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Scale-wise relaxation to isotropy in direct numerical simulations (turbulent channel and turbulent boundary layer)

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Introduction / Theory

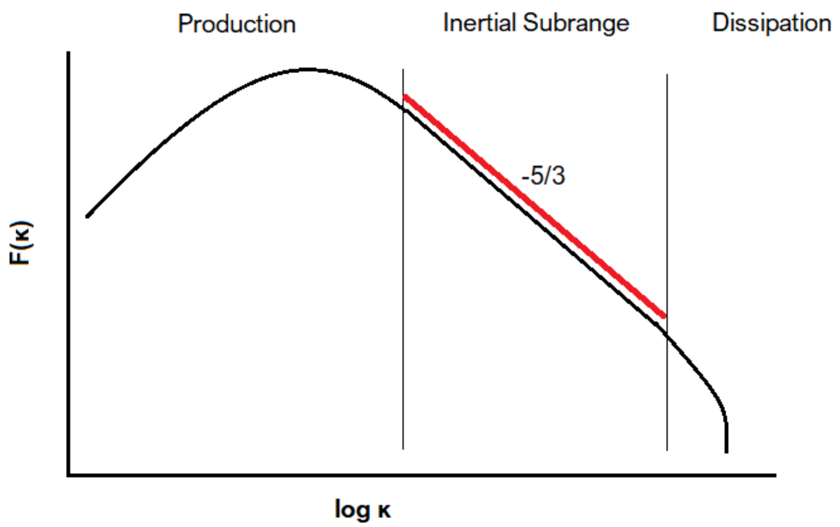
Isotropic turbulence and Kolmogorov hypotheses:

- **Isotropy** $\overline{u'^2} = \overline{v'^2} = \overline{w'^2}$
- Local isotropy
- 2nd similarity hypothesis:

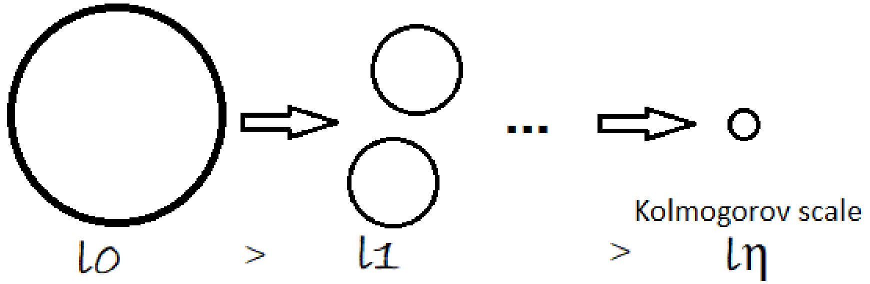
  $F(\kappa) = c_E \, \varepsilon^{2/3} \, \kappa^{-5/3}$ or $S(r) = c_{sf} \, \varepsilon^{2/3} \, r^{2/3}$

- For 2nd order structure functions:

  $S_v/S_u = S_w/S_u = 4/3$



Turbulent Kinetic Energy (TKE) Spectrum



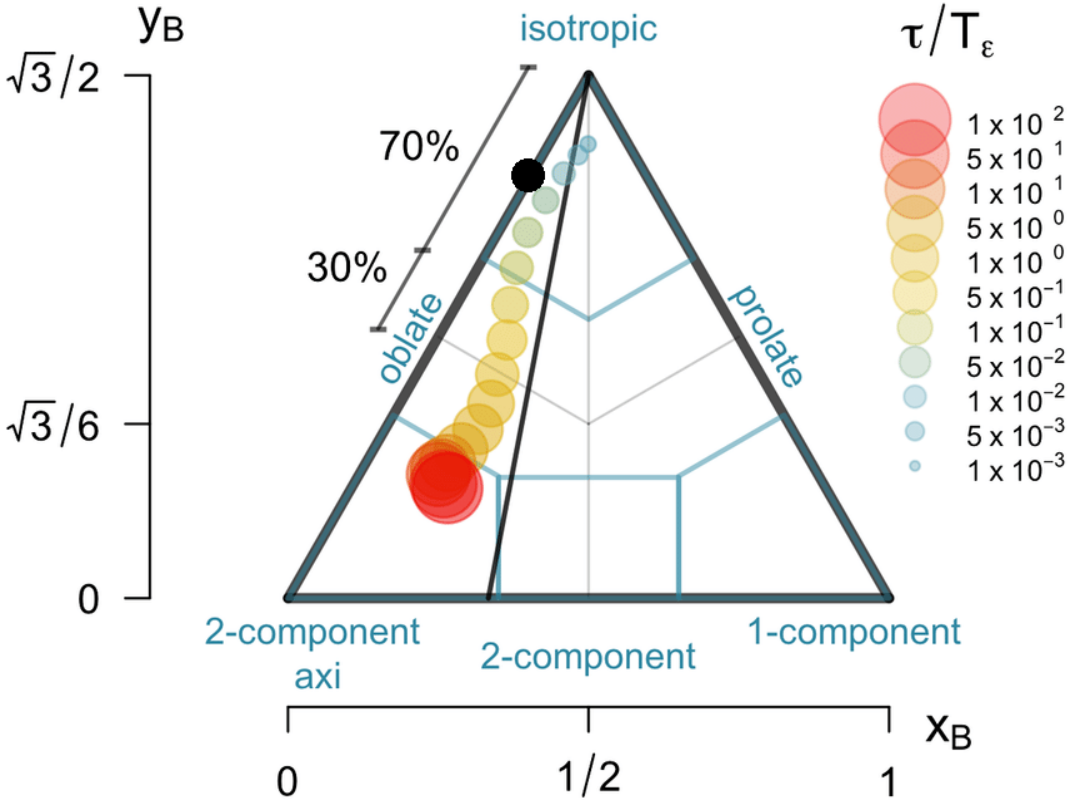
Introduction / Theory

Barycentric map (scalewise):

A linear representation of anisotropy invariant map (AIM, Lumley triangle)

1. Anisotropy stress tensor: $b_{ij} = \frac{\overline{u'_i u'_j}}{\overline{u'_l u'_l}} - \frac{1}{3}\delta_{ij}$
2. 3 eigenvalues: $\lambda_1, \lambda_2, \lambda_3$
3. Anisotropy invariants: $x_B = \lambda_1 - \lambda_2 + \frac{1}{2}(3\lambda_3 + 1)$

$$y_B = \frac{\sqrt{3}}{2}(3\lambda_3 + 1)$$



Stiperski et al.(2021)

Simulations

Turbulent channel (neutral stratification):

- Re=180 (Mansour, Kim and Moin 1988)
- Re=5200 (Lee and Moser 2014)

$$Re_\tau = \frac{u_* h}{\nu}$$

Turbulent boundary layer (TBL):

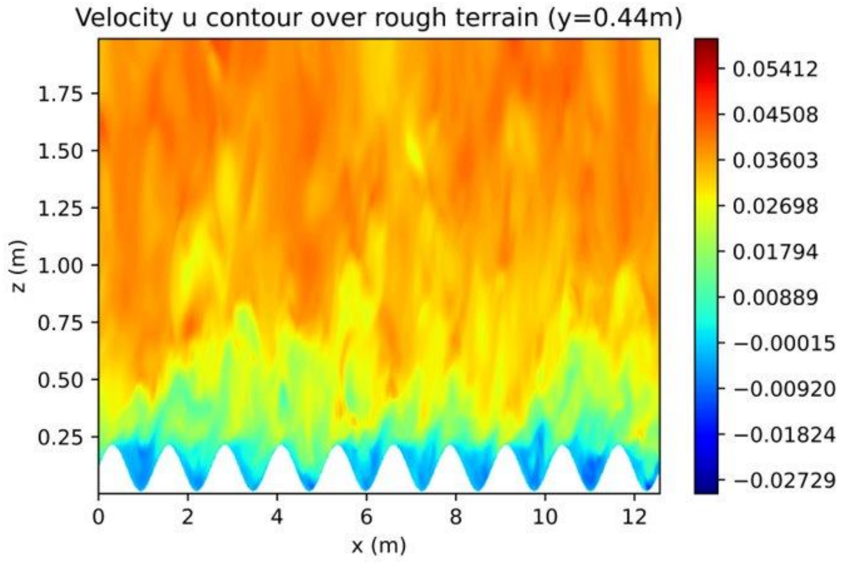
- MicroHH (4th order numerical schemes, top BC: free slip, bottom BC: no-slip, lateral BC: periodic)
- 4 cases (neutral stratification):

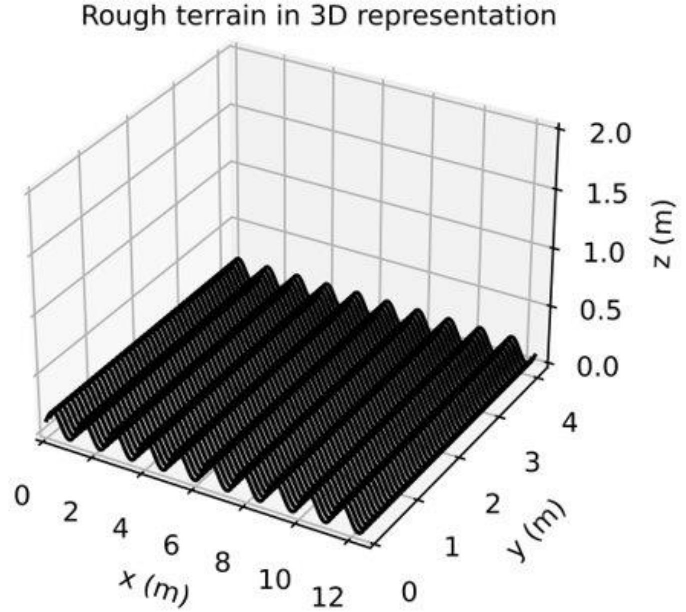
a) Low Re (180), flat terrain

b) Low Re (180), rough terrain (wavy)

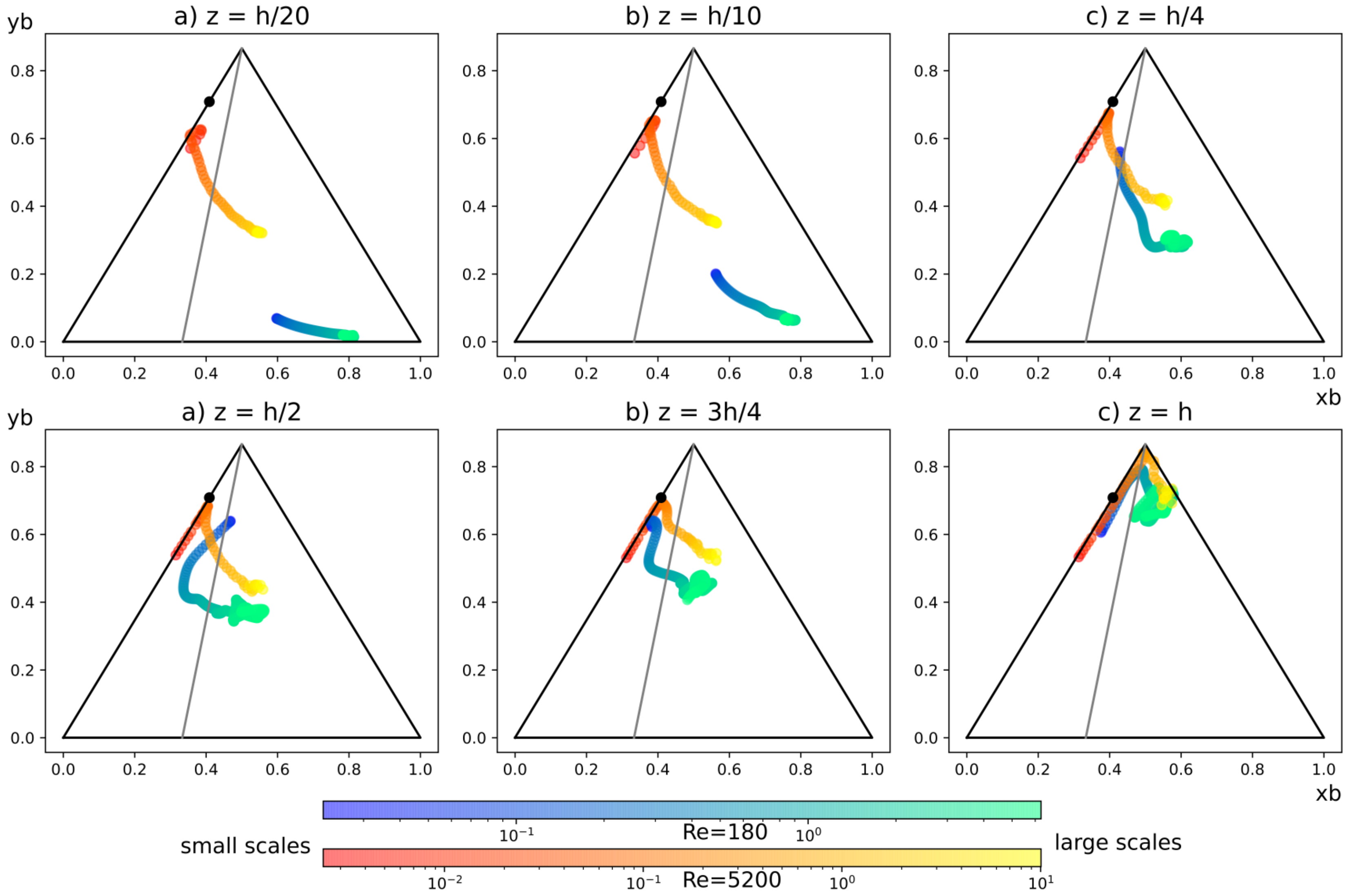
c) High Re (3800), flat terrain

d) High Re (3800), rough terrain (wavy)





Channel flow (low Re vs high Re)

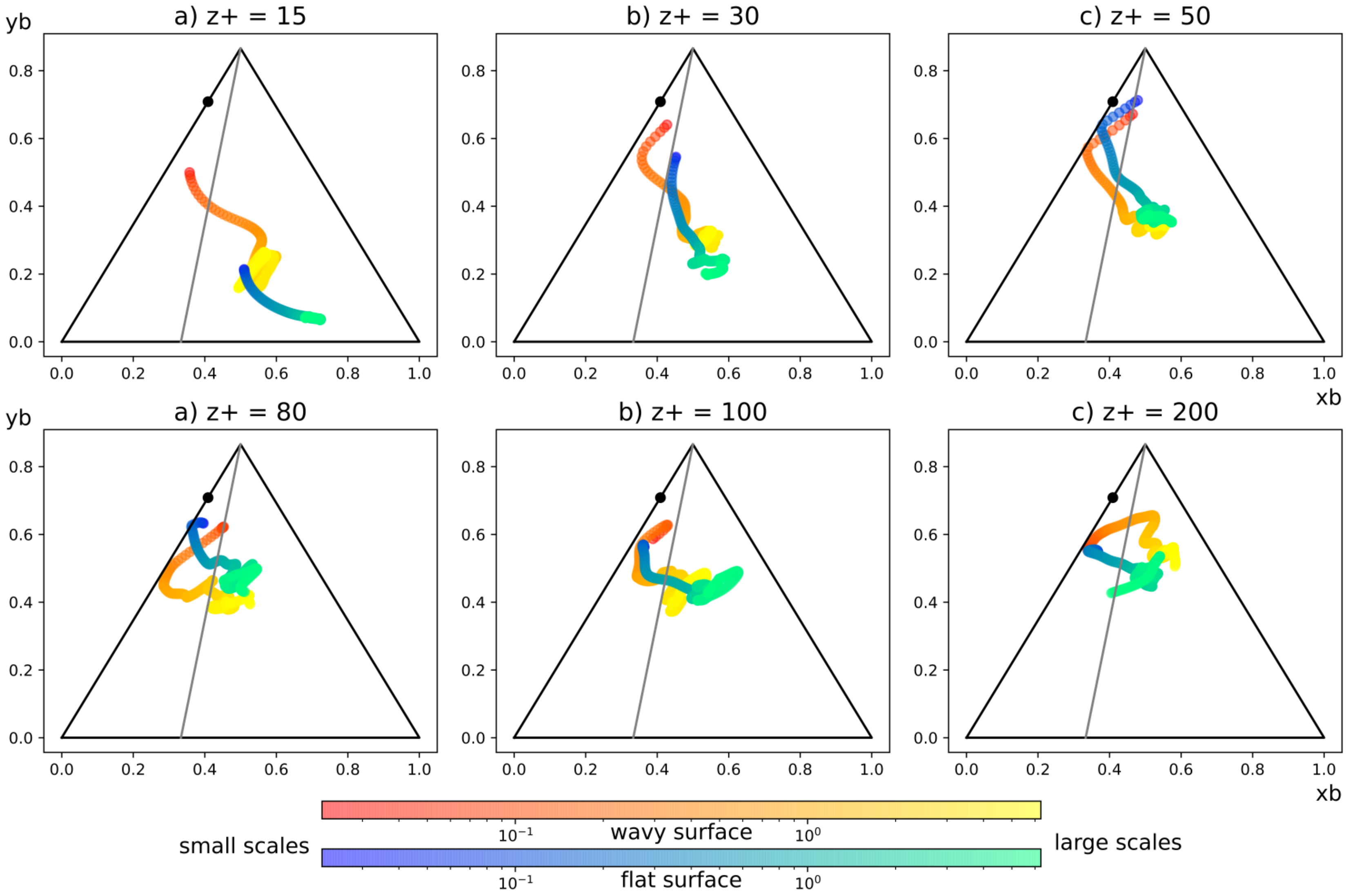


I. For **high Re integral** scales are more isotropic

II. The **further** from the **surface** the more isotropic the flow

III. Deviation of **dissipative scales** from isotropy (high Re)

TBL (low Re, smooth vs rough)



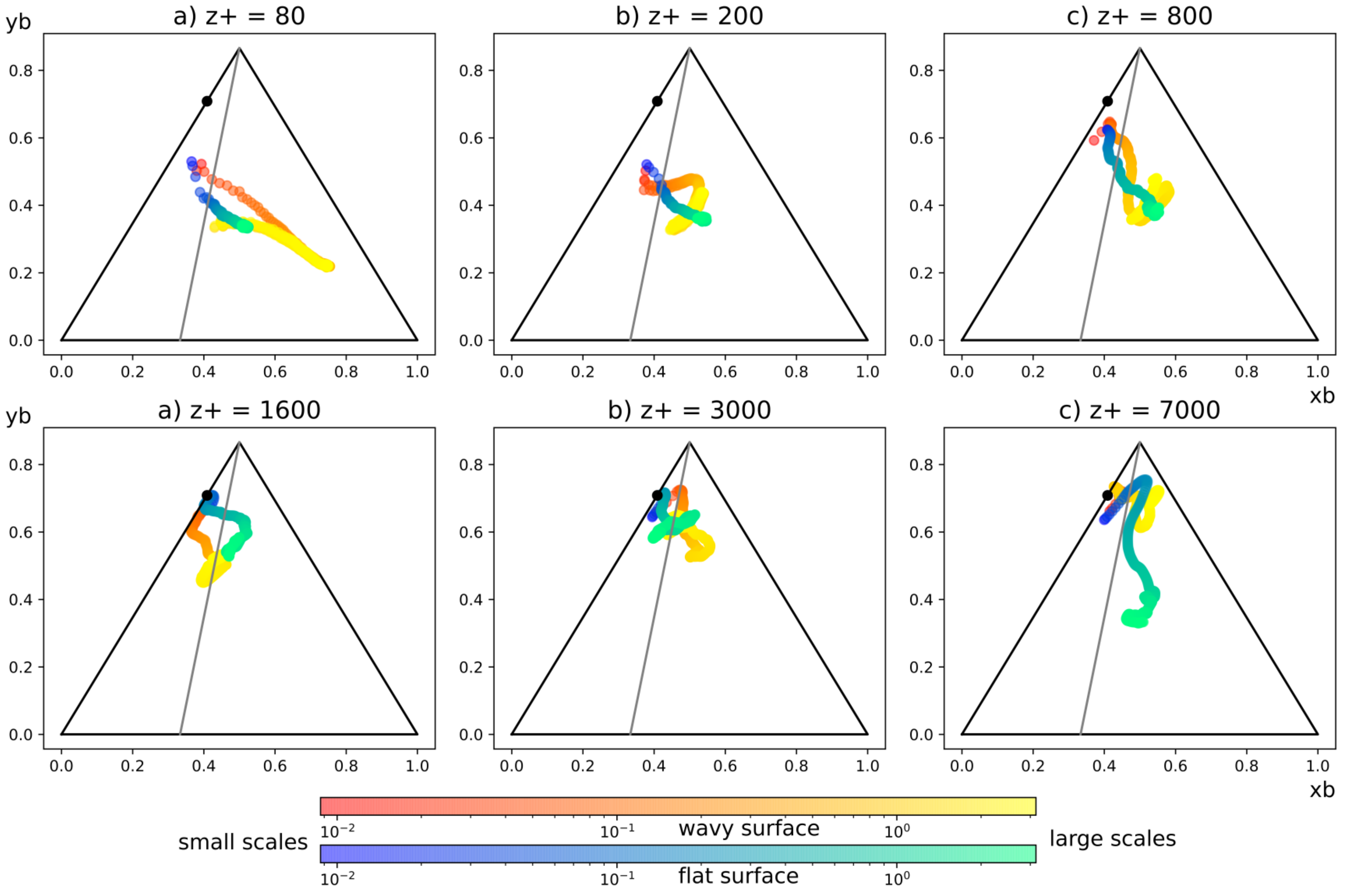
Non-dimensional height z+:

$$z+ = \frac{zu_*}{\nu}$$

I. Close to the **rough** surface the relaxation to isotropy is more significant

II. Away from the surface both cases tend to have similar behaviour

TBL (high Re, smooth vs rough)

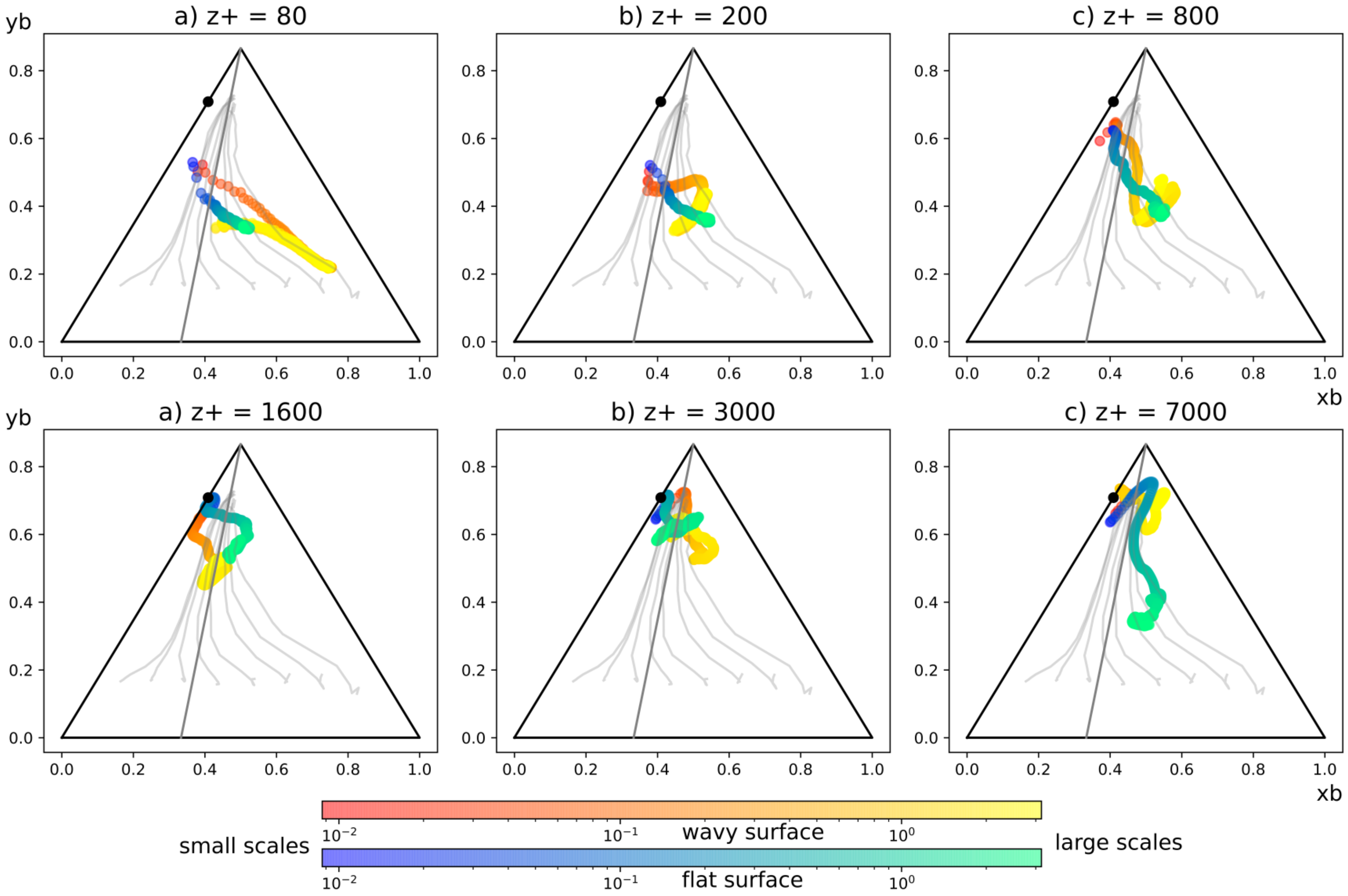


I. The **dissipative scales** are **independent of roughness**

II. The **bigger scales** are affected by roughness within the **roughness sublayer**

III. Out of the **surface layer** the **dissipative scales** are isotropic

TBL (high Re, smooth vs rough vs observations)



I. There is **no match with observations** of Stiperski et al (2021)

II. Observations are clustered and the **trajectories converge towards plane strain**

Conclusions

- Scale-wise relaxation to isotropy depends on **Re**
- Away from the surface the **dissipative scales** are isotropic
- **Roughness** benefits the return to isotropy within the **surface layer** (for low Re)
- In **channel flow** and in **high Re TBL** there is a deviation of **dissipative scales** from the "expected" trajectory...

Thank you for your attention!

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