



# POLITECNICO DI TORINO

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Corso di laurea in Ingegneria Aerospaziale

## **Analisi del flusso turbolento in un canale piano con la teoria delle reti complesse**

### **Relatore**

prof.ssa Stefania Scarsoglio

### **Correlatore**

ing. Giovanni Iacobello

### **Candidato**

Michele Pio Savino

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Ottobre 2018

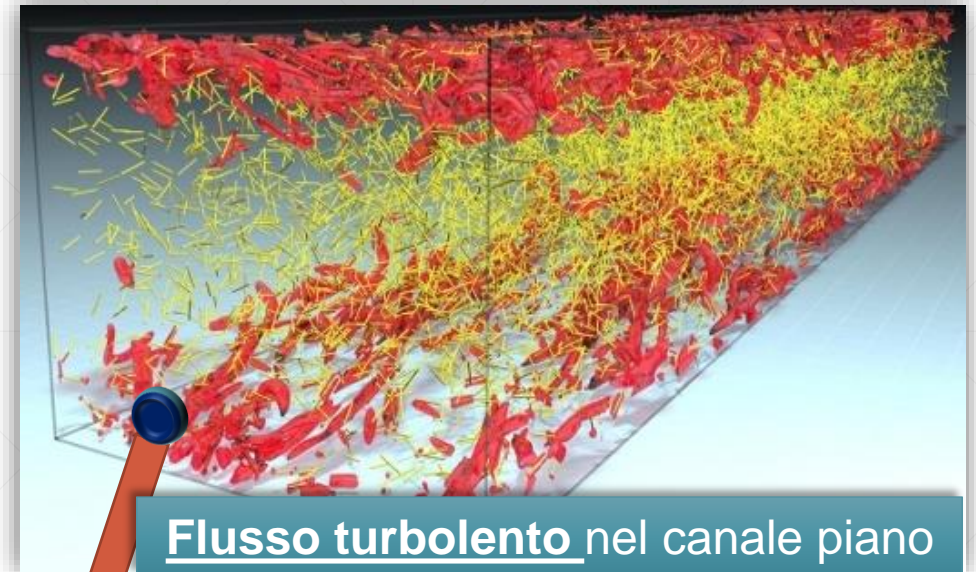
# Sommario

- Motivazioni dello studio
- Metodi
  - La teoria delle reti complesse
  - L'algoritmo di visibilità orizzontale
  - Le metriche
  - Database e configurazione
- Risultati
  - Legame tra serie temporali e metriche
  - Confronto tra i database
- Conclusioni

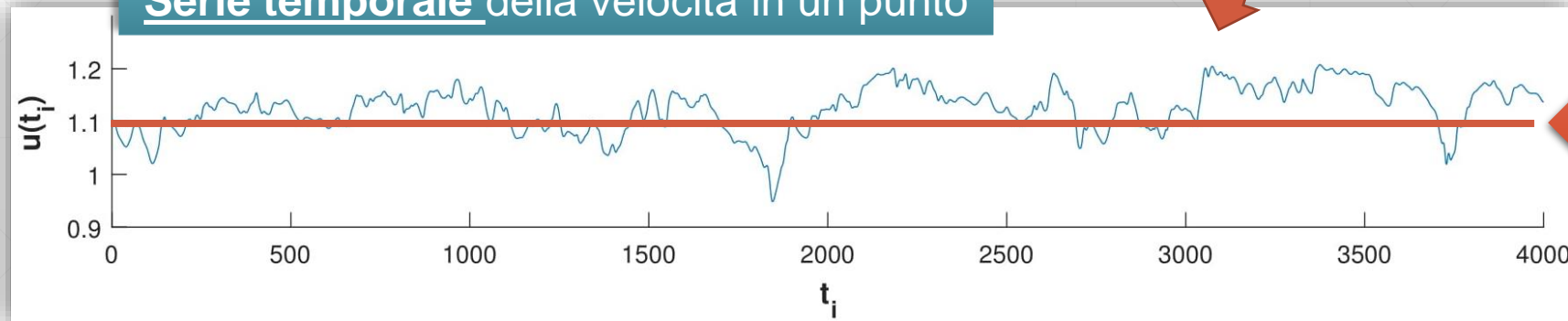
# Motivazioni dello studio

La **turbolenza** è un fenomeno:

- Instazionario
- Tridimensionale
- Non lineare
- Fortemente dissipativo

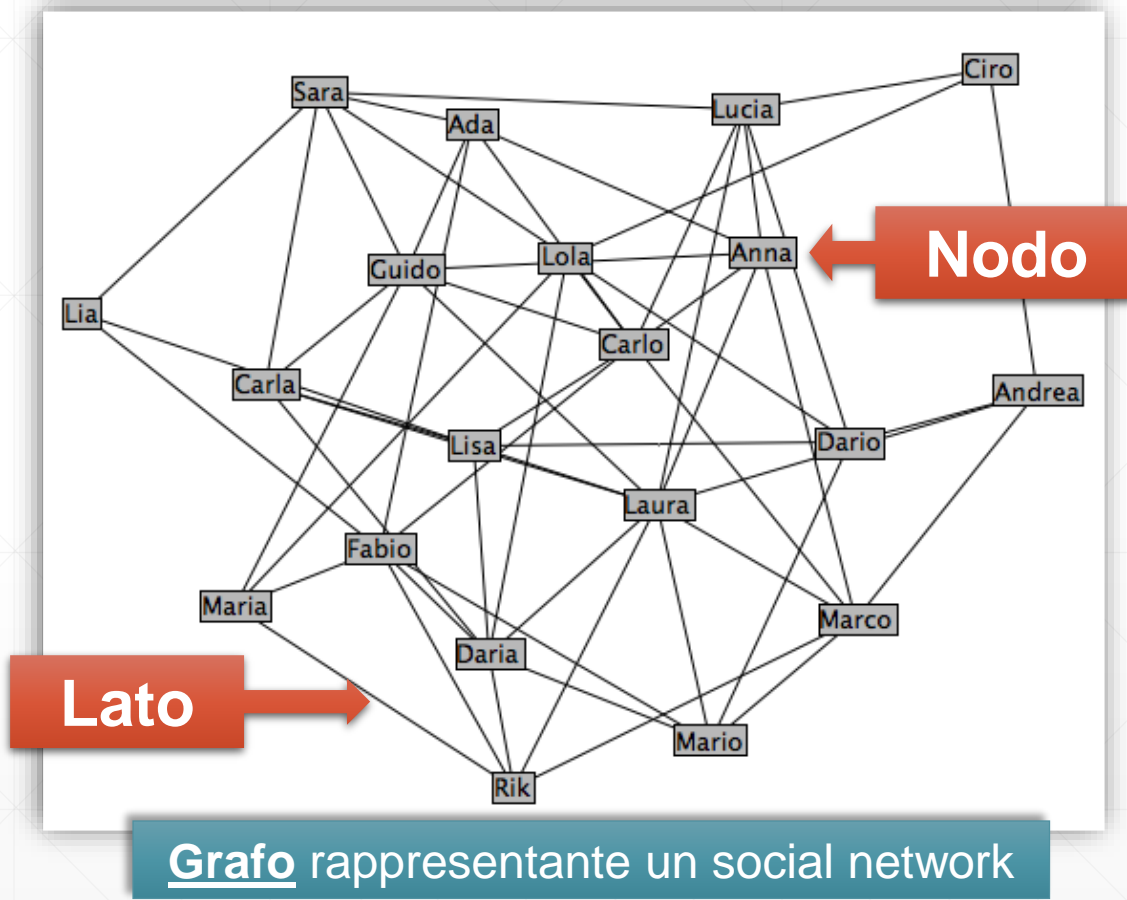


Serie temporale della velocità in un punto

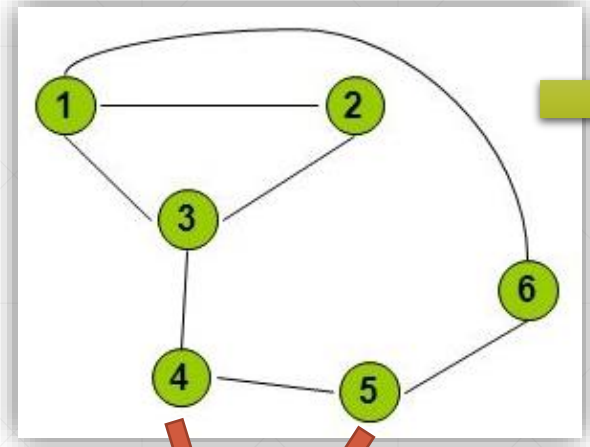


**Valore medio**

# La teoria delle reti complesse



$$G = (\mathcal{N}, \mathcal{L})$$

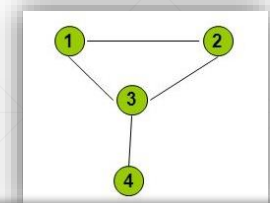


**A =**

	1	2	3	4	5	6
1	0	1	1	0	0	1
2	1	0	1	0	0	0
3	1	1	0	1	0	0
4	0	0	1	0	1	0
5	0	0	0	1	0	1
6	1	0	0	0	1	0

**Matrice di adiacenza**

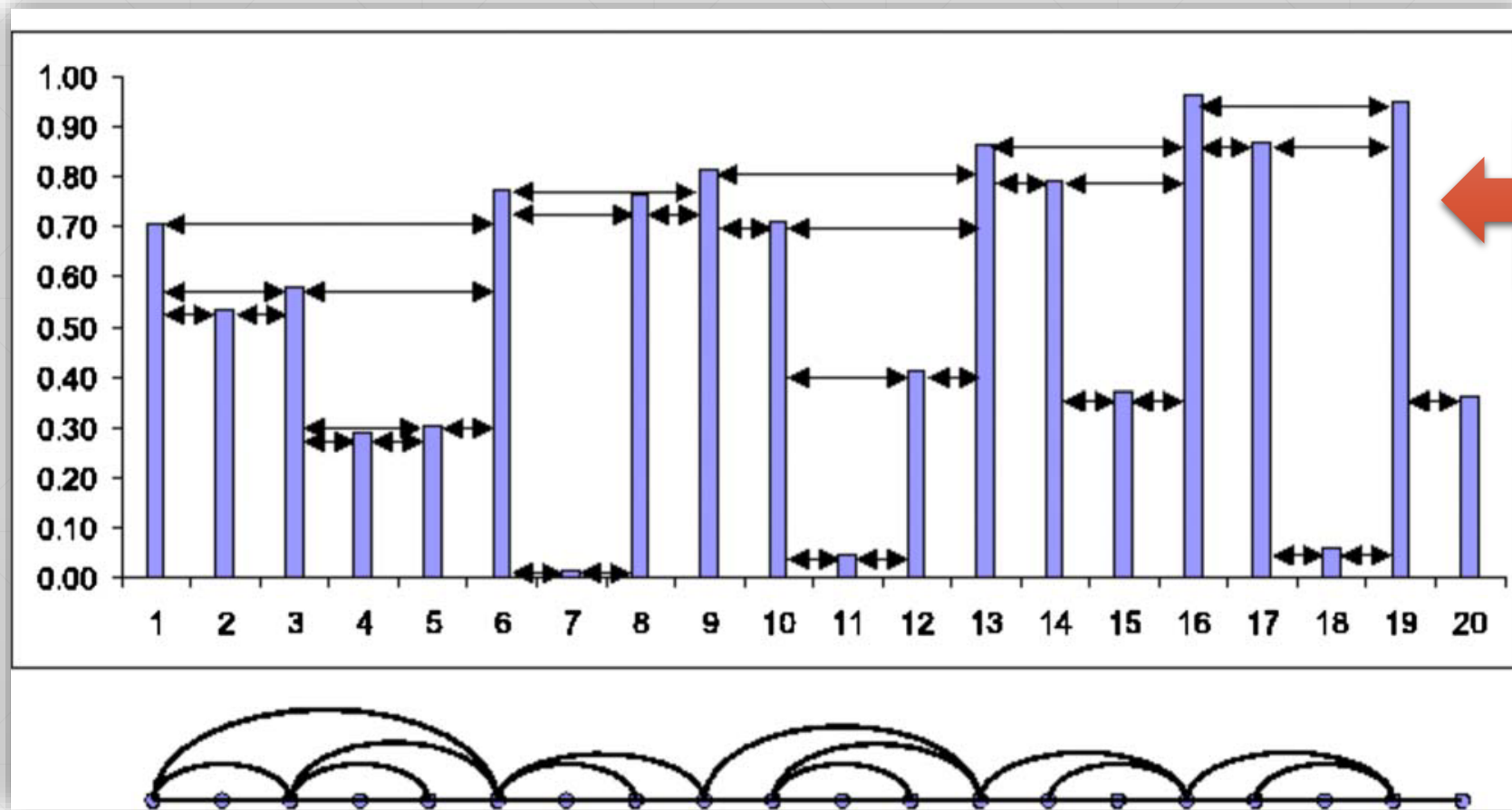
**Nodi adiacenti**



**Sottografo indotto dal nodo 3**

- Il grafo è:
- Connesso
  - Non orientato
  - Non pesato

# L'algoritmo di visibilità orizzontale



← Serie temporale

Criterio di visibilità



$$x_i, x_j > x_n \quad \forall n \text{ tale che } i < n < j$$

# Le metriche

## Grado

$$k_i = \sum_{j=1}^N A_{ij}$$

## Mean link-length

$$d_{1n}(i) = \frac{1}{k_i} \sum_{j \in \Gamma_i} |t_j - t_i|$$

## Transitivity

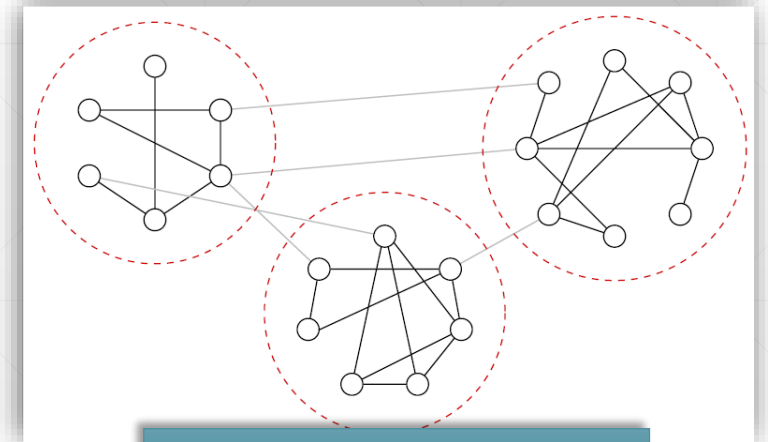
$$Tr = \frac{3N_{\Delta}}{N_{\wedge}}$$

## Coeff. di clustering

$$C_i = \frac{2e_i}{k_i(k_i - 1)}$$

## Modularity

$$Q = \frac{1}{4m} \sum_{ij} \left( A_{ij} - \frac{K_i K_j}{2m} \right) s_i s_j$$

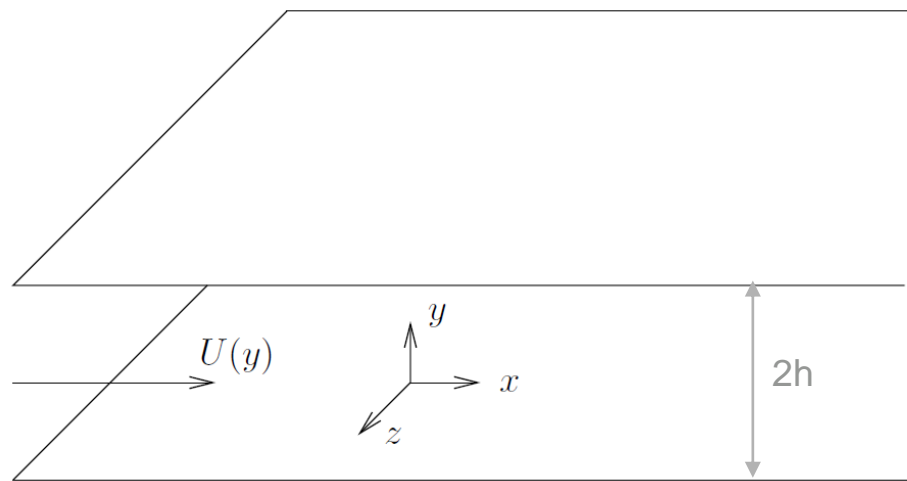


Tre raggruppamenti

# Database e configurazione

$$Re_{\tau} = \frac{hu_{\tau}}{\nu}$$

$u_{\tau}$  = velocità di attrito  
 $\nu$  = viscosità cinematica



$$y^+ = \frac{y}{h} Re_{\tau}$$

## I. Database JHTDB ( $Re_{\tau} = 1000$ )

$$u_{\tau} = 4.9968 \cdot 10^{-2}$$

$$\nu = 5 \cdot 10^{-5}$$

$$N_t = 4000$$

Griglia:

$$(S_x \times S_y \times S_z) = (64 \times 70 \times 3)$$

## II. Database $Re_{\tau} = 180$

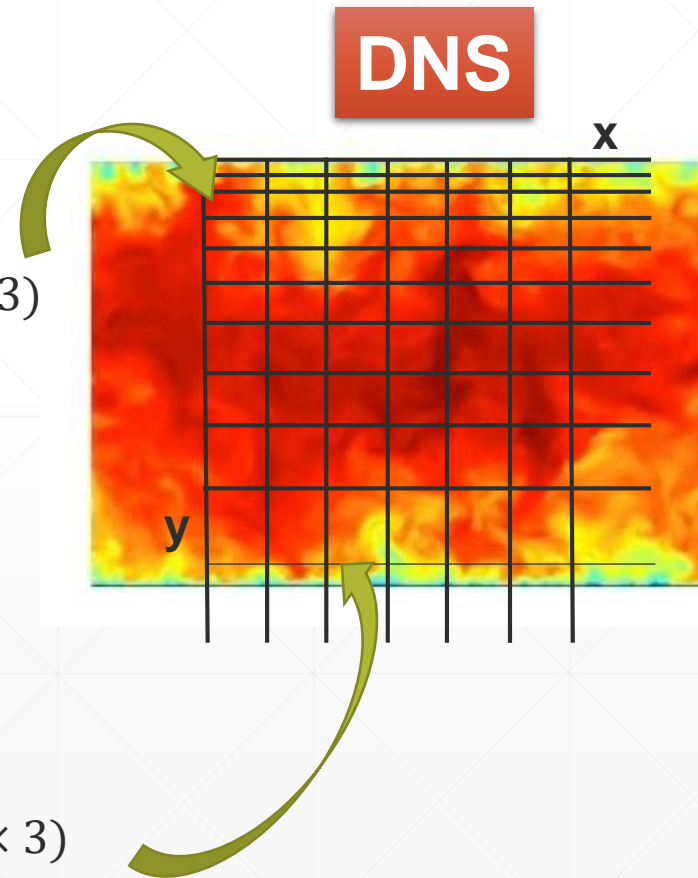
$$u_{\tau} = 1$$

$$\nu = 1/180$$

$$N_t = 5000$$

Griglia:

$$(S_x \times S_y \times S_z) = (144 \times 96 \times 3)$$

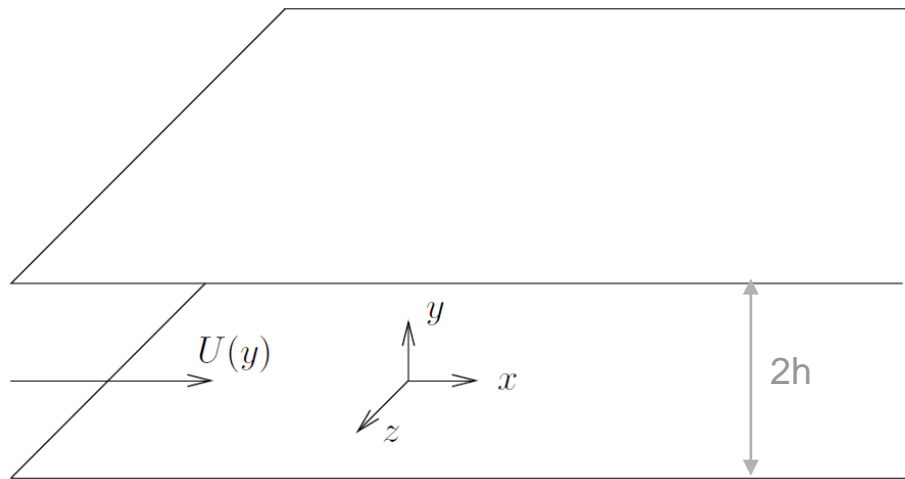


# Database e configurazione

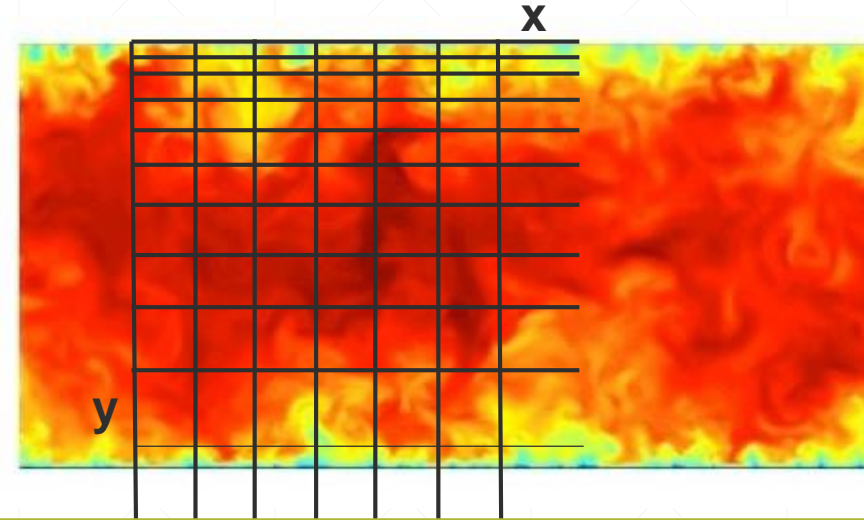
$$Re_{\tau} = \frac{hu_{\tau}}{\nu}$$

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$$y^+ = \frac{y}{h} Re_{\tau}$$



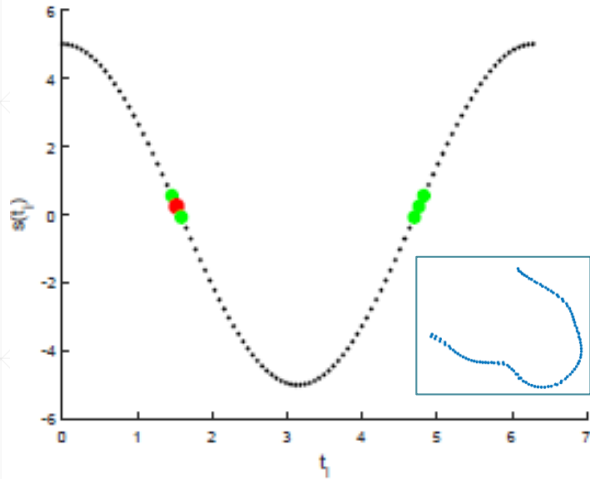
$$\tilde{\mathcal{F}}(Y) = \frac{1}{S_x S_z} \sum_X \sum_Z \mathcal{F}(X, Y, Z)$$

Serie temporali scelte

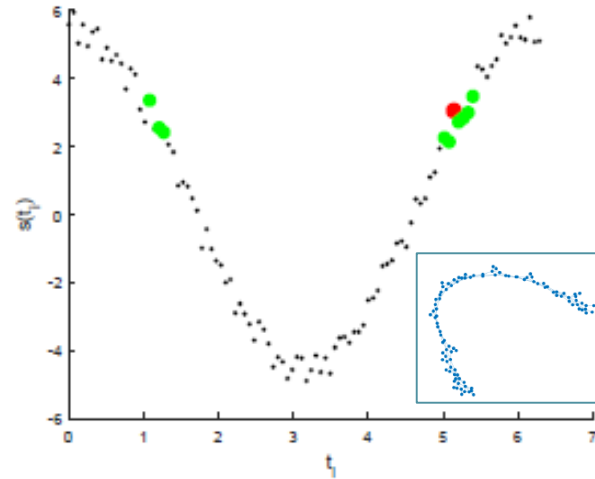
↓  
Componente  $\underline{u}$  della velocità istantanea nella direzione del flusso



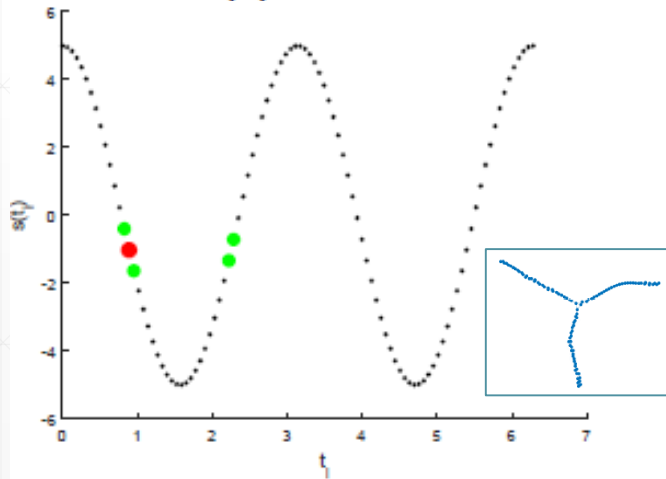
# Legame tra serie temporali e metriche



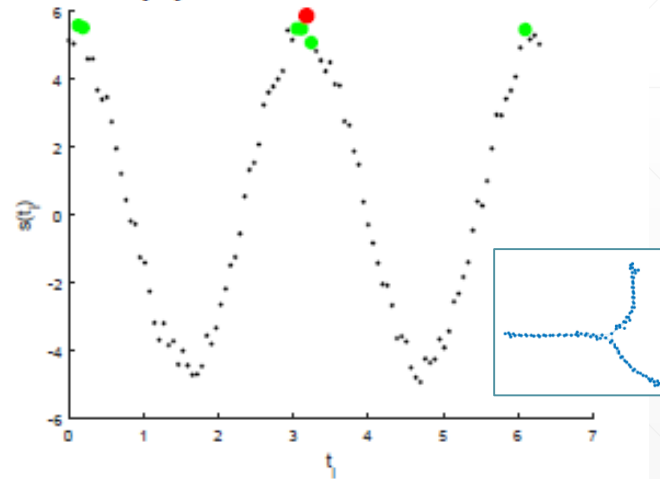
(a) Coseno.



(b) Coseno con rumore.



(c) Coseno con periodo dimezzato.



(d) Coseno con periodo dimezzato e rumore

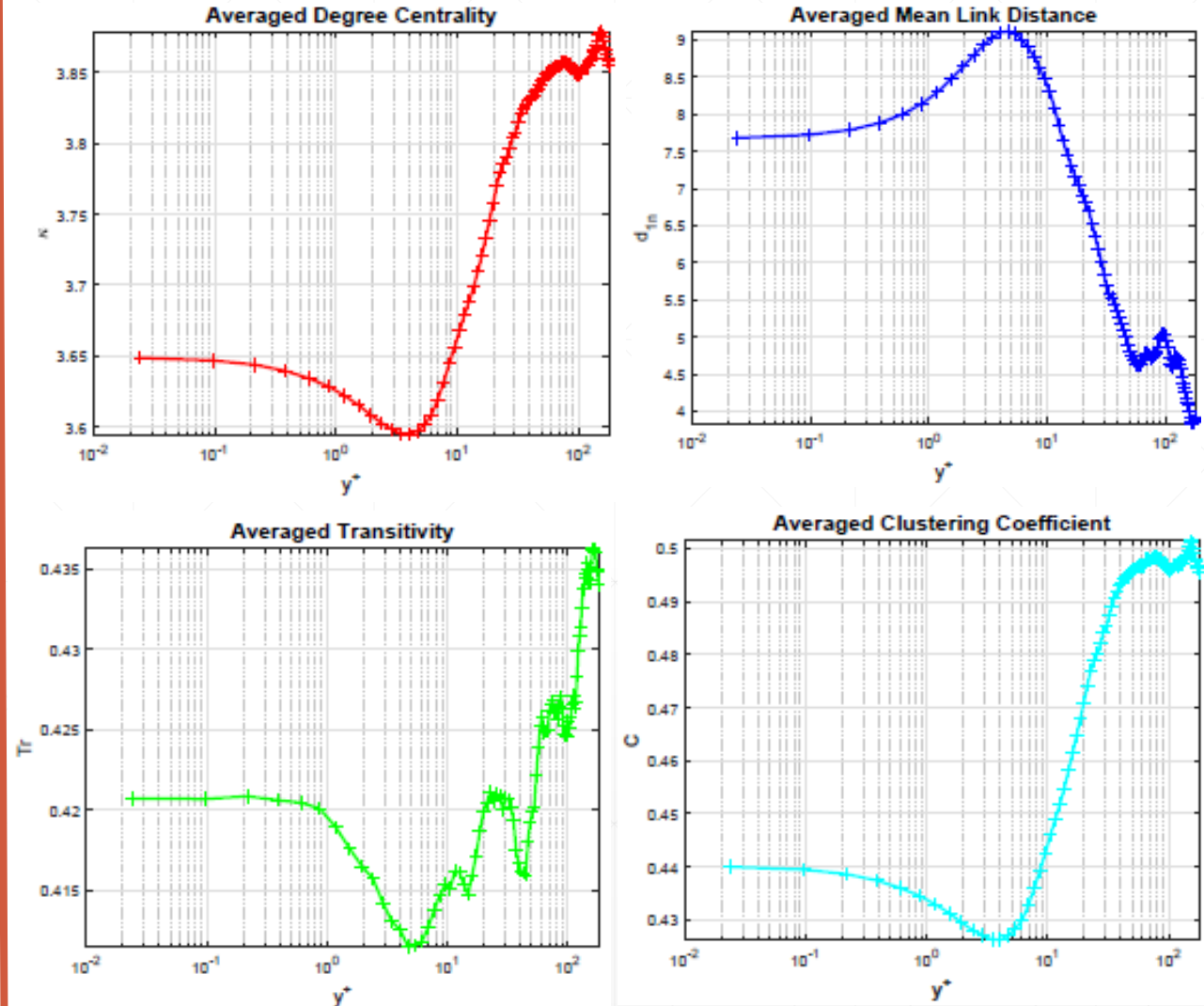
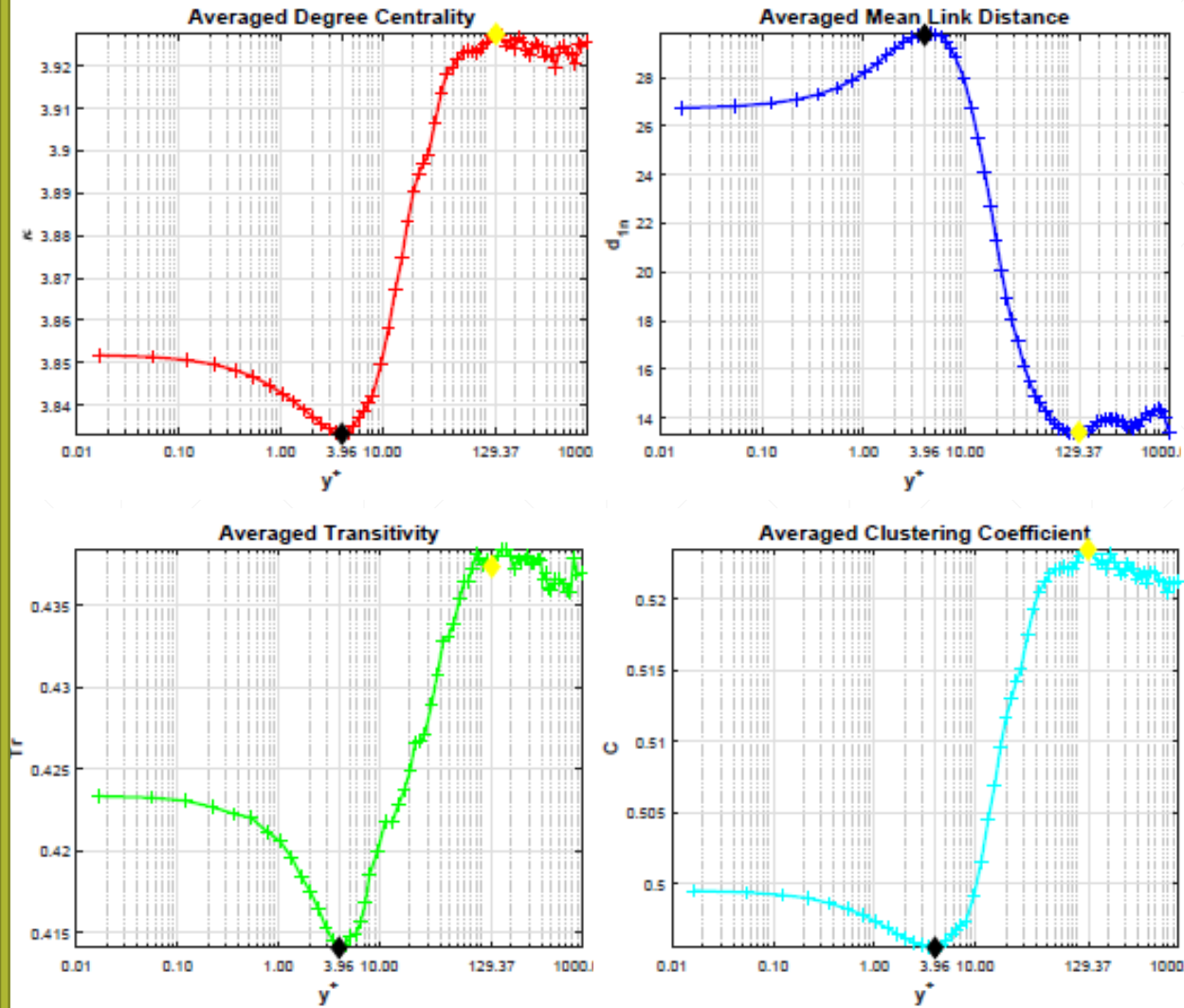
Da una combinazione delle metriche si possono rilevare:

- la ricorrenza dei picchi
- la frequenza delle fluttuazioni

	(a)	(b)	(c)	(d)
$T_r$	0.152	0.303	0.171	0.101
$C$	0.464	0.585	0.492	0.578
$d_{1n}$	24.20	12.52	13.45	9.85
$\kappa$	3.70	3.00	3.92	3.90

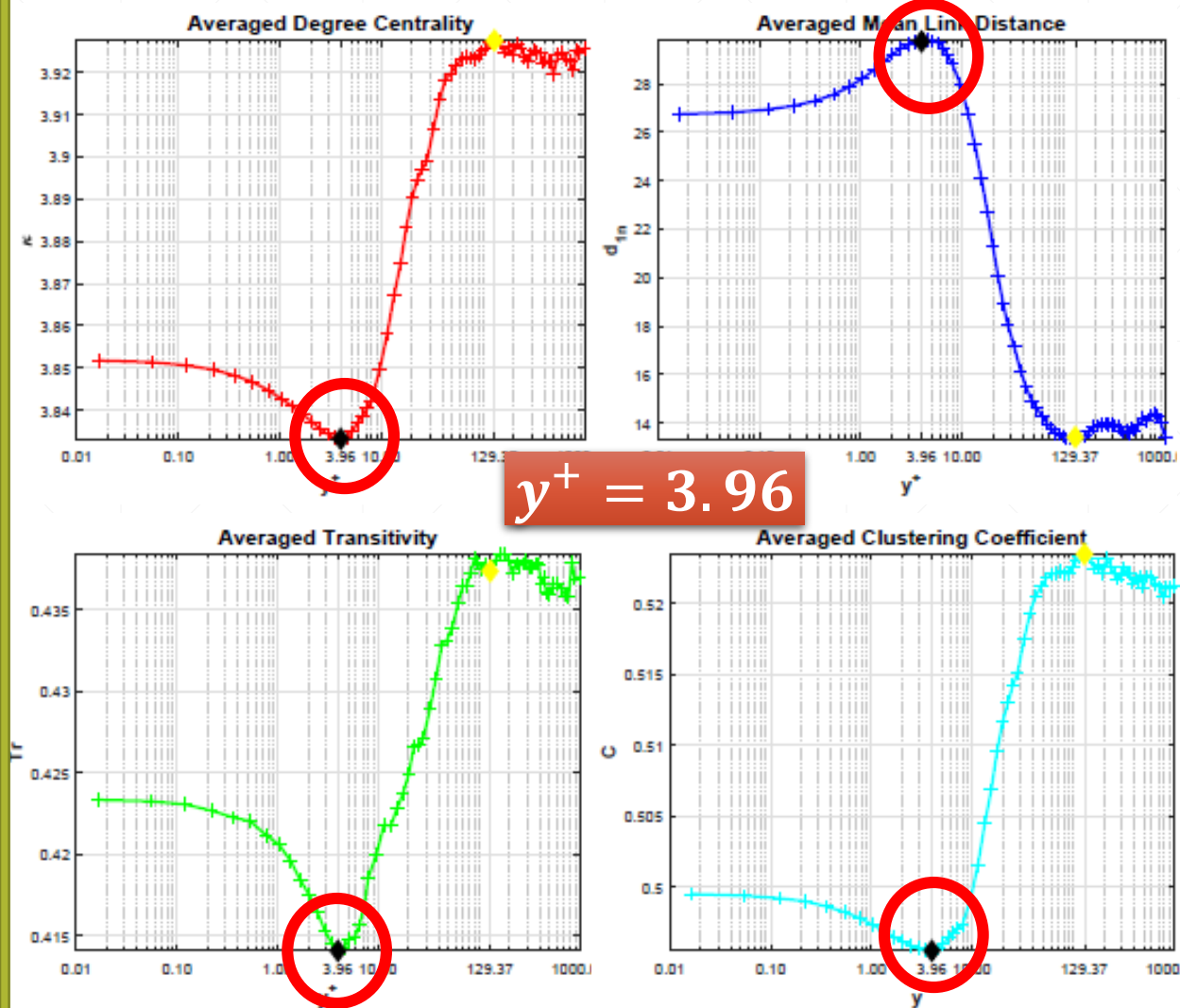
# Metriche $Re_T = 1000$

# Metriche $Re_T = 180$

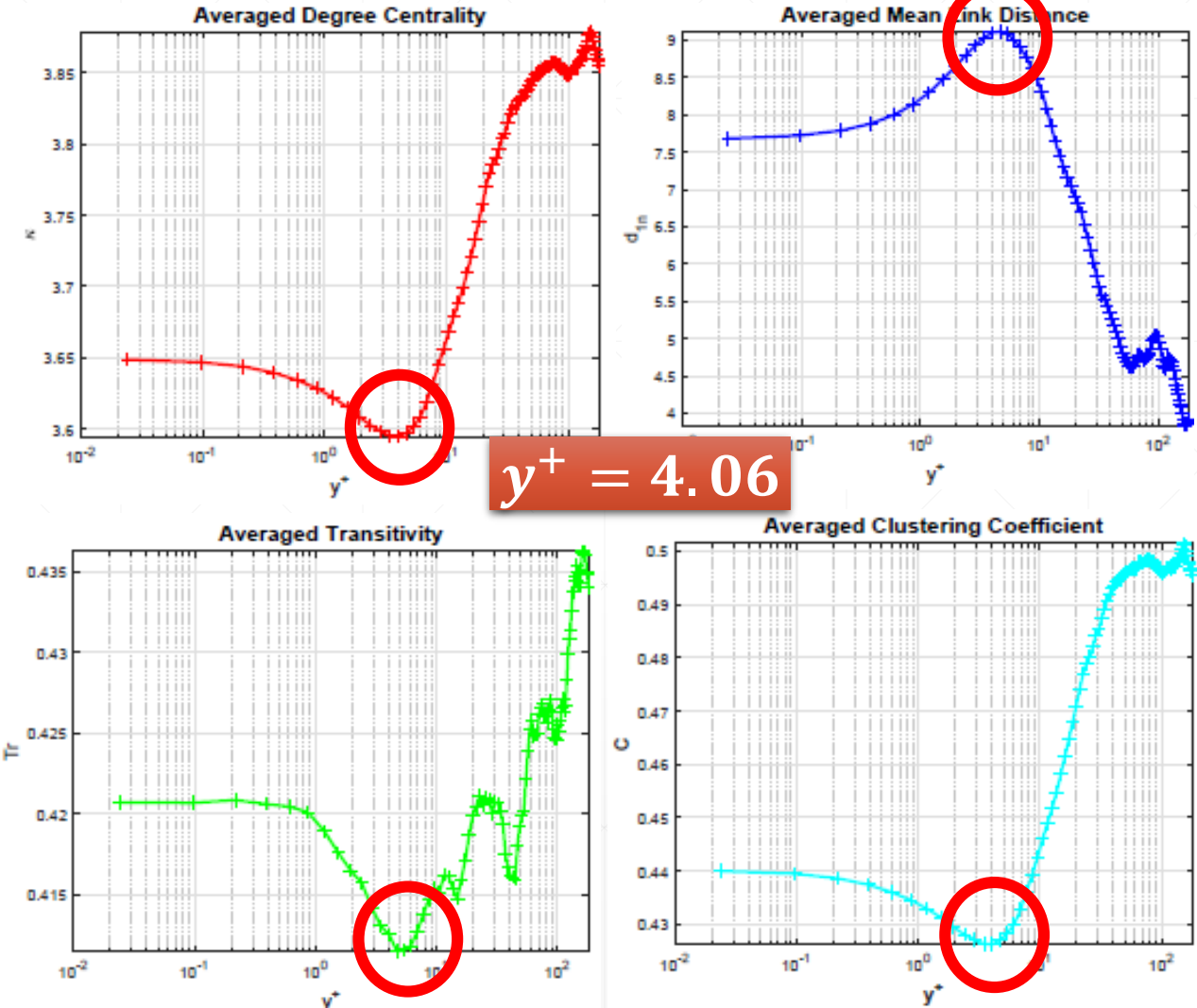


# Metriche $Re_T = 1000$

# Metriche $Re_T = 180$

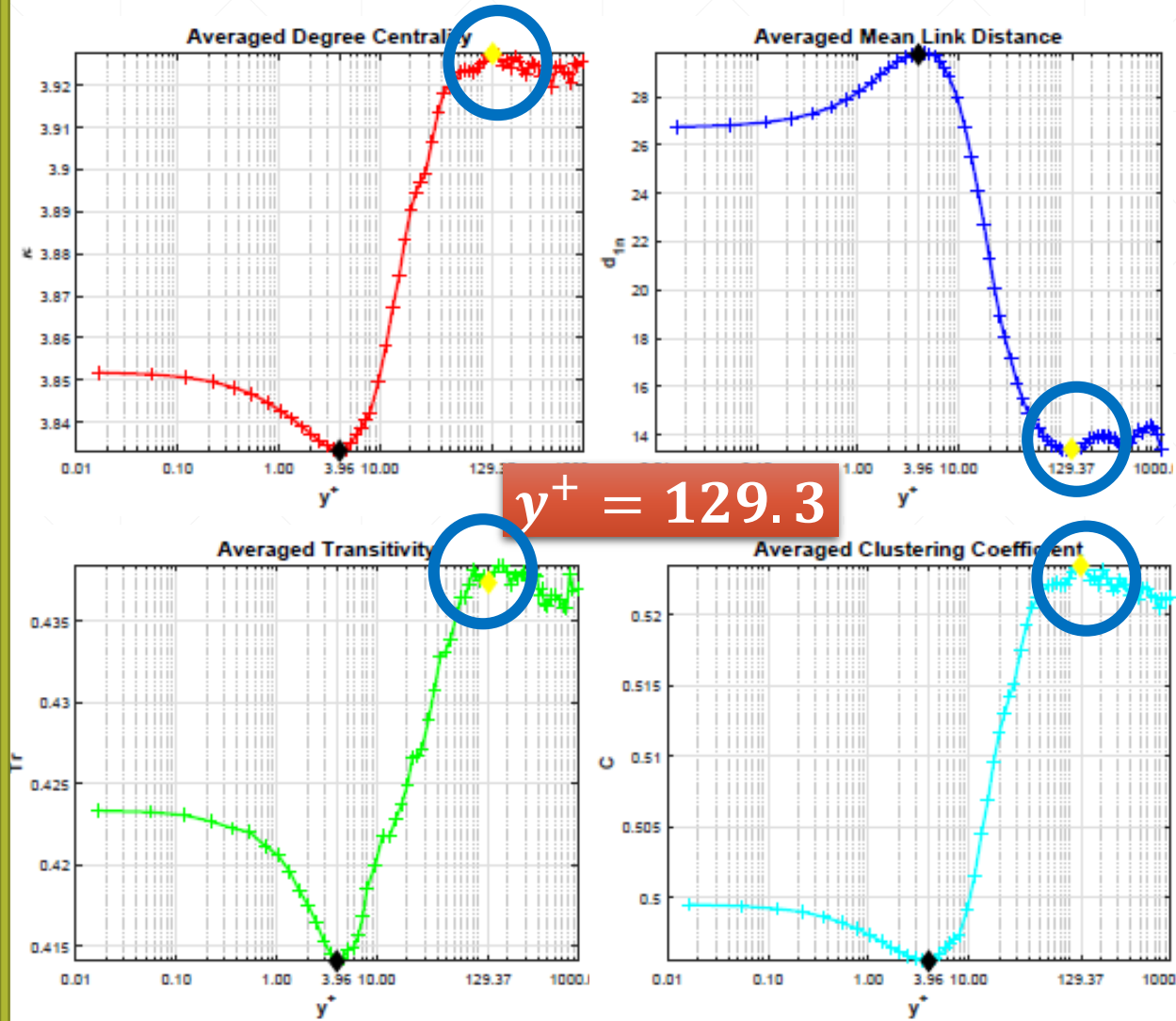


$y^+ = 3.96$

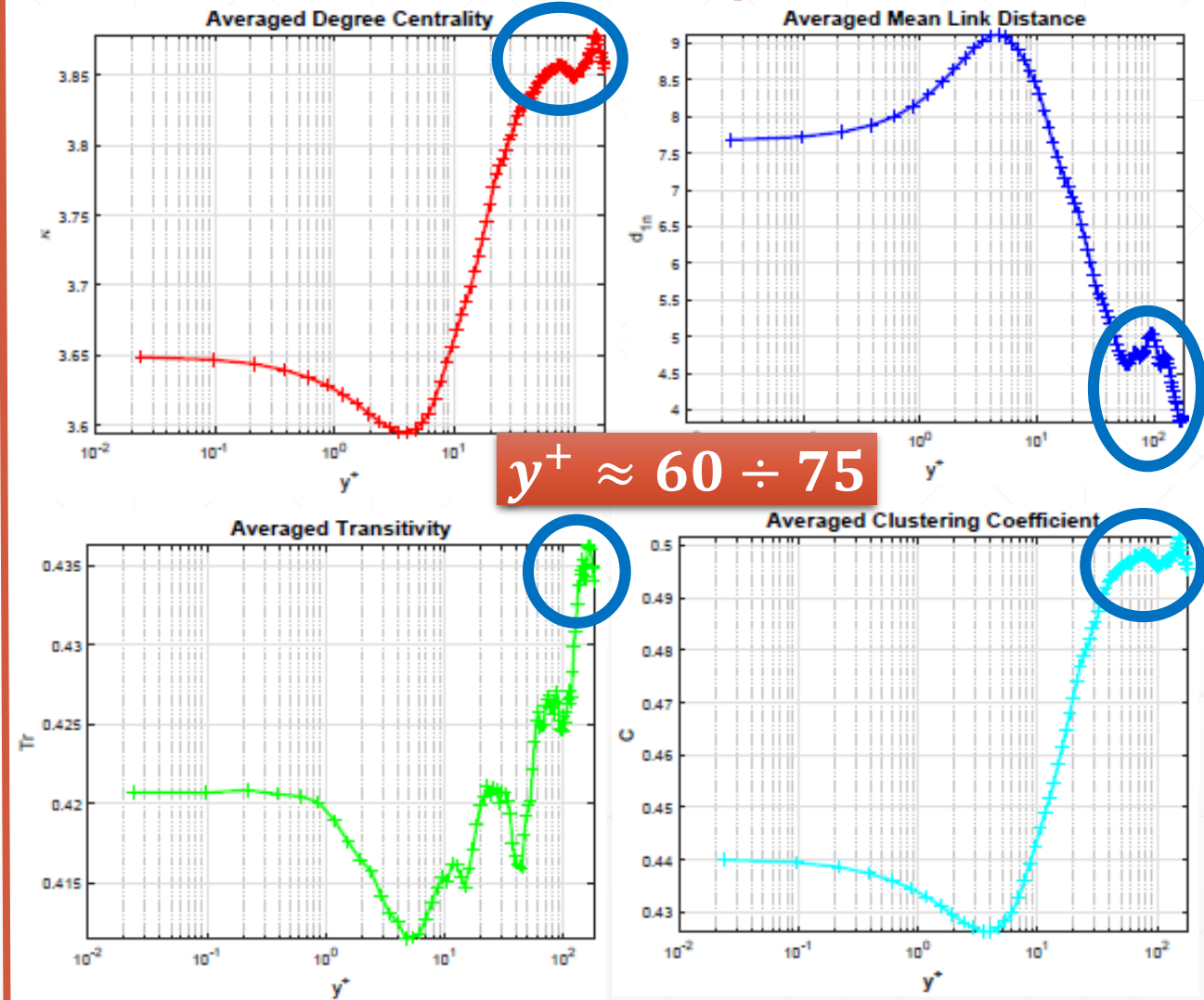


$y^+ = 4.06$

# Metriche $Re_T = 1000$

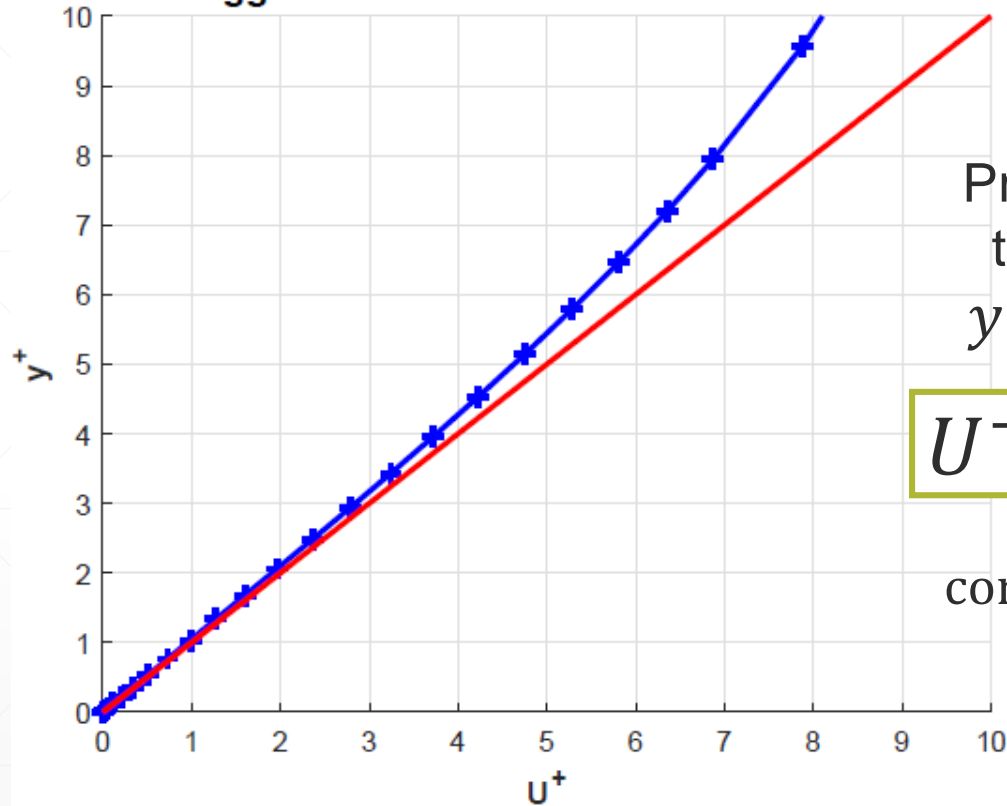


# Metriche $Re_T = 180$



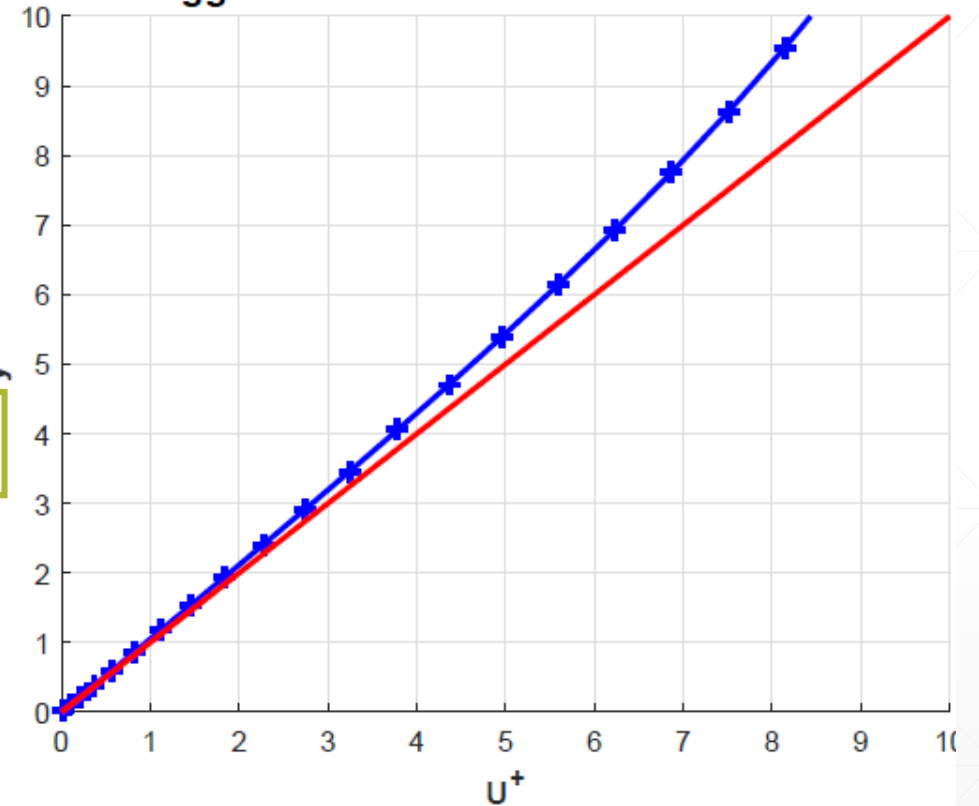
# Il sottostrato viscoso

Legge di velocità nel sottostrato viscoso



(a)  $Re_\tau = 1000$ .

Legge di velocità nel sottostrato viscoso

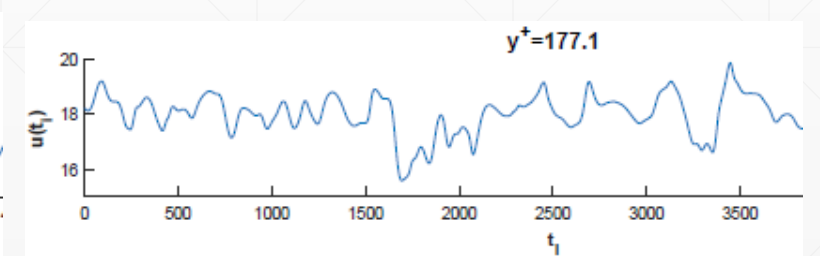
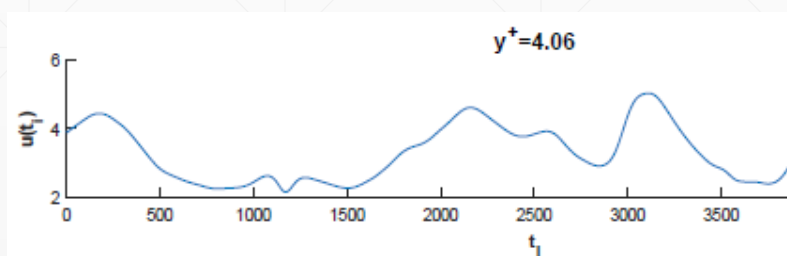
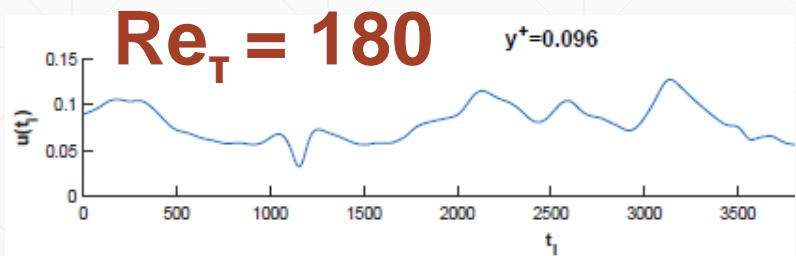
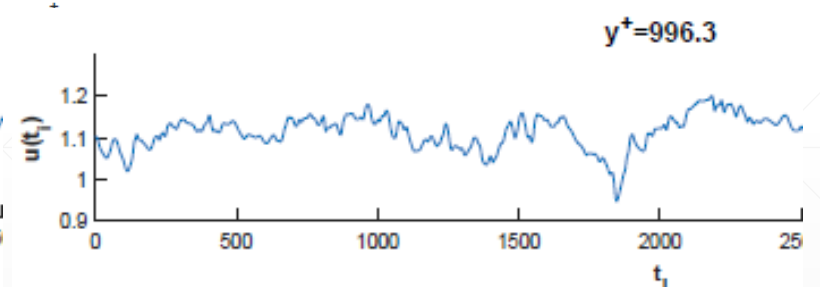
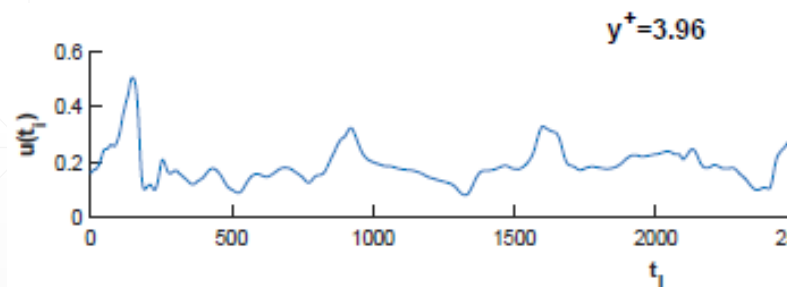
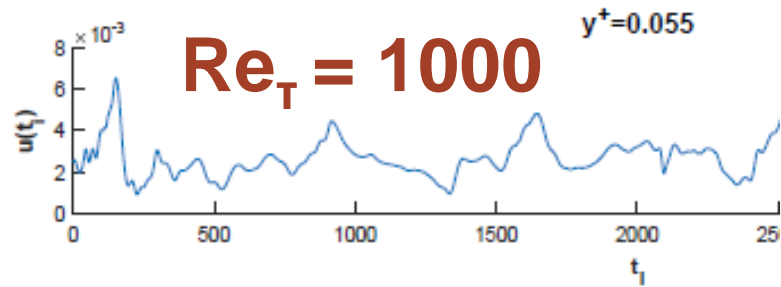
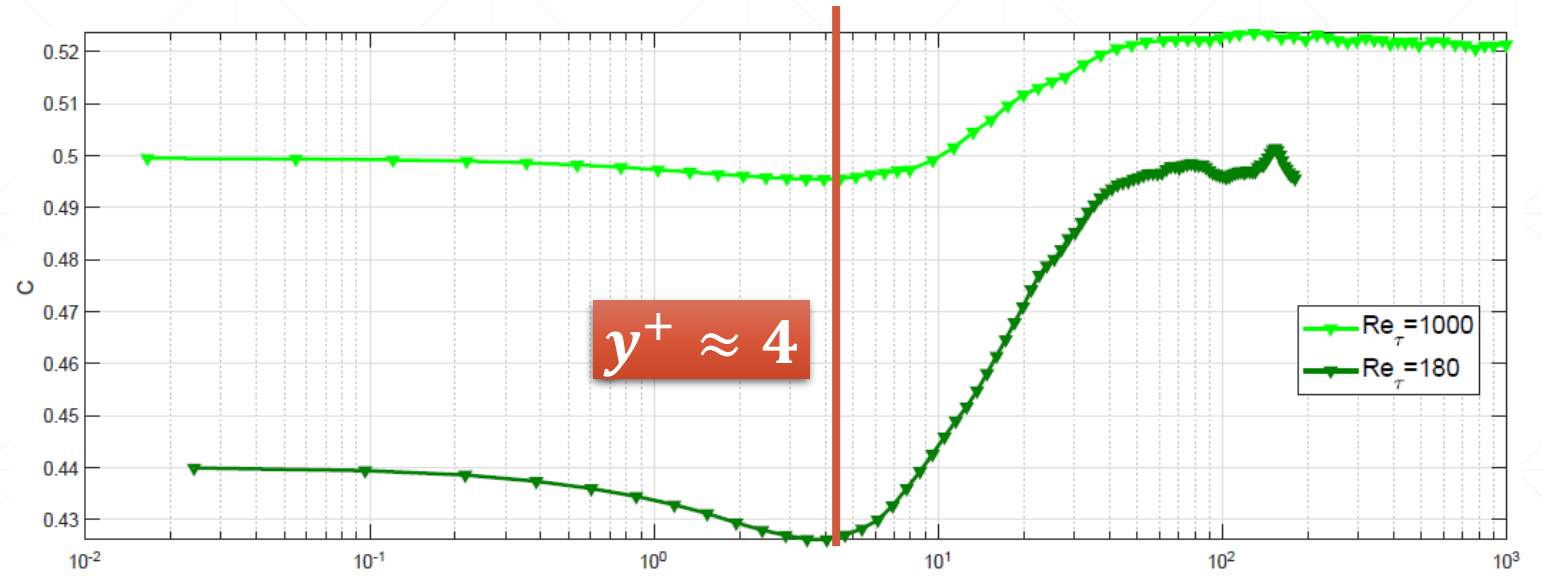


(b)  $Re_\tau = 180$ .

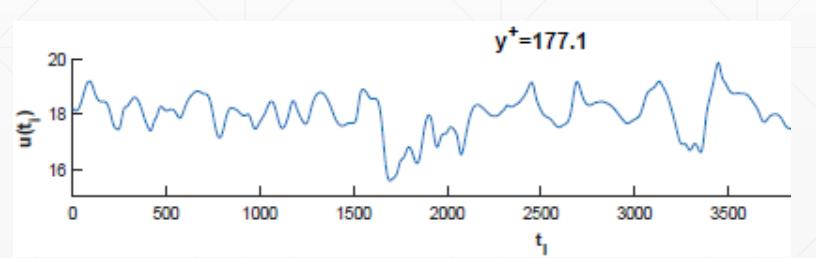
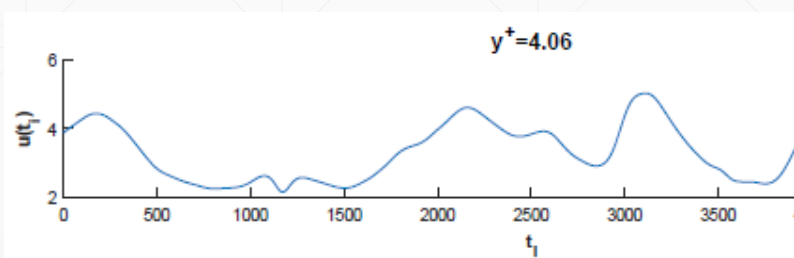
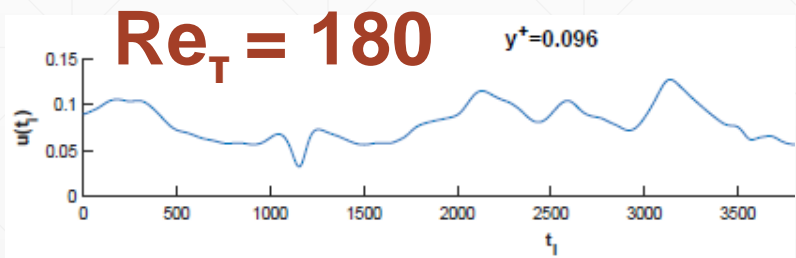
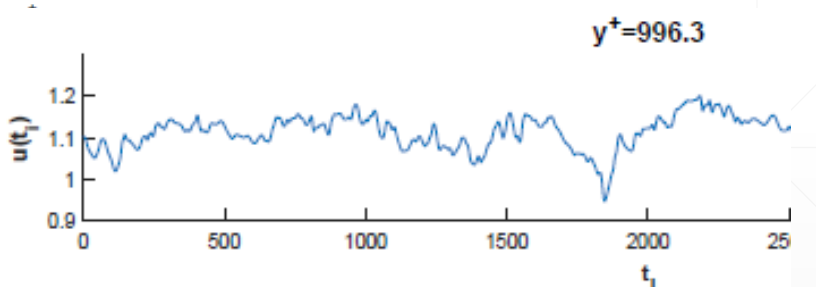
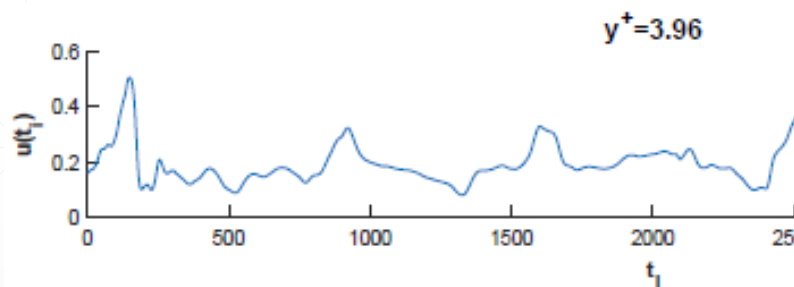
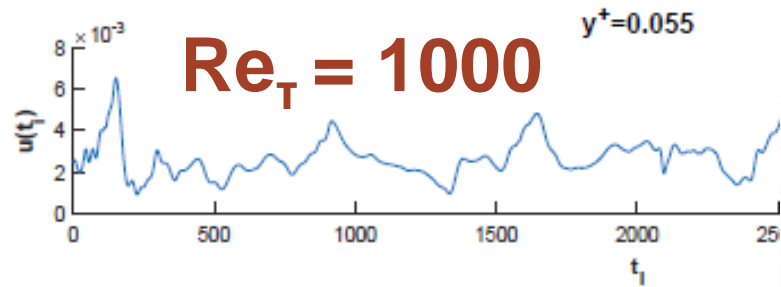
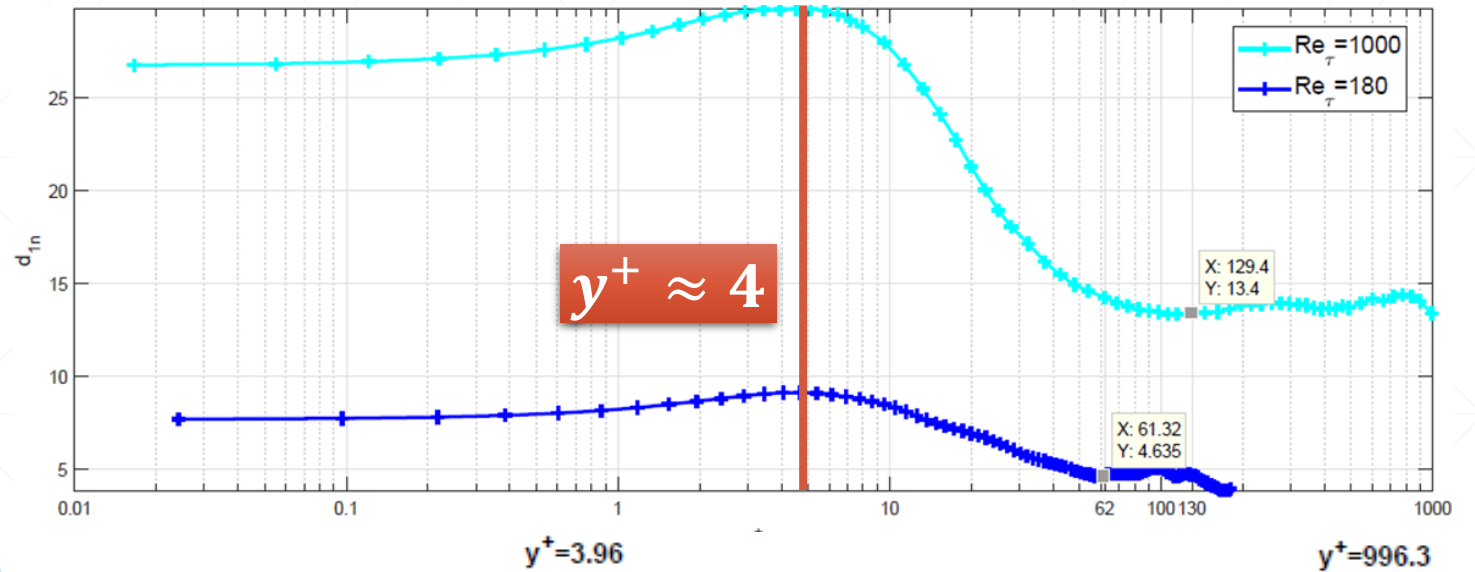
Andamento teorico

Dati numerici

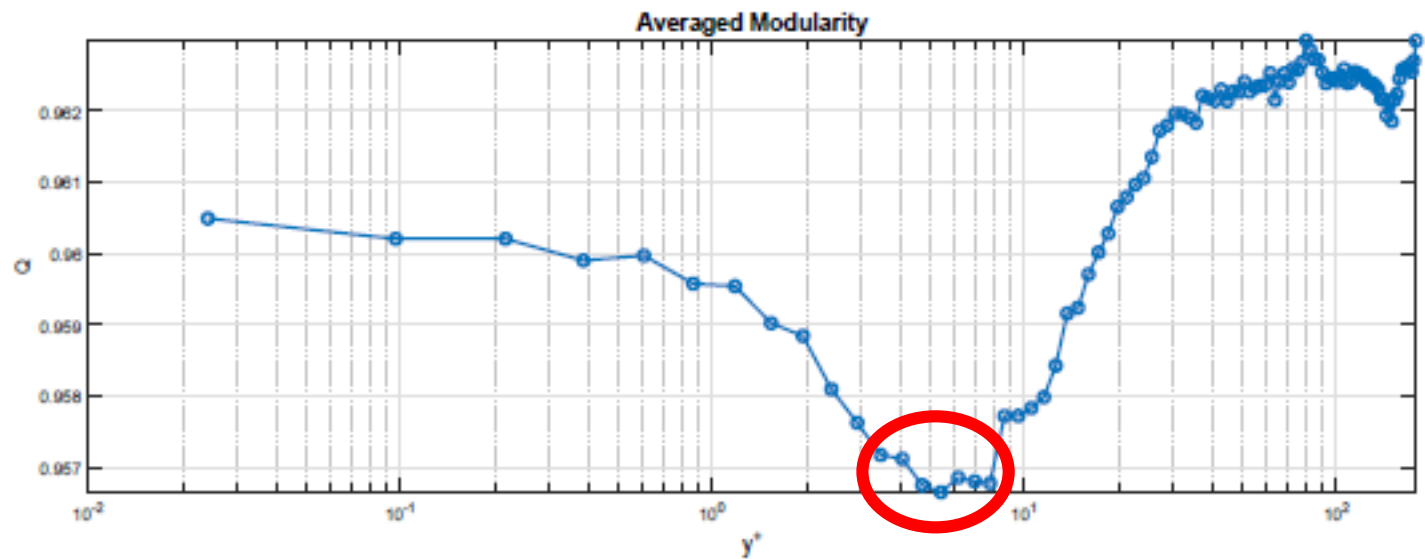
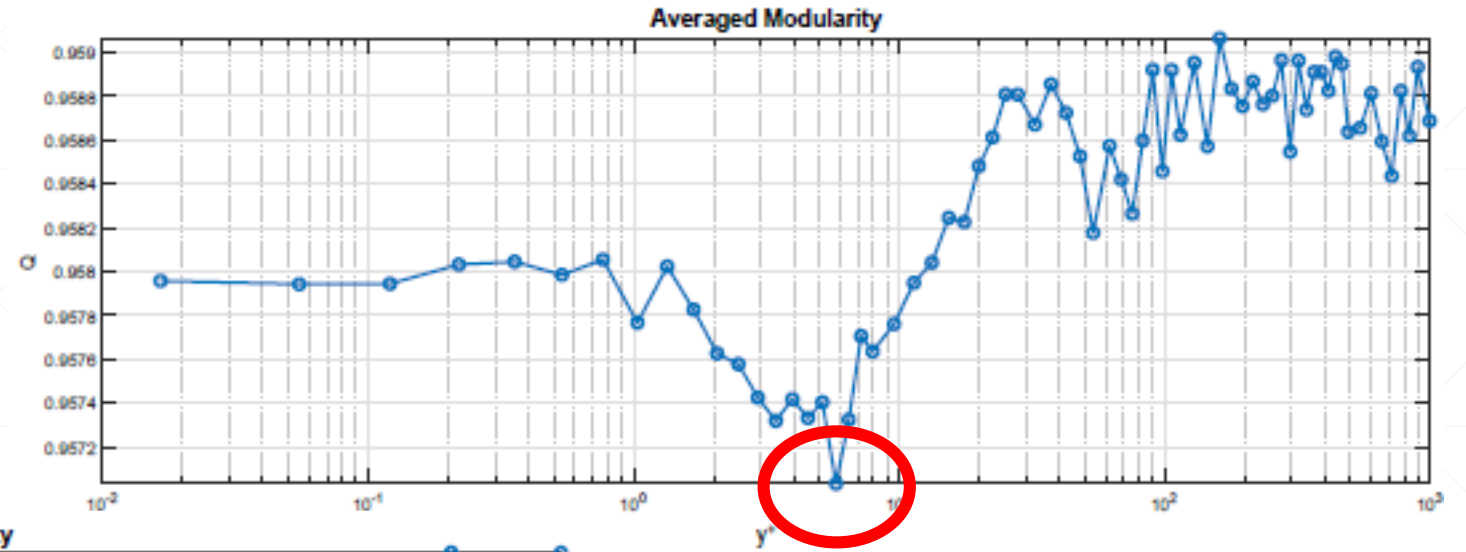
# Legame tra $C$ e le serie temporali



# Legame tra $d_{1n}$ e le serie temporali



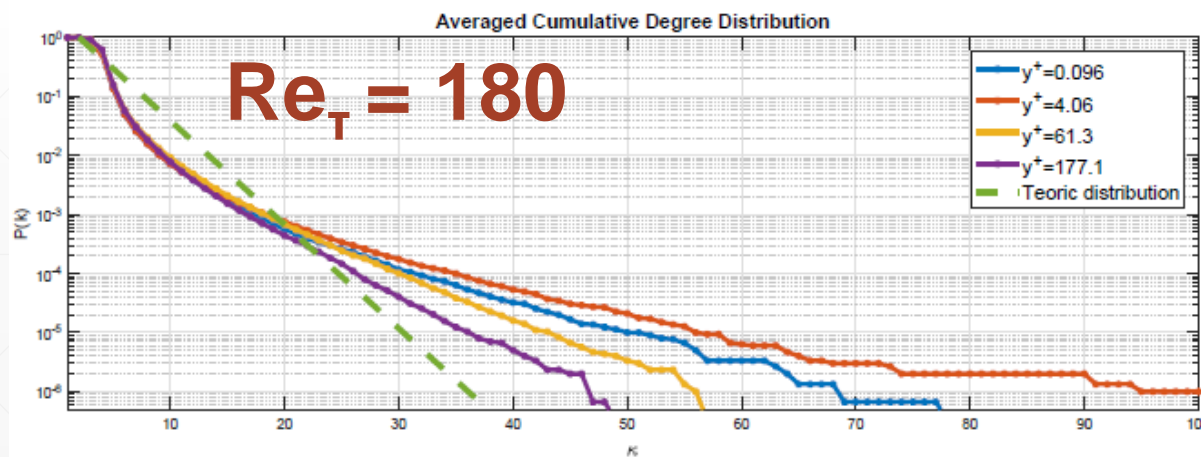
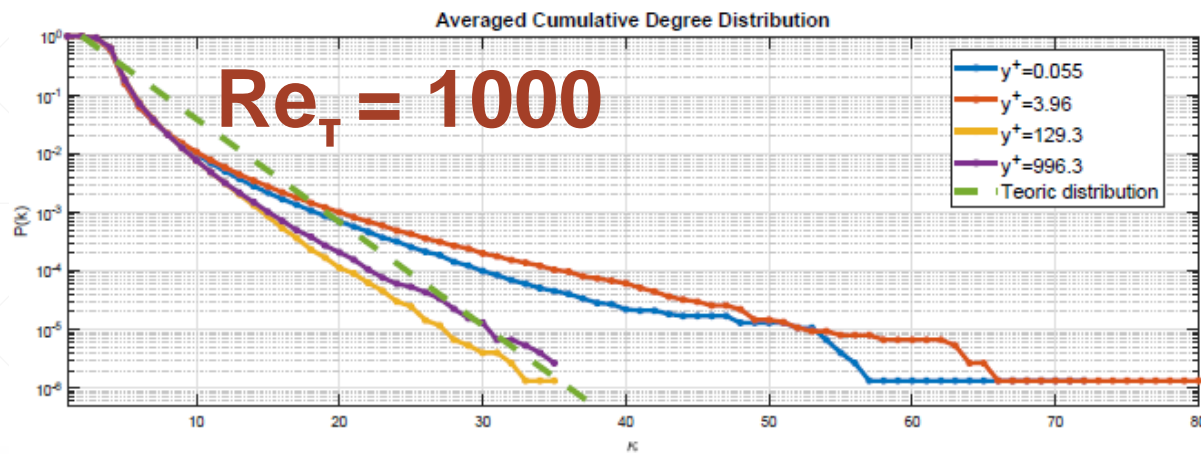
# La modularity $Q$



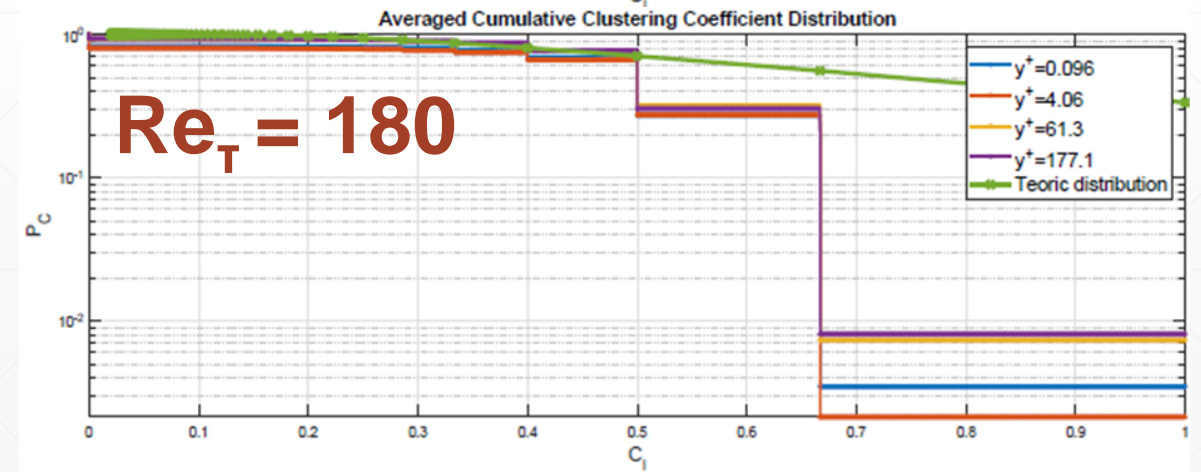
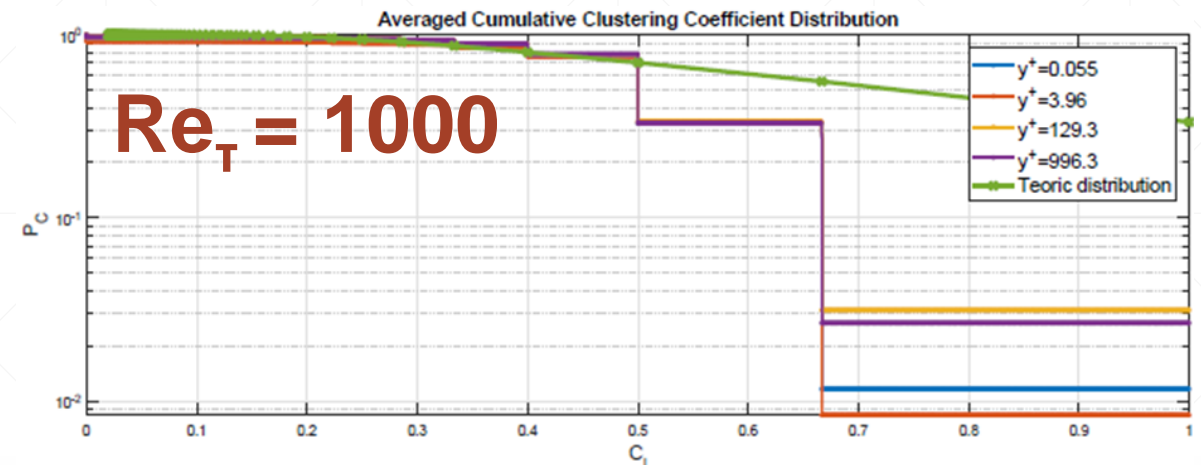
$$y^+ = 5 \div 6$$



# Distribuzione cumulativa di $P_k$



# Distribuzione cumulativa di $P_C$



# Conclusioni

L'applicazione dell'algoritmo di visibilità orizzontale allo studio delle serie temporali turbolente ha permesso di:

- evidenziare la loro struttura temporale caratteristica:

- **Picchi**
- **Irregolarità**

La loro ricorrenza dipende dall'energia del flusso e quindi da  $Re_\tau$

- riconoscere regioni del flusso turbolento (es. **sottostrato viscoso**)

## Vantaggi

- Strumento semplice e potente
- Grandi quantità di dati
- La struttura temporale delle serie si conserva nelle reti
- Analisi di grandezze non mediate
- Metodo predittivo

## Svantaggio

- Irreversibilità della mappatura



Grafi pesati o orientati

# Grazie per l'attenzione

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