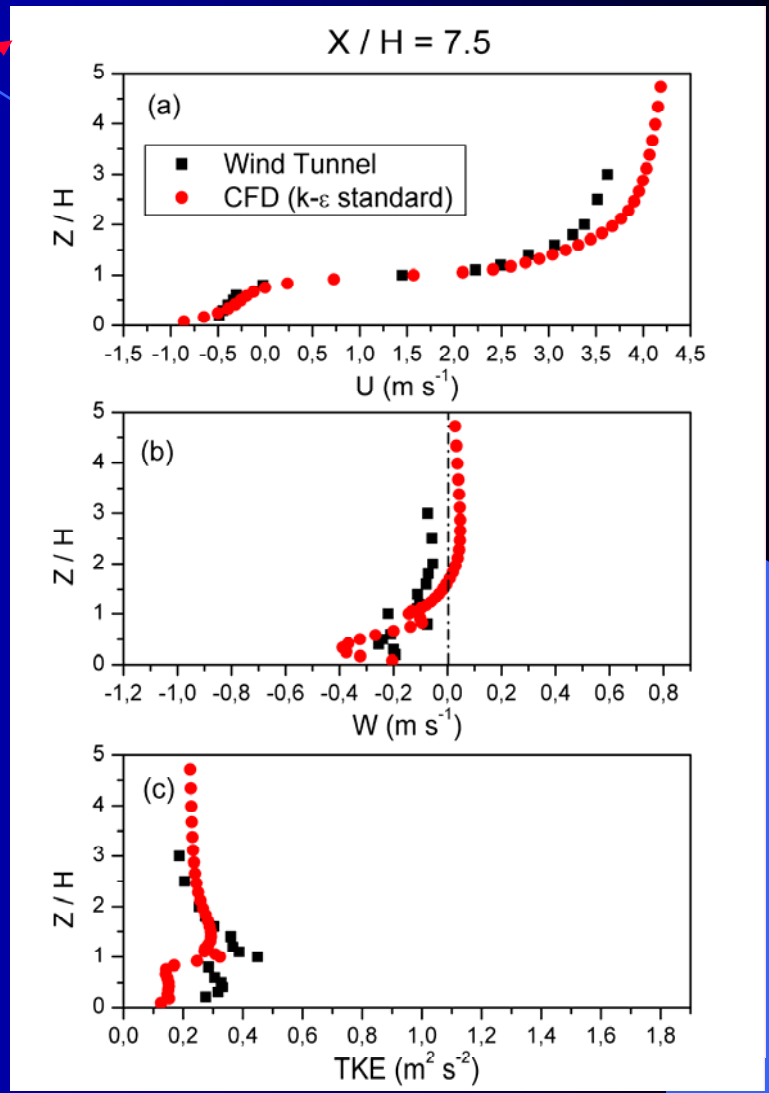

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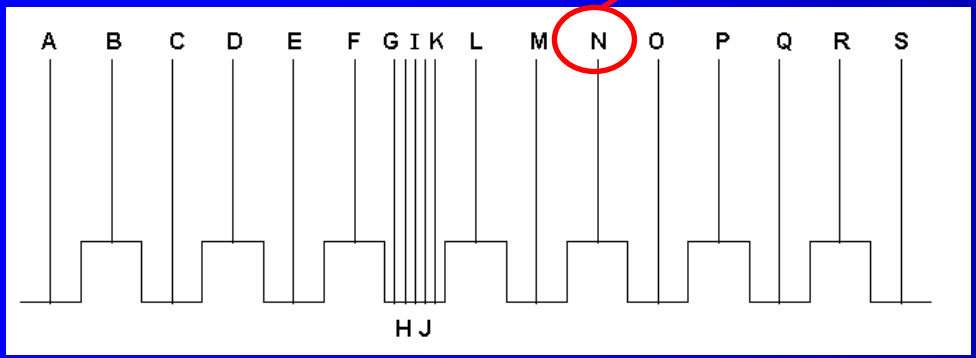

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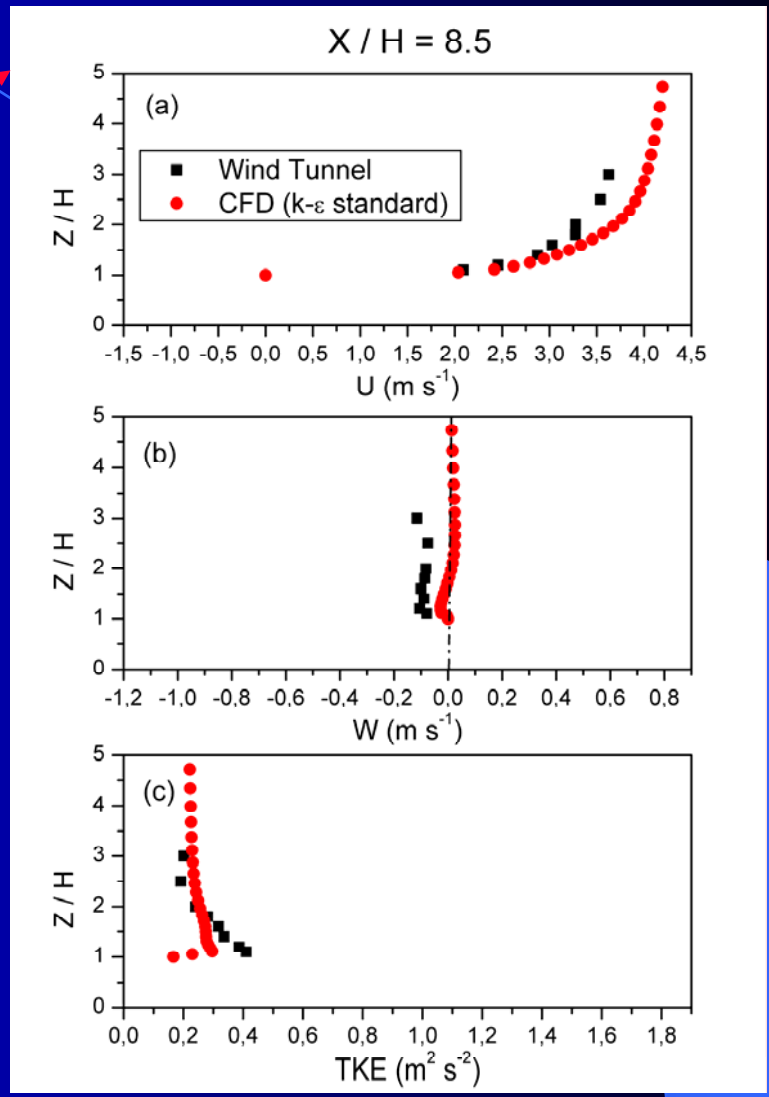
I J K L M N O P
Q R S



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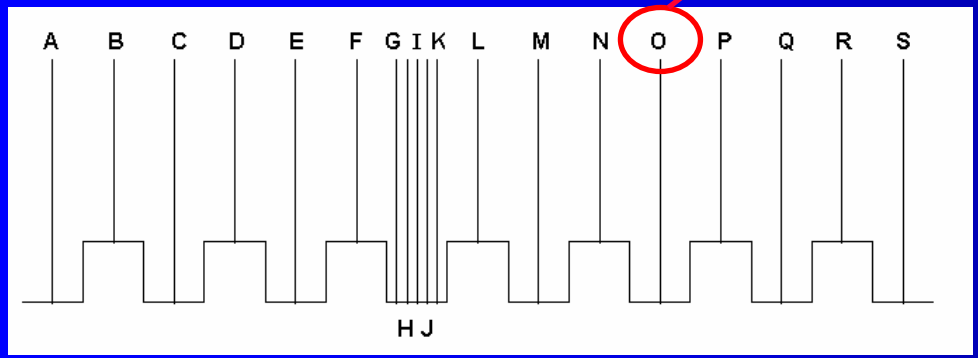

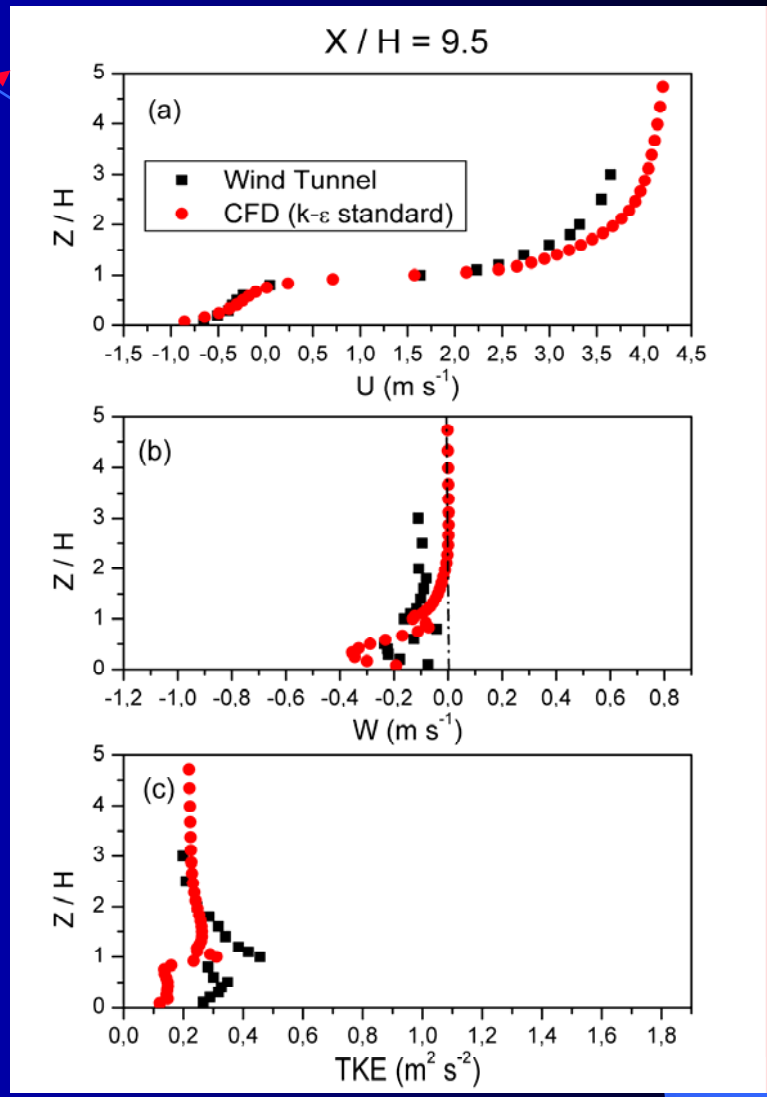

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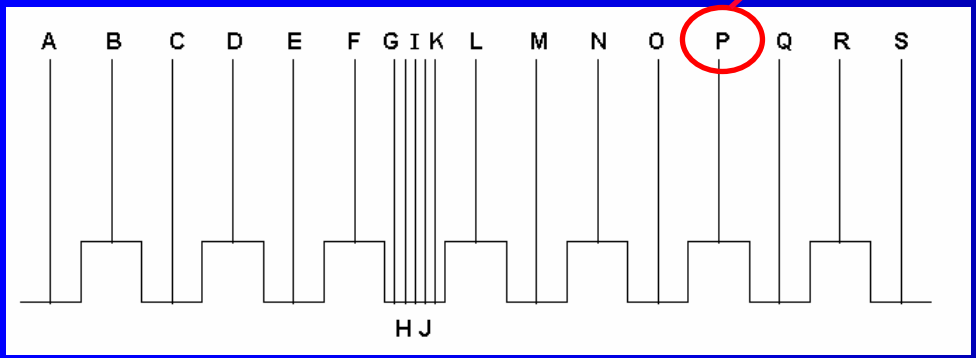
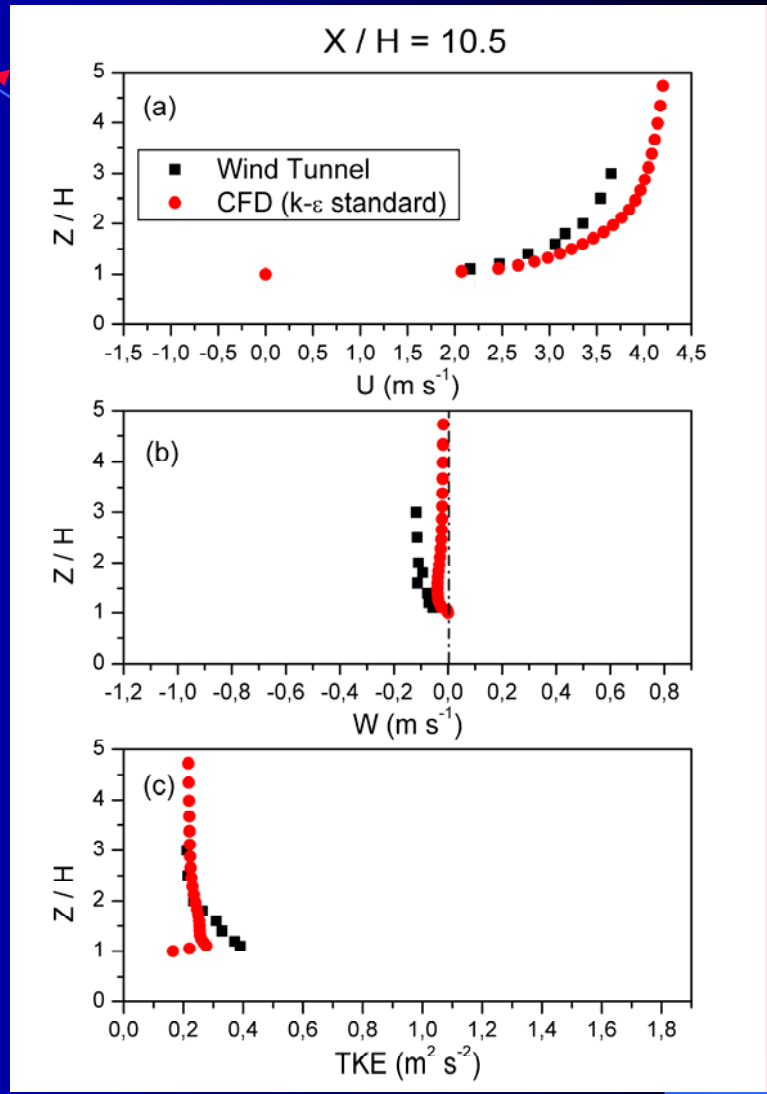
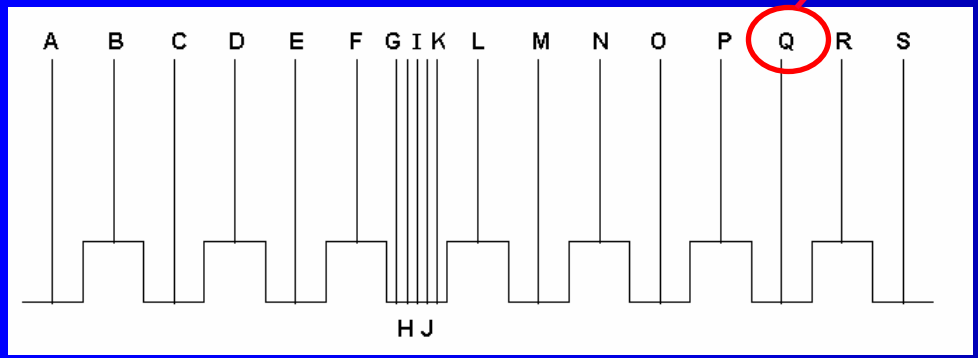
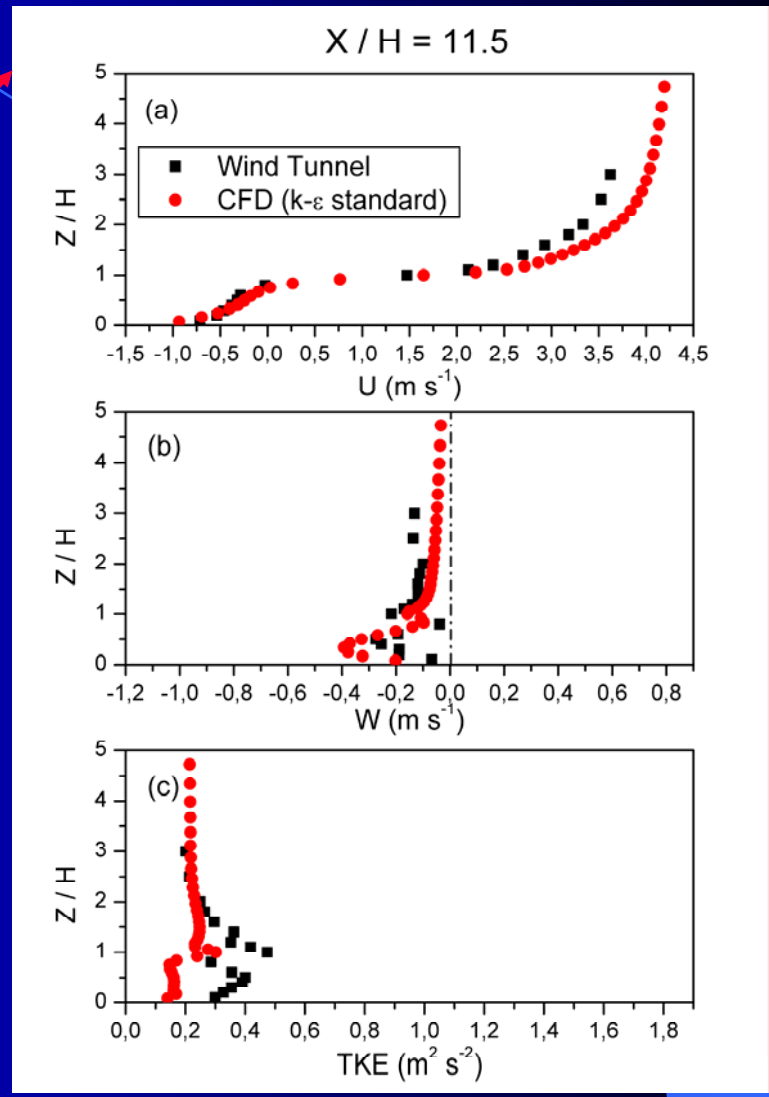




COMPARISON OF VERTICAL PROFILES





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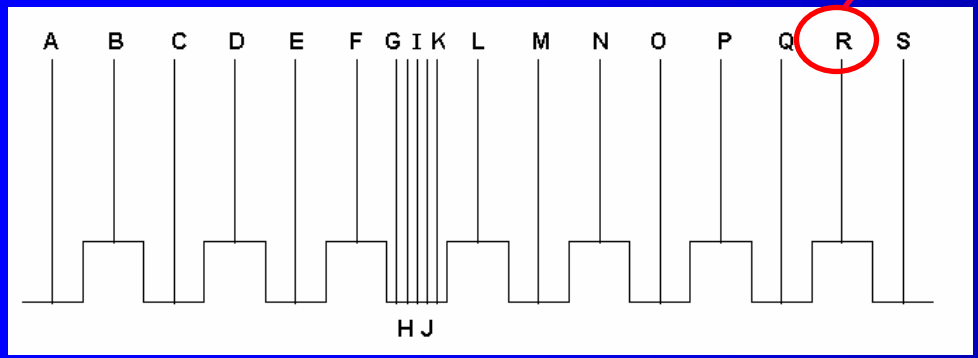
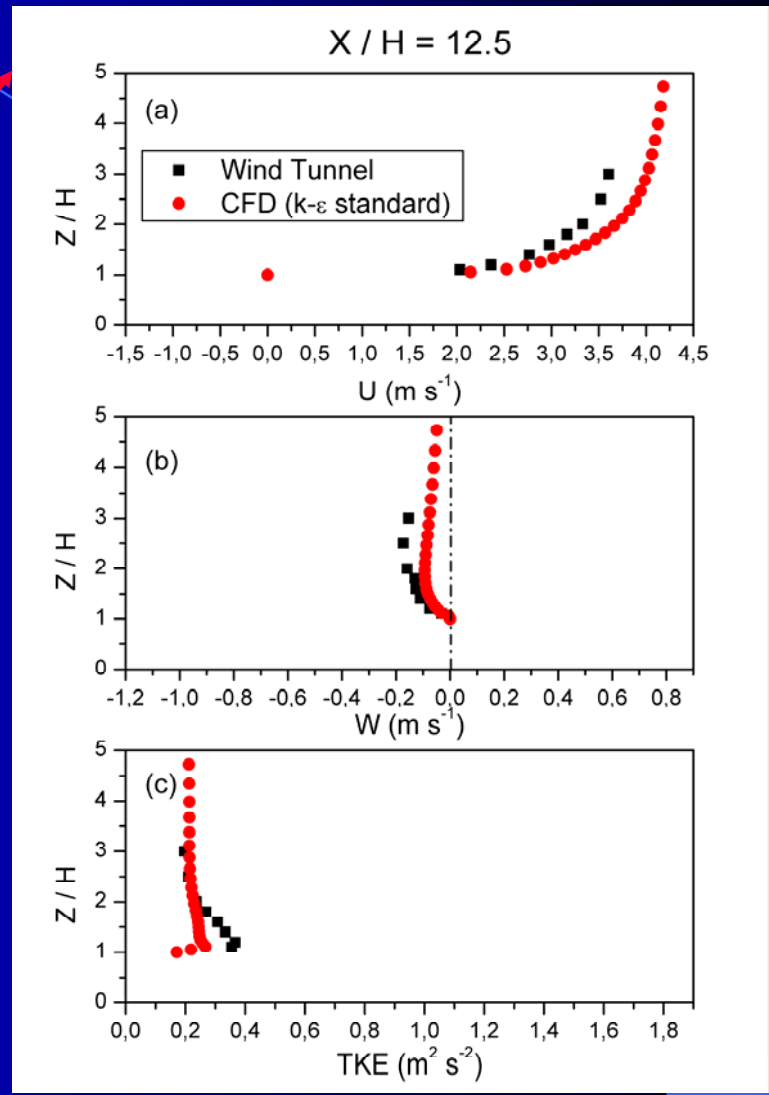


A	B	C	D	E	F	G	H
I	J	K	L	M	N	O	P
		Q	R	S			



COMPARISON OF VERTICAL PROFILES