Wind veer and wind speed in turbulent Ekman flow

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(1) Peculiarities of PBL Turbulence

interacts with other processes in the PBL system

Boundary conditions, cloud physics, radiation, energy extraction

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turbulent at high Reynolds number, but never everywhere (external flow)

external intermittency, even close to the surface

stratified convective and stable, but never truly neutral

strongly convective (Rayleigh–Benard like) to near-laminar regimes

rotates important despite small Rossby number

height-dependent wind; mean flow normal to pressure gradient; symmetry breaking

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- fundamentally – Turbulence closure: flux = F (?)
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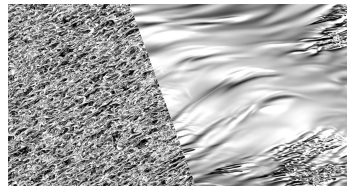
processes interaction

Wake clouds (Hasager et al., energies, 2017)

turbulence breakdown/suppression



Enstrophy of neutral/stable PBL

heterogeneity/non-stationarity

(Photo: C Ansorge)

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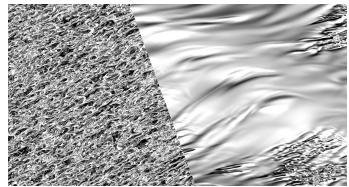

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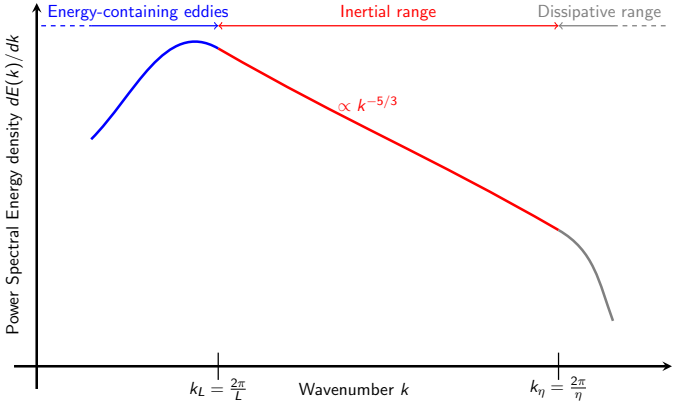
Violation of scale-invariance assumption **at small scale**

... What can we do?

(3) Scale similarity and turbulence simulation



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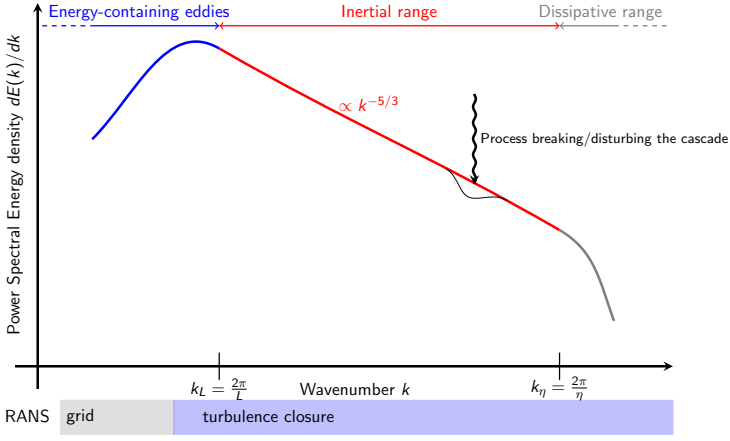

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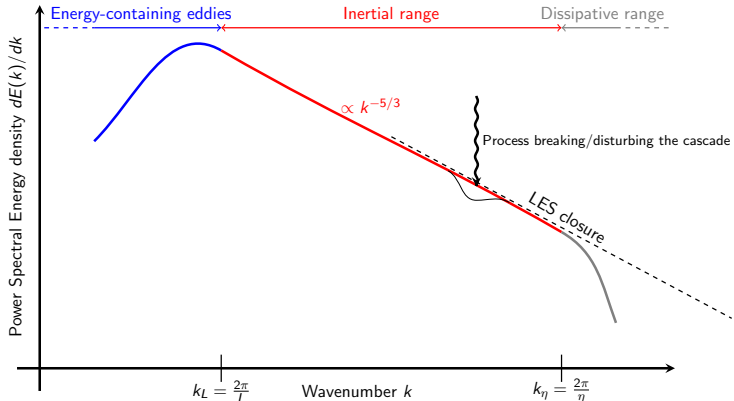

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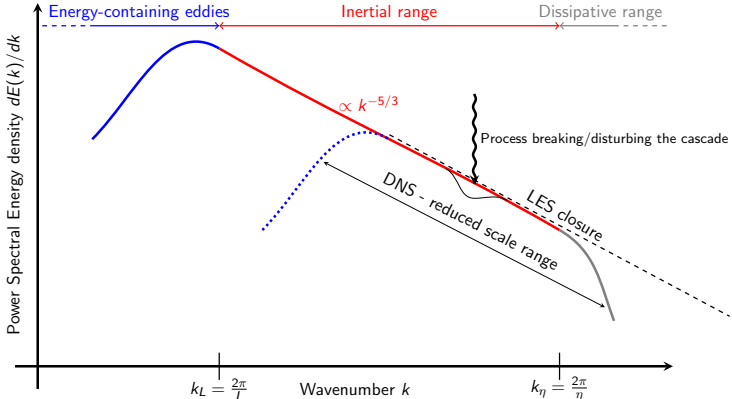

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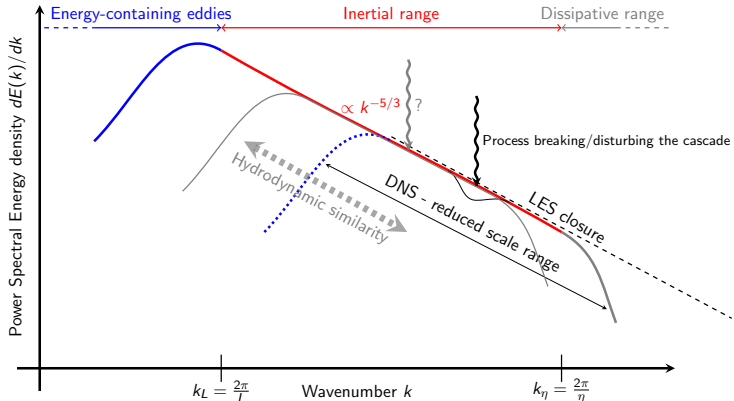
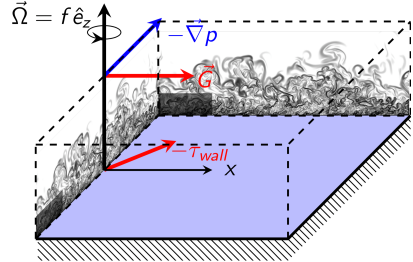


(4) Ekman flow as virtual Lab

[Ansorge & Mellado, BLM (2014)]

- strip problem to fluid-mechanical core
- solve as accurately as possible (DNS)
- postulate scale similarity [video]



Examples

(1) Rough Boundary Layer ($\rightarrow$ this session, EGU22-9463 2:09pm)

(2) Very stable Arctic ABL ($\rightarrow$ AS2.13, EGU22-9646, Tue 5:00pm)

(3) **Wind profiles**

(5) Wind profiles – Do we known $\underbrace{(U, V)}_{\text{Speed + Direction}} = f_{\text{neutral}}(RE)$?

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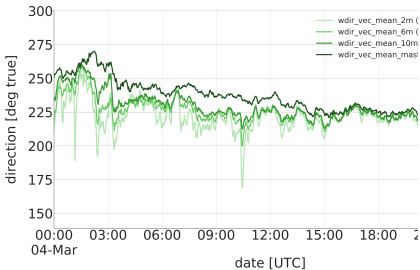
  $\Rightarrow$ systematic yaw for wind turbines



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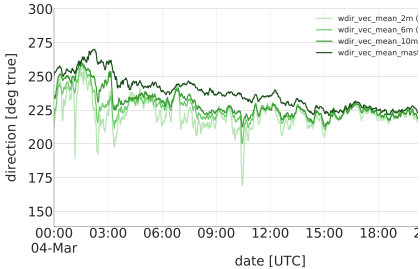
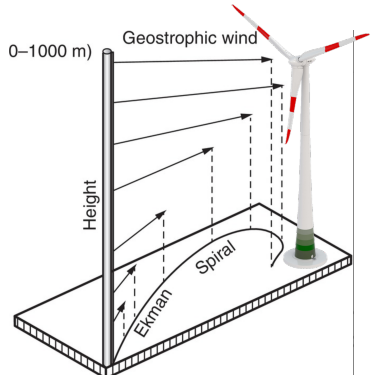


MOSAiC 2019/20 Wind direction data at 30, 10, 6, 2m; Courtesy of M. Shupe (NOAA)

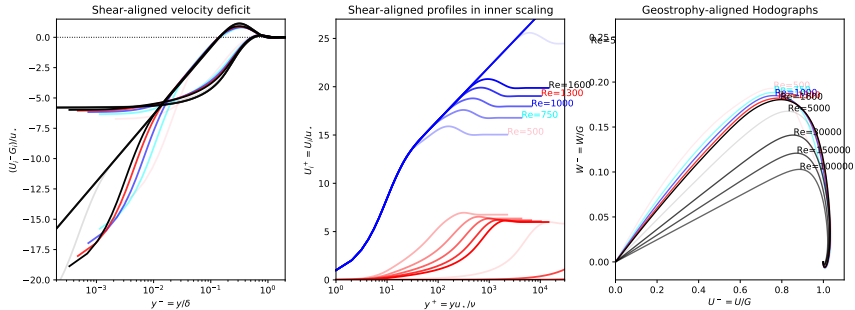


Modified after Brasseur & Jacob: Parameterization of SGS Processes in: Modelling of Atmospheric Chemistry.

(6) Wind profiles – Do we known $\underbrace{(U, V)}_{\text{Speed + Direction}} = f_{\text{neutral}}(RE)$?

DNS data for Ekman flow + Scaling Hypotheses

$\Rightarrow$ Closed formulation for any RE based on DNS data up to $RE_\tau \approx 3000$



- quantified trend towards high-RE
- bridged scale gap between DNS and atmosphere

(7) What comes next?

(1) extension of profile theory to **stable stratification**
incorporate measurements

(2) suppose, we can let $f(RE, z_0) = f(RE/RE_r)$
investigate different roughness configurations directly [cf. Ansorge, BLM 2019]

(3) extension to complex (real) problems
(urban environments / wind energy)