Centre Tecnològic de Transferència de Calor
UNIVERSITAT POLITÈCNICA DE CATALUNYA

# An Efficient Strategy of Parcel Modeling for Polydispersed Multiphase Turbulent Flows

**Linda Bahramian**, Jordi Muela, Carles Oliet,
C.David Pérez-Segarra and F.Xavier Trias

Heat and Mass Transfer Technological Center (CTTC), Universitat Politècnica de Catalunya – Barcelona Tech (UPC), ESEIAAT, Terrassa (Barcelona), Spain

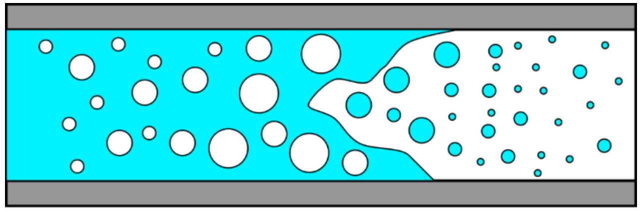
Email: linda.bahramian@upc.edu

ECCOMAS CONGRESS 2022

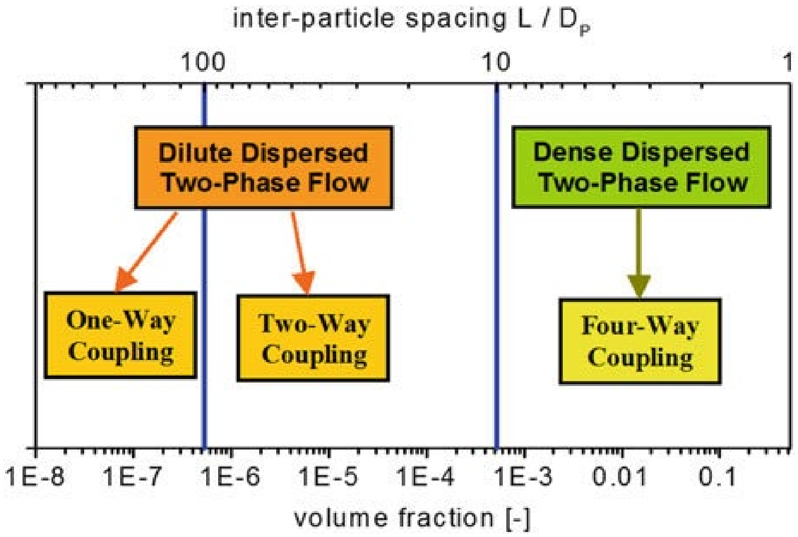
8th European Congress on Computational Methods in Applied Sciences and Engineering

5-9 June 2022, Oslo, Norway

- composed of a **continuous phase** and a **dispersed phase** in the form of unconnected particles or droplets.
- Using **Eulerian-Lagrangian** method (particle tracking)
- That is the best-suited for dispersed multiphase flows with **thousands or millions of particles**, and with a flow regime ranging from the very **dilute** up to relatively **dense**.
- to simulate the **fuel injection of combustion chambers**, **cyclone separators**, **evaporative cooling**, **dispersion of pollutants**, **deposition of inhaled medicine** in the human airways



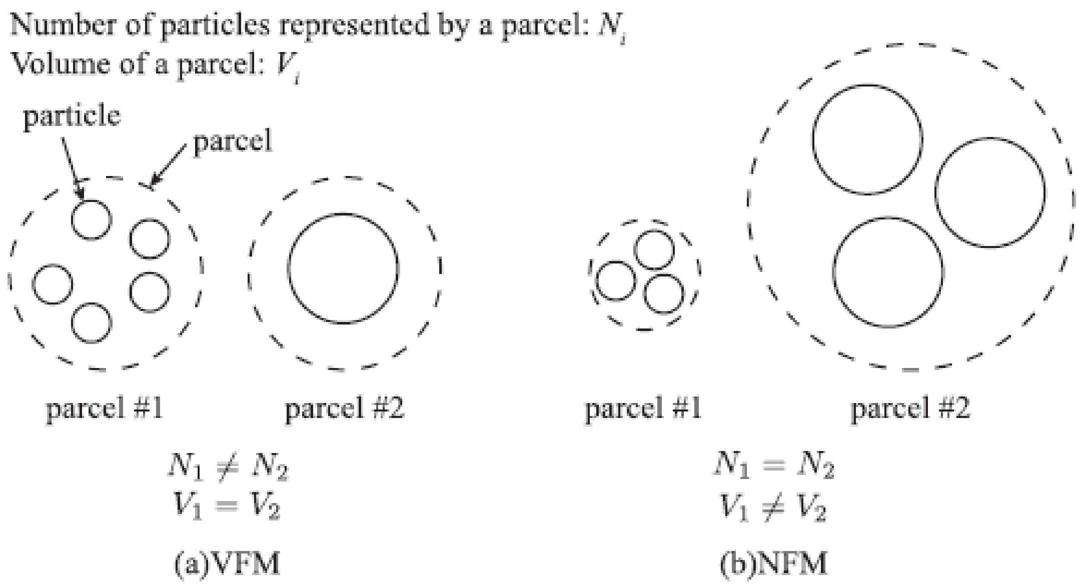

## Coupling Between Particles and Fluid:




$$\phi_p = \frac{V_p}{V}$$

## Using Parcels:

- In order to decrease the **computational cost** due to tracking each particles
- Each **parcel** represents the specified number of particles with the same properties
- two methods for arranging the particles in parcels: Number fixed method, **NFM** and Volume fixed method, **VFM**
- With increasing the volume for the **VFM** the results are not accurate for the **smaller particles**
- With increasing the Number of particles per parcel for **NFM** the results are not accurate for the **bigger particles**




## The Objective:

- Implementing a new approach **NFM-VFM** which is a combination of **NFM** and **VFM**

## Dispersed phase:

**Particle Equations of Motion:**

$$\frac{d\mathbf{x}_\mathbf{p}^\mathbf{n}}{dt} = \mathbf{v}_\mathbf{p}^\mathbf{n} \qquad m_\mathrm{p}^n \frac{d\mathbf{v}_\mathbf{p}^\mathbf{n}}{dt} = \sum_i \mathbf{F}_\mathbf{i}$$

for simplicity is assumed that the drag force is the only significant fluid-particle interaction force:

$$m_\mathrm{p}^n \frac{d\mathbf{v}_\mathbf{p}^\mathbf{n}}{dt} = m_\mathrm{p}^n \frac{\beta^n \left[\mathbf{u}(\mathbf{x}_\mathbf{p}^\mathbf{n}) - \mathbf{v}_\mathbf{p}^\mathbf{n}\right]}{\rho_\mathrm{p}} \qquad \beta^n = \frac{3}{4}\frac{C_D \rho}{d_\mathrm{p}} \left|\mathbf{u}(\mathbf{x}_\mathbf{p}^\mathbf{n}) - \mathbf{v}_\mathbf{p}^\mathbf{n}\right|$$

## Continuous phase:

- **Convective operator:** Symmetry-preserving scheme
- **Pressure-velocity coupling:** Fractional step method
- **Poisson equation:** iterative Conjugate-Gradient (CG) method with Jacobi preconditioner

**Continuity equation:**

$$\nabla \cdot \mathbf{u} = 0$$

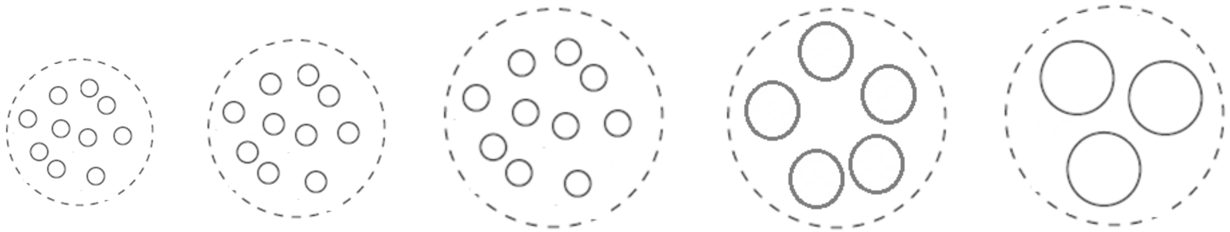
**Momentum equation:**

$$\rho\left[\frac{\partial \mathbf{u}}{\partial t} + \nabla \cdot (\mathbf{u}\mathbf{u})\right] + \nabla p = \mu \nabla^2 \mathbf{u} + S_u \qquad S_u = -\sum_{n=1}^{N_\mathrm{p}} \frac{m_\mathrm{p}^n \beta^n \left[\mathbf{u}(\mathbf{x}_\mathbf{p}^\mathbf{n}) - \mathbf{v}_\mathbf{p}^\mathbf{n}\right]}{\rho_\mathrm{p}}$$

## Designing new approach NFM-VFM:

- The particles with sizes above the Sauter mean diameter, **SMD**, are arranged with the **VFM** and the rest of them arranged with **NFM**
- Calculating the Sauter mean diameter in terms of a finite number of discrete size classes:
  p = 3 and q = 2

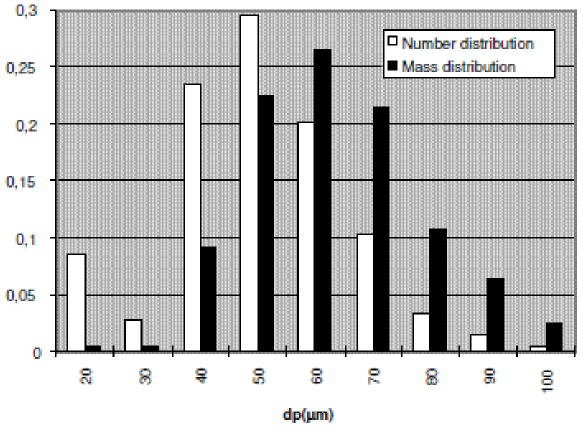
$$D_{pq} = \left[ \frac{\sum_{i=1}^{\infty} n_i D_i^p}{\sum_{i=1}^{\infty} n_i D_i^q} \right]^{1/(p-q)}$$

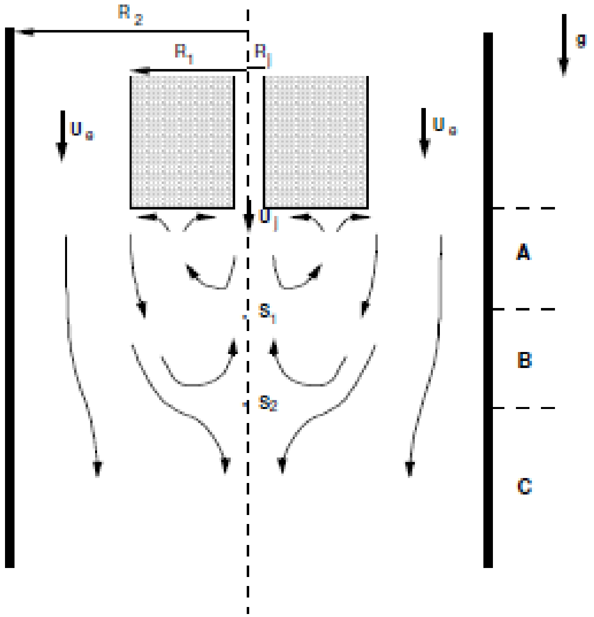


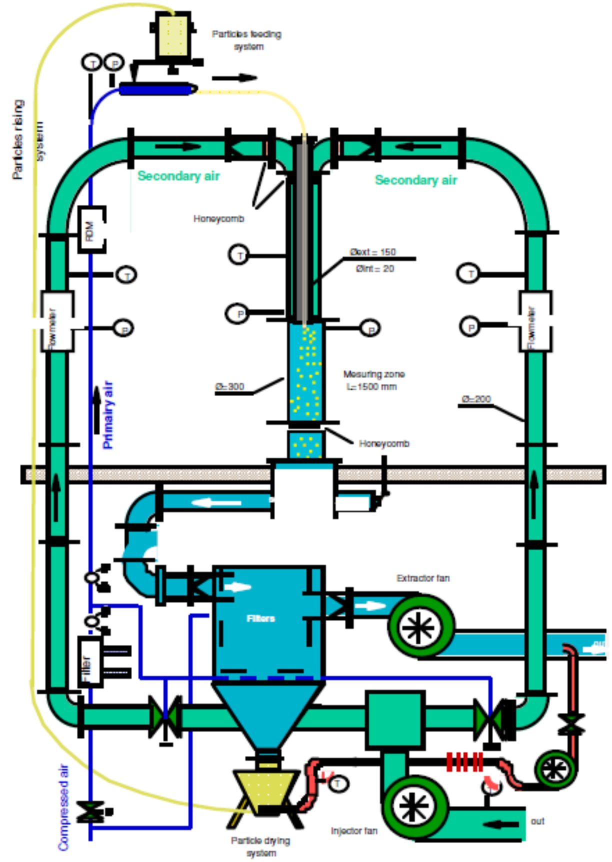
**SMD**

## Benchmark case:

- The flow loop Hercule of Borée et al.[1] which generates an axisymmetric confined bluff body flow
- Particle-laden turbulent flow using two-way coupling approach by means of large eddy simulation (LES)
- Mass loading ratio in the inner jet of M=22%
- Total volume fraction of particles: : $\emptyset_p = 5 \times 10^{-4}$
- Diameter distribution: 20 µm, 30 µm, 40 µm, 50 µm, 60 µm, 70 µm, 80 µm, 90 µm, 100 µm



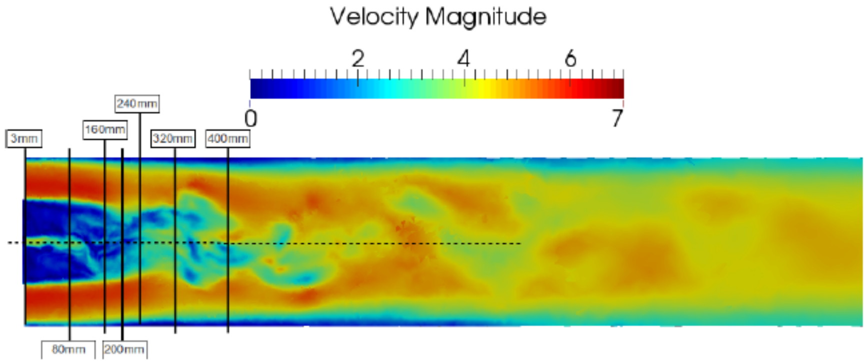




[1] Borée J, Ishima T and Flour I 2001 the effect of mass loading and inter-particle collision on the development of the polydispersed two-phase flow downstrean of a confined bluff body *Journal of Fluid Mchaninics* **443** *129-165*

## Validation:

**Figure.** Radial profiles of **fluid** mean streamwise velocity for particle-laden configuration (M=22%). Circle: Experiment; solid line: Numerical simulation. (a) z=0.08m; (b) z=0.16m; (c) z=0.20m; (d) z=0.24m; (e) z=0.32m; (f) z=0.40m



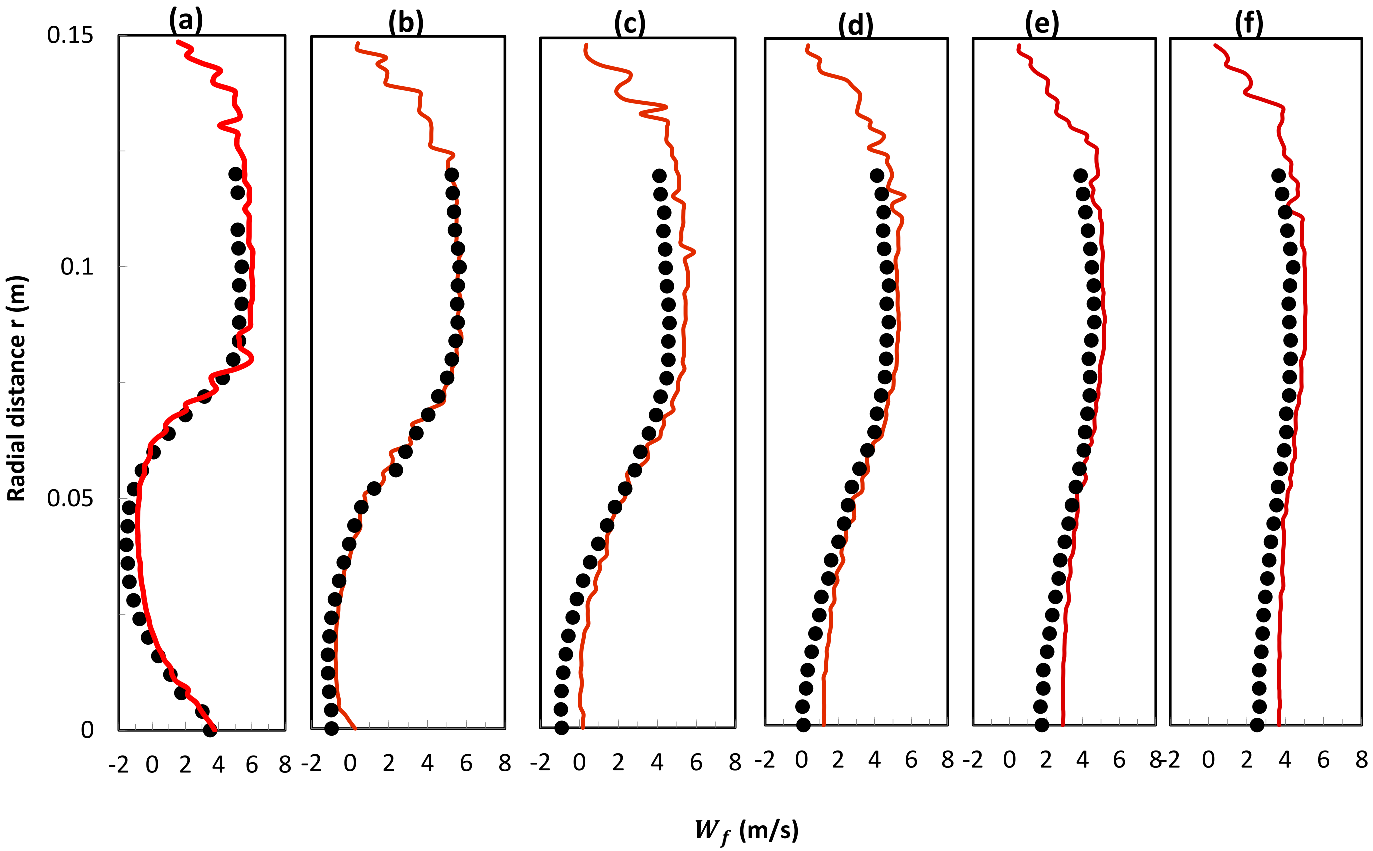
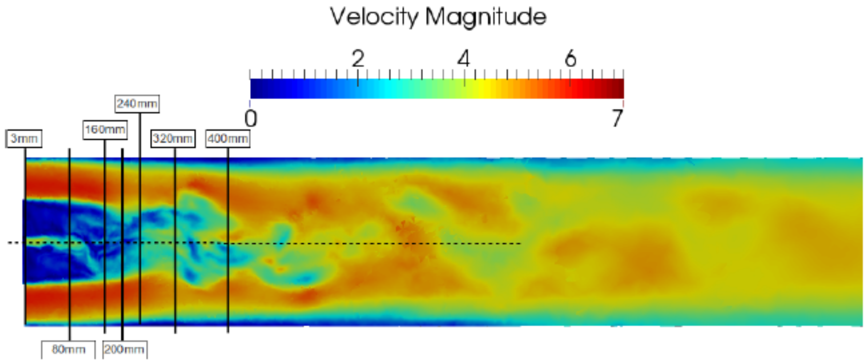
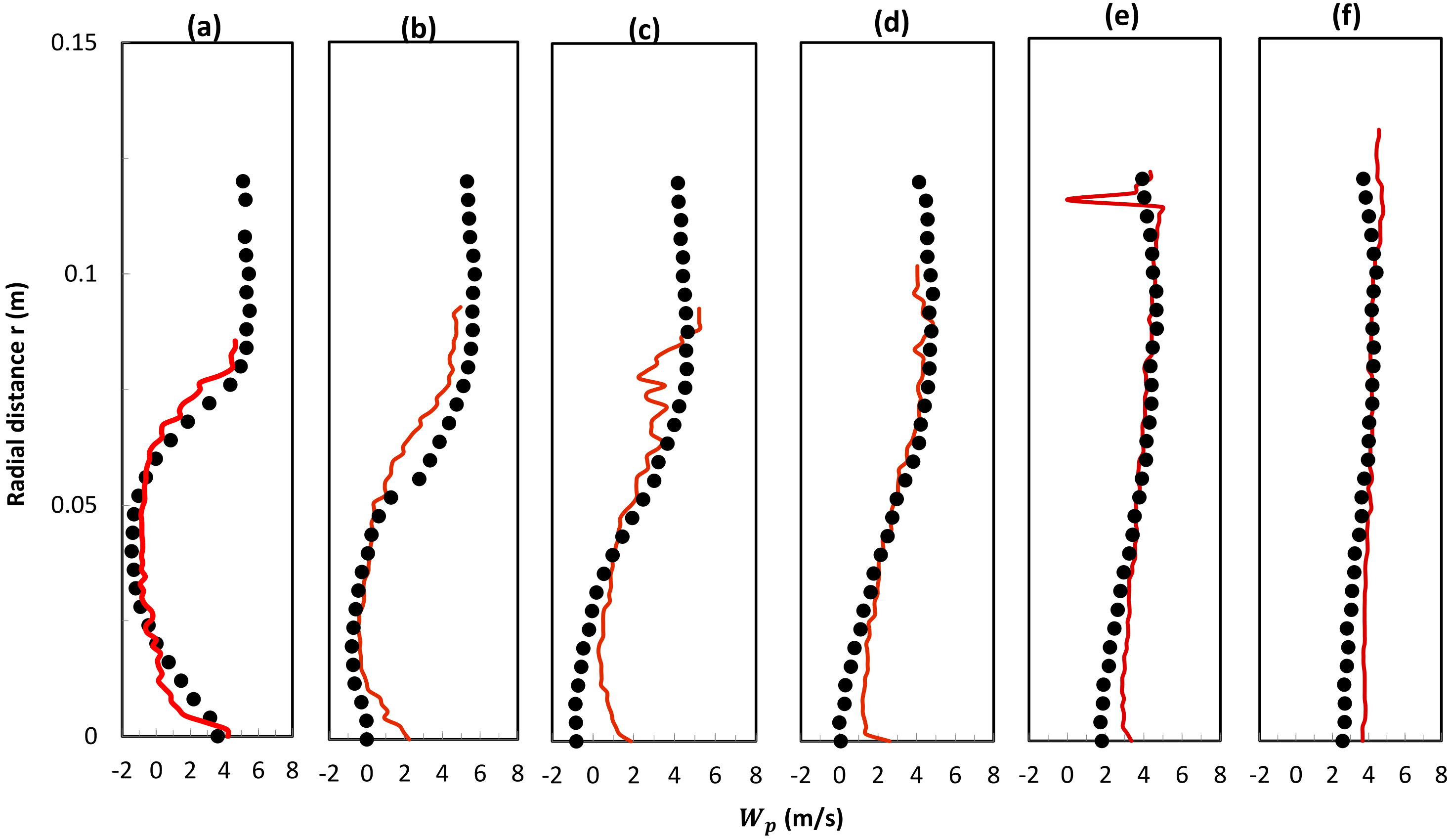



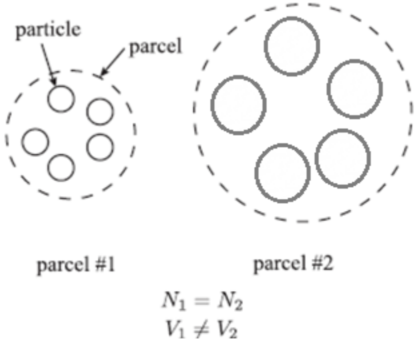
**Figure.** Radial profiles of **particle (dp=20µm)** mean streamwise velocity for particle-laden configuration (M=22%). Circle: Experiment; solid line: Numerical simulation. (a) z=0.08m; (b) z=0.16m; (c) z=0.20m; (d) z=0.24m; (e) z=0.32m; (f) z=0.40m



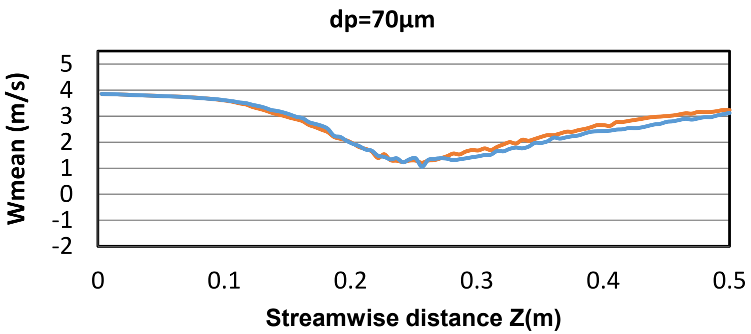



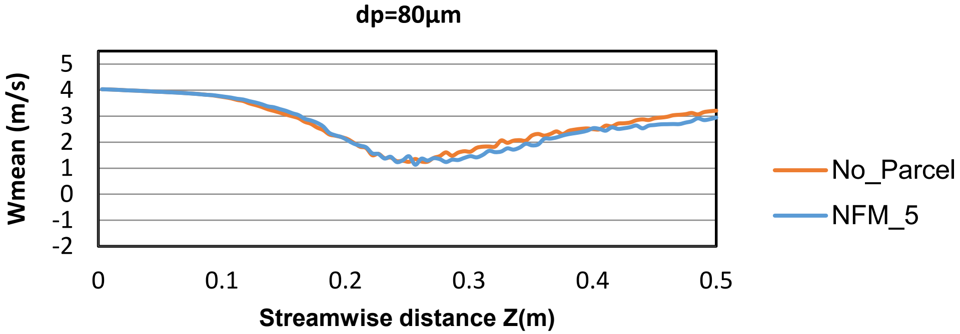
## Implementing new approach NFM-VFM :

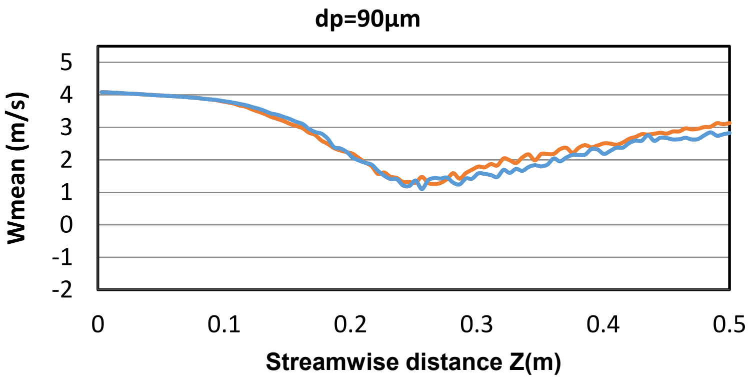
- ✓ By comparing the results of dispersed phase for **the larger diameters** by means of **NFM**
- ✓ **Sauter Mean Diameter = 60 µm**

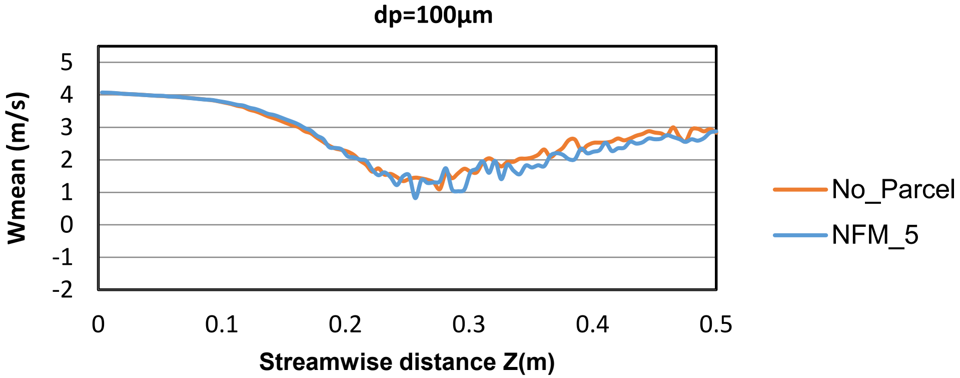



## NFM: Number of particle per Parcel = 5

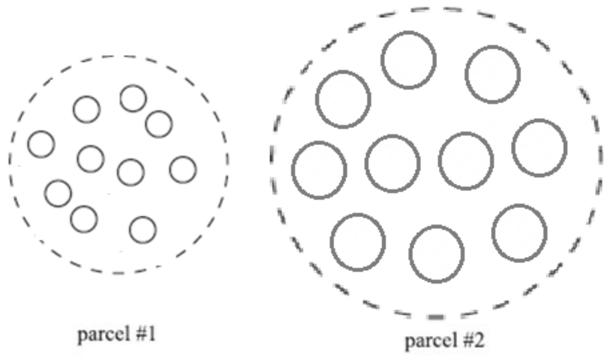


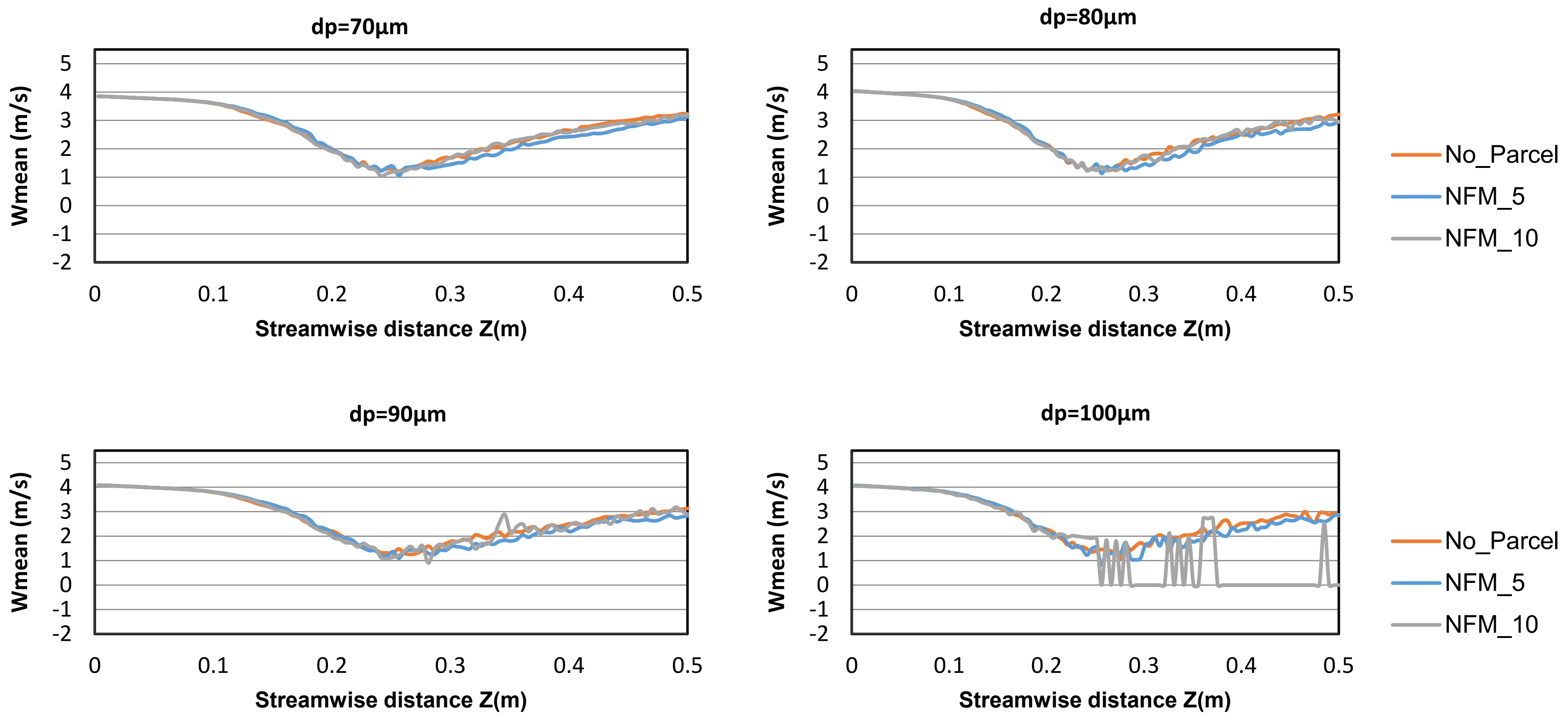



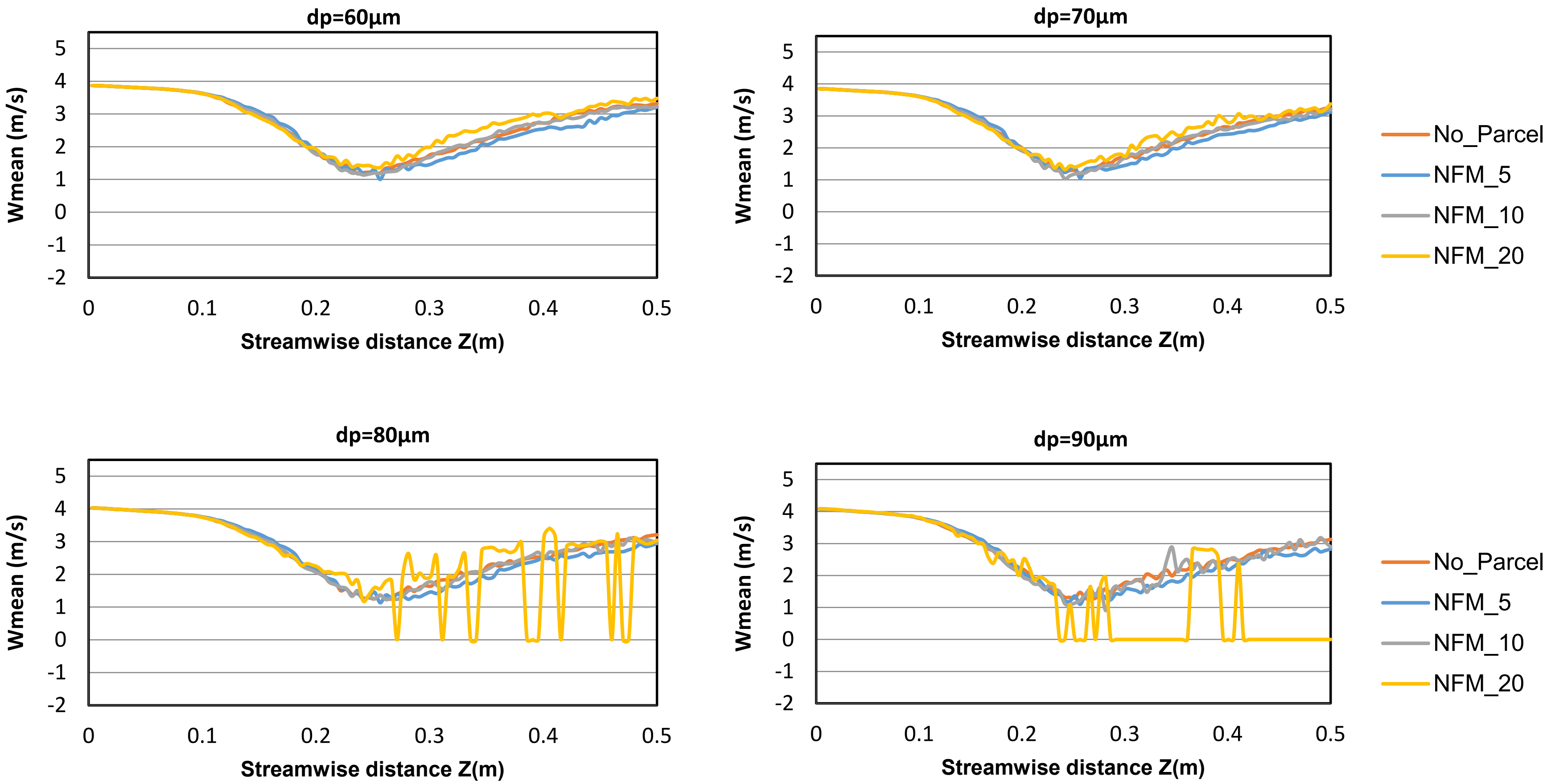



## NFM: Number of particle per Parcel = 10

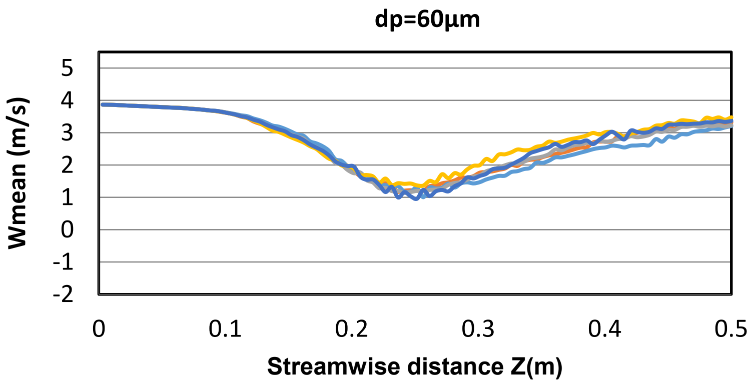


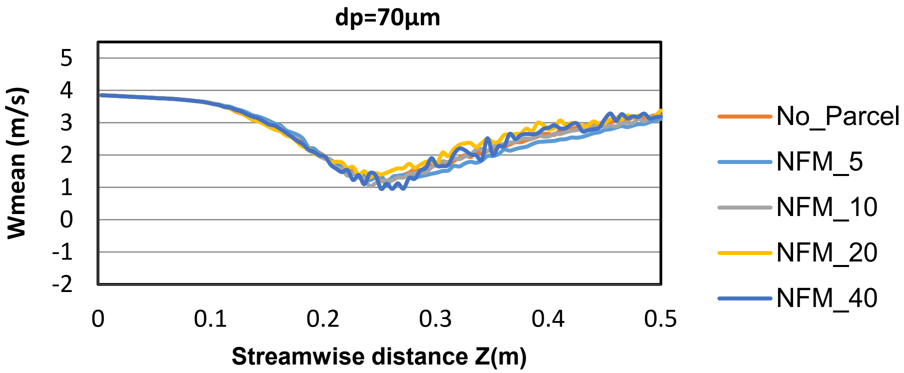



## NFM: Number of particle per Parcel = 20



## NFM: Number of particle per Parcel = 40




| dp \ Np | 5 | 10 | 20 | 40 |
|---|---|---|---|---|
| 70 µm | ✔ | ✔ | ✔ | ✔ |
| 80 µm | ✔ | ✔ | ✘ | ✘ |
| 90 µm | ✔ | ✔ | ✘ | ✘ |
| 100 µm | ✔ | ✘ | ✘ | ✘ |

$$dp = 80\mu m \quad , \quad SMD = 60\mu m$$

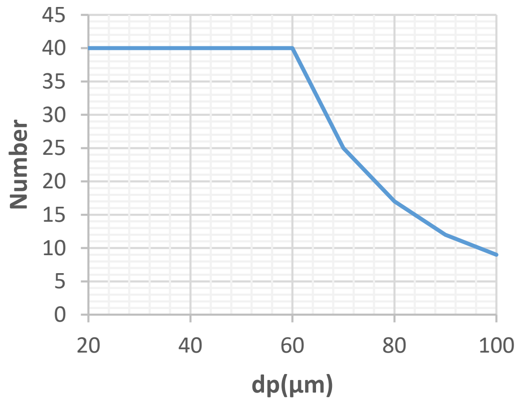
$$N_p\big|_{80} = 10 \quad \Rightarrow \quad V_p\big|_{80} = N_p\big|_{80} \times \frac{4}{3}\pi \times \left(\frac{d_p}{2}\right)^3 = 10 \times \frac{4}{3}\pi \times \left(\frac{80 \times 10^{-6}}{2}\right)^3$$

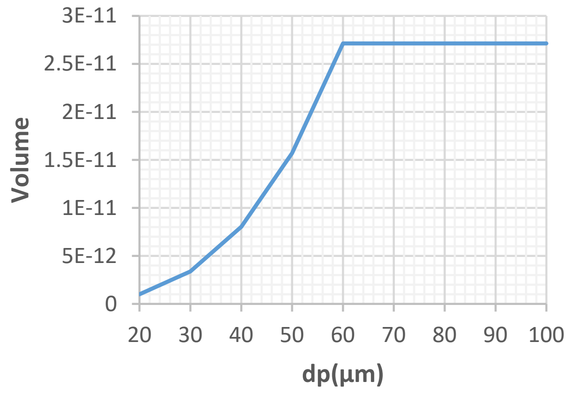
$$V_p\big|_{80} = V_p\big|_{60} \quad \Rightarrow \quad N_p\big|_{60} = 23.7$$

$$N_p\big|_{80} = 20 \quad \Rightarrow \quad V_p\big|_{80} = N_p\big|_{80} \times \frac{4}{3}\pi \times \left(\frac{d_p}{2}\right)^3 = 20 \times \frac{4}{3}\pi \times \left(\frac{80 \times 10^{-6}}{2}\right)^3$$

$$V_p\big|_{80} = V_p\big|_{60} \quad \Rightarrow \quad N_p\big|_{60} = 47.4$$

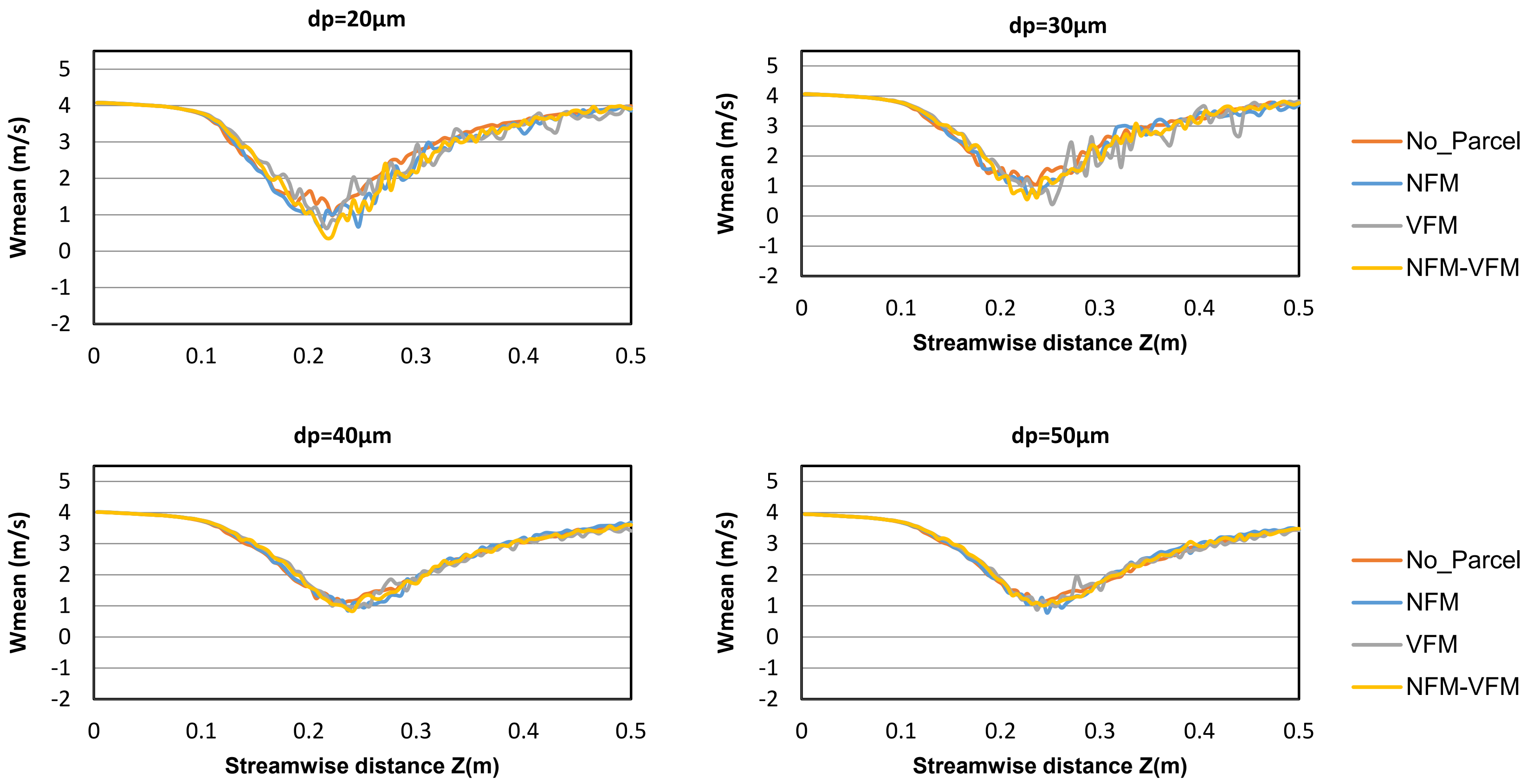
$$23.7 < N_p\big|_{60} < 47.4 \quad \Rightarrow \quad N_p\big|_{60} = 40$$



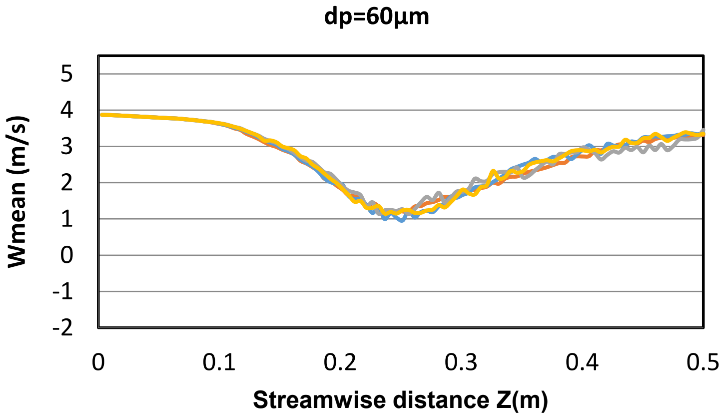



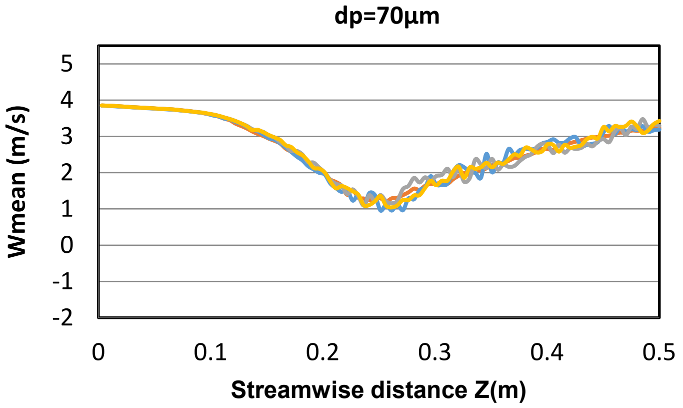

| dp | 20µm | 30µm | 40µm | 50µm | 60µm | 70µm | 80µm | 90µm | 100µm |
|---|---|---|---|---|---|---|---|---|---|
| Parcel Type | NFM | NFM | NFM | NFM | NFM/VFM | VFM | VFM | VFM | VFM |

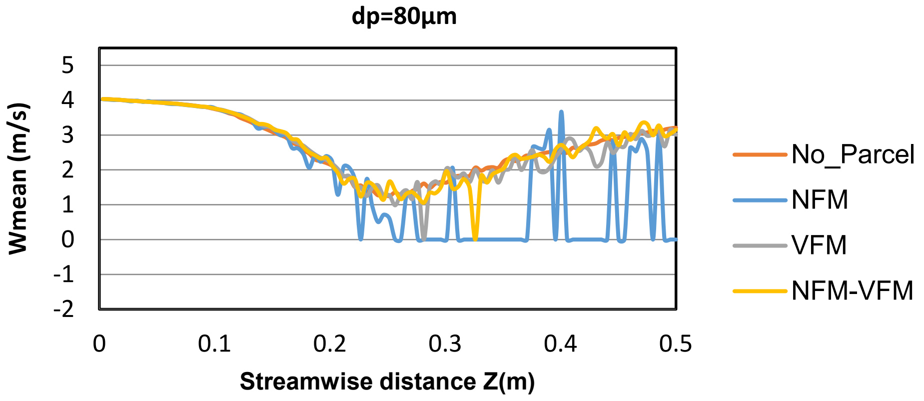
## Comparing NFM, VFM, NFM-VFM:



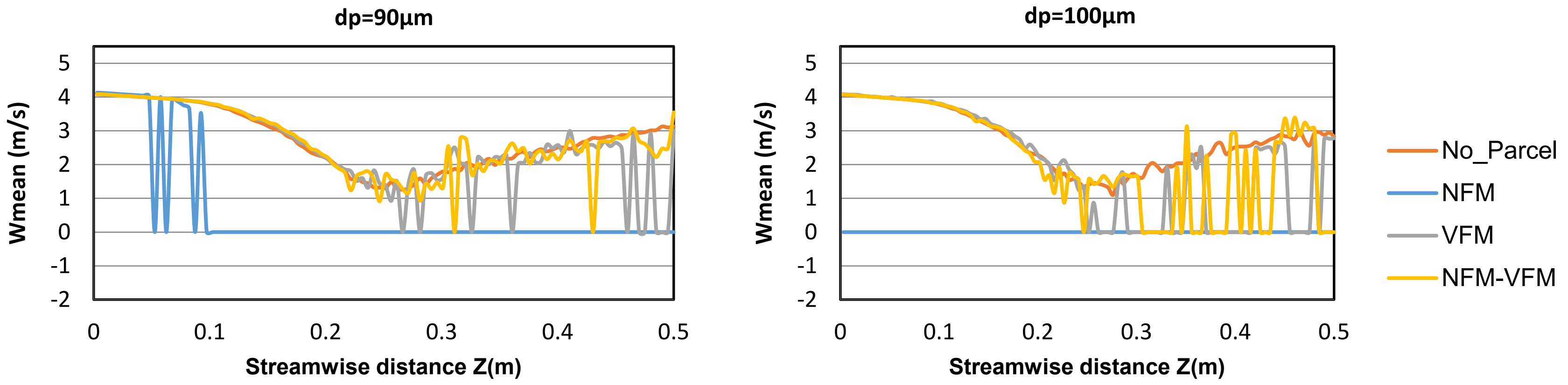
## Comparing NFM, VFM, NFM-VFM:



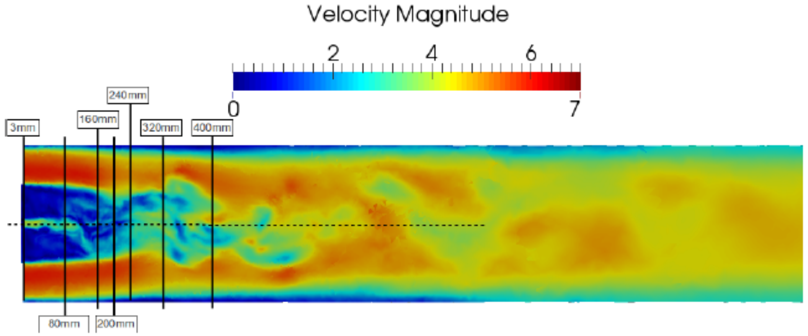



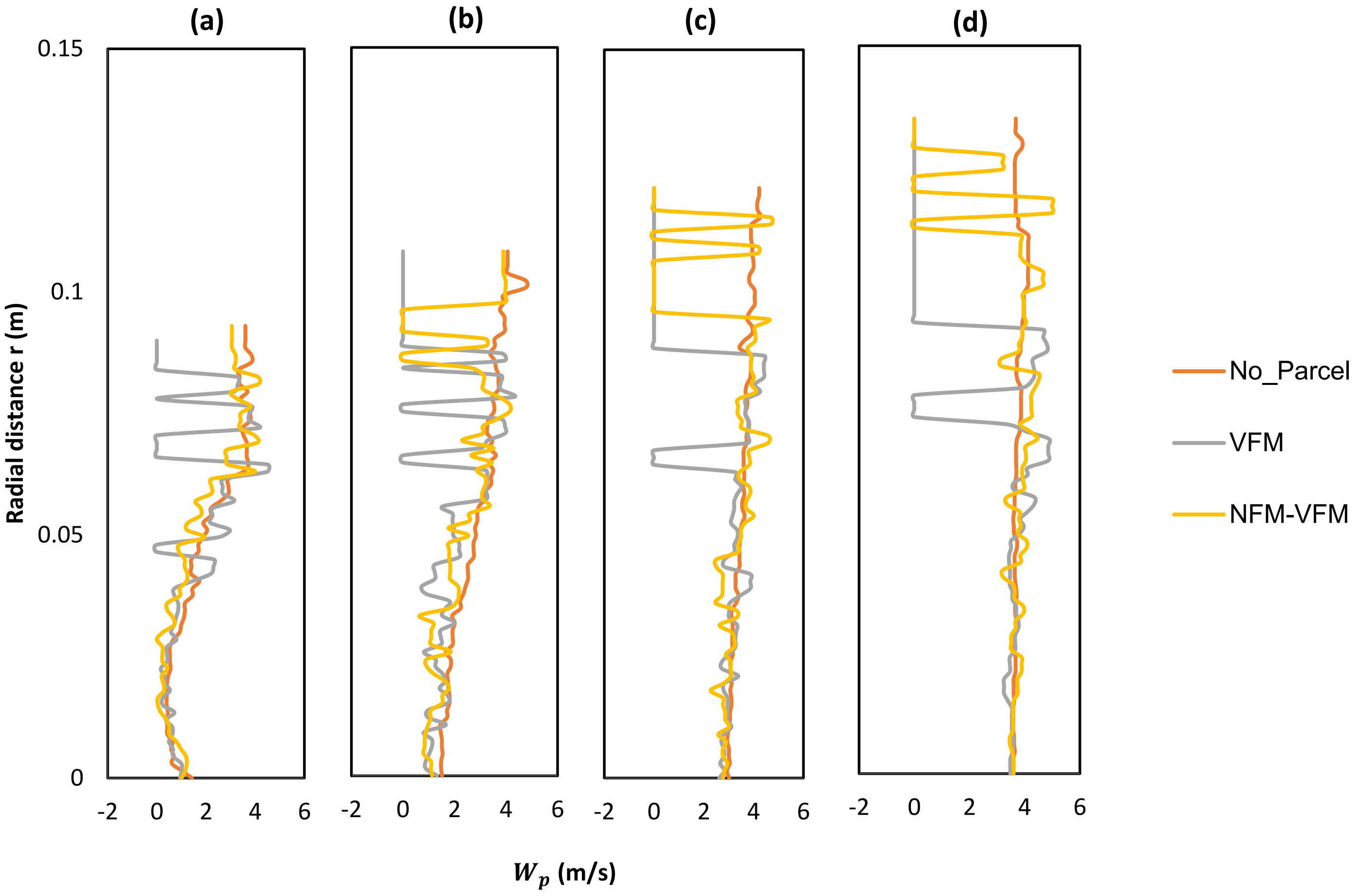
## Comparing NFM, VFM, NFM-VFM:



## Comparing NFM, VFM, NFM-VFM:

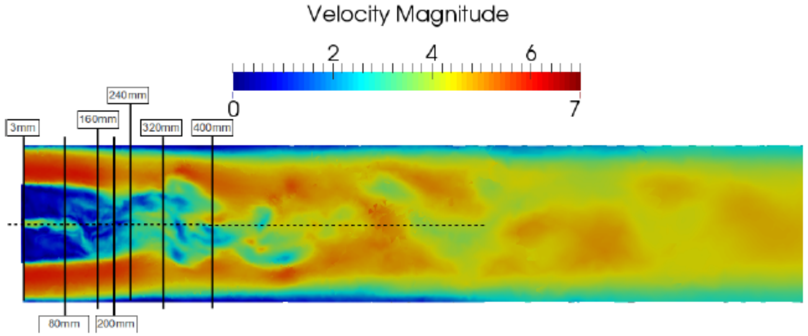
**Figure.** Radial profiles of **particle (dp=20µm)** mean streamwise velocity for particle-laden configuration (M=22%). Numerical simulation. (a) z=0.20m; (b) z=0.24m; (c) z=0.32m; (d) z=0.40m

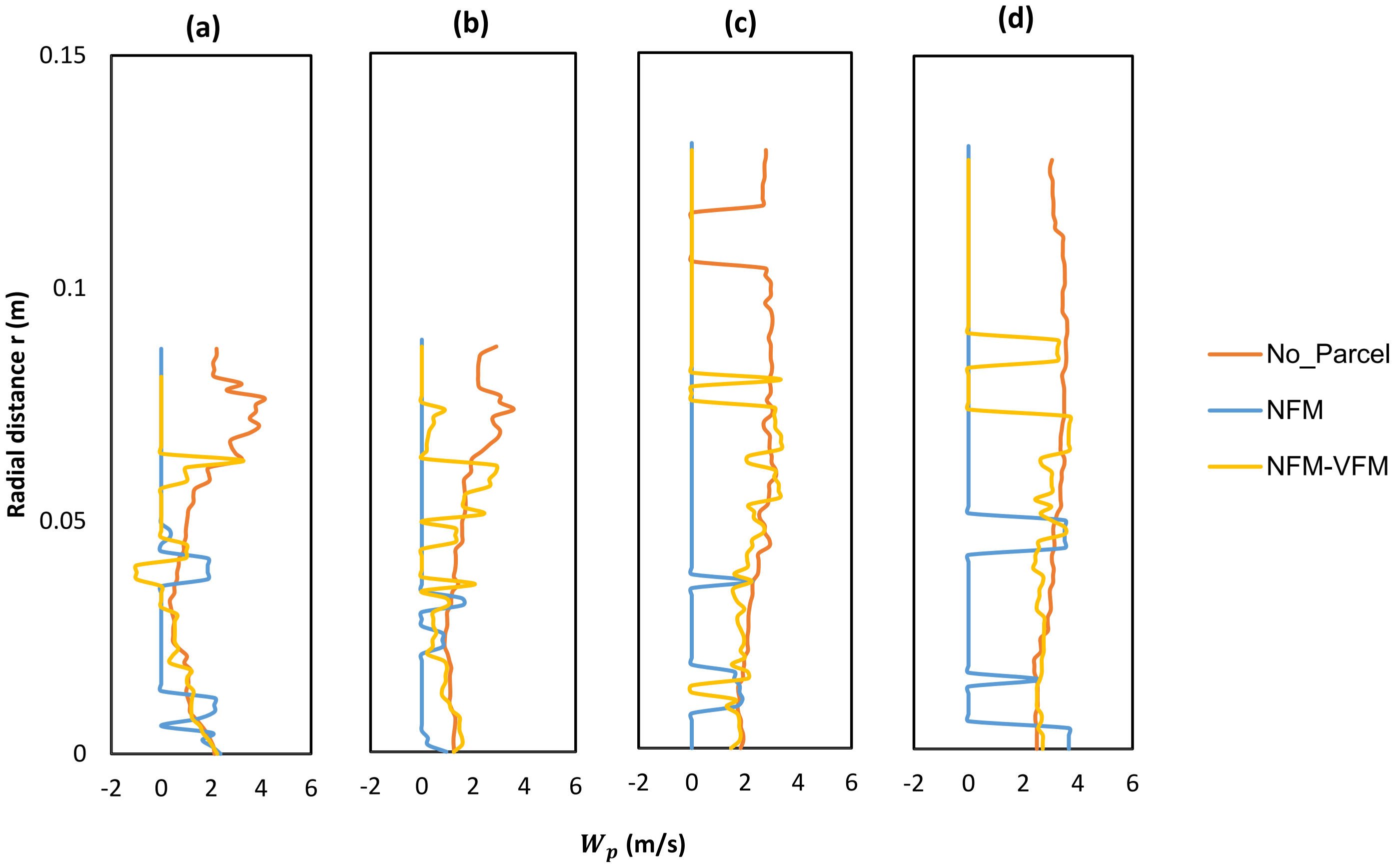


## Comparing NFM, VFM, NFM-VFM:

**Figure.** Radial profiles of **particle (dp=80µm)** mean streamwise velocity for particle-laden configuration (M=22%). Numerical simulation. (a) z=0.20m; (b) z=0.24m; (c) z=0.32m; (d) z=0.40m



## Conclusion:

- According to the results of the new approach, an optimal trade-off between **accuracy** and **computational cost** has achieved

## Future work:

- Comparison of time-averaged distribution of **particle dispersion**, **particle volume fraction** and **computational cost**

- Increasing the **mass loading ratio** in the inner jet to **M=110%**  using Hercule Experiment benchmark case using **NFM**, **VFM** and **NFM-VFM** parcel methods

Centre Tecnològic de Transferència de Calor
UNIVERSITAT POLITÈCNICA DE CATALUNYA

**Thanks For your attention**

**Any question?**

8th European Congress on Computational Methods in Applied Sciences and Engineering
5-9 June 2022, Oslo, Norway