Spectral transfer of TKE and scalar variance in the meso- and micro-scale range: direction of the average flow and the significance of backscatter

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The spectral gap ...

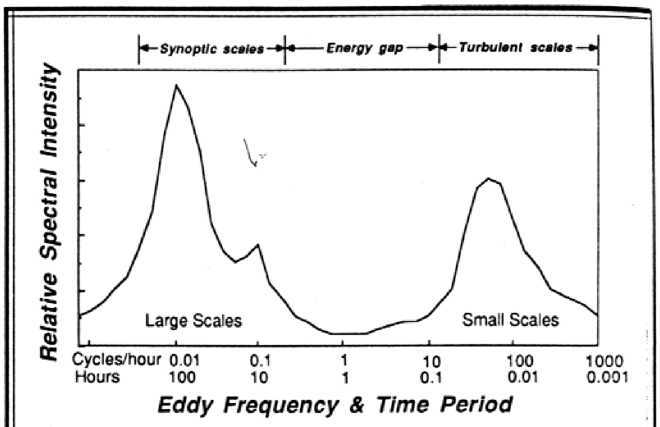
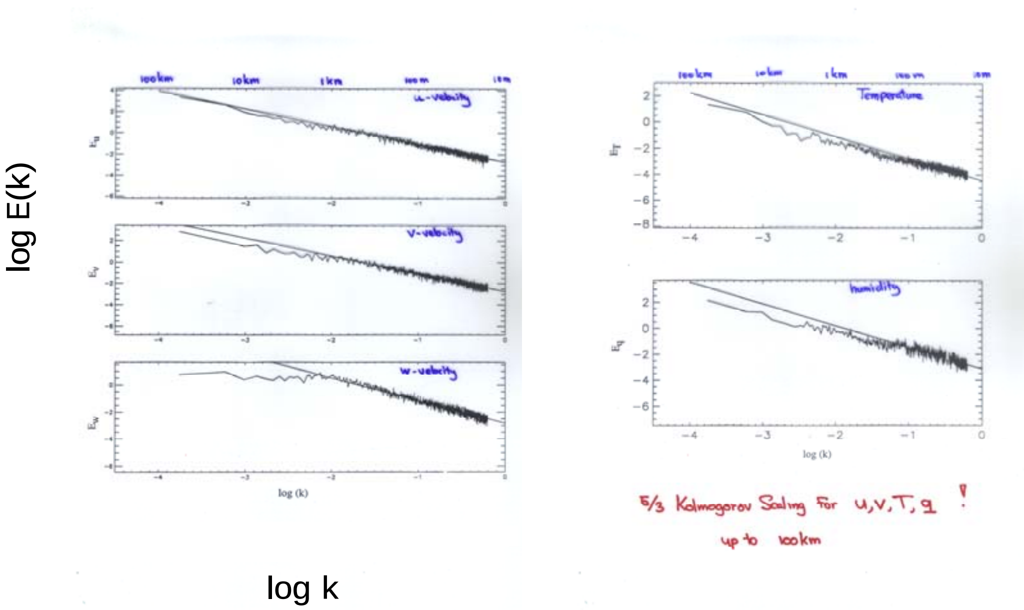
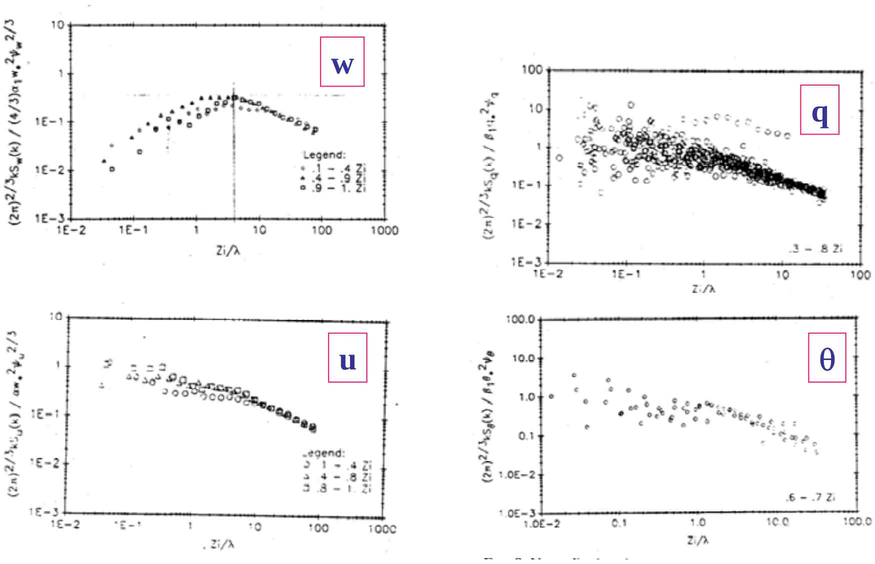


Fig. 2.2 Schematic spectrum of wind speed near the ground estimated from a study of Van der Hoven (1957).

ASTEX aircraft observations

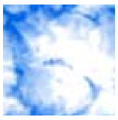


Atmospheric Observations: Sc
Nucciarone & Young 1991

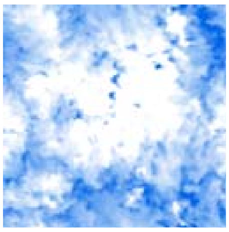


LES of Sc (ASTEX) Horizontal slice, t = 12hr, liquid water ql

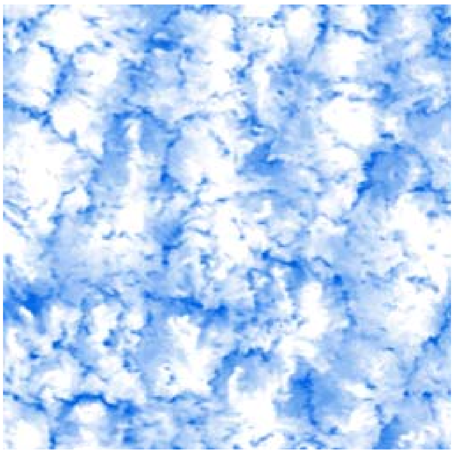
L = 6.4km



L = 12.8km



L = 25.6km



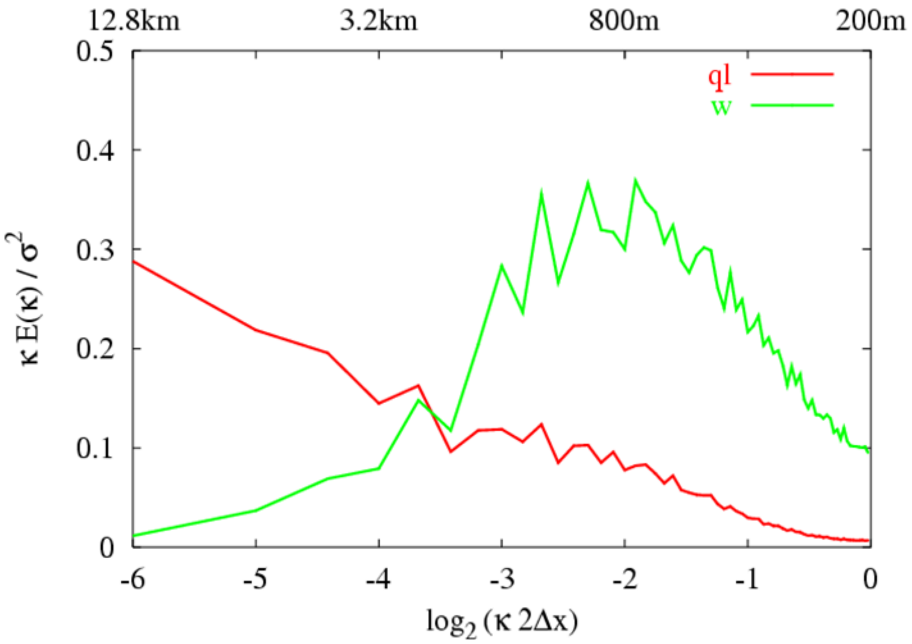
Dx = Dy = 100m

LES of Sc (ASTEX)

Horizontal slice, t = 1...12hr, liquid water ql

L = 12.8km Dx = Dy = 100m

"Large Eddy Simulations: How large is large enough?", de Roode, Duynkerke, Jonker, JAS 2004



1) the formation of **dominating** mesoscale fluctuations is an integral part of PBL dynamics!

- no mesoscale forcings

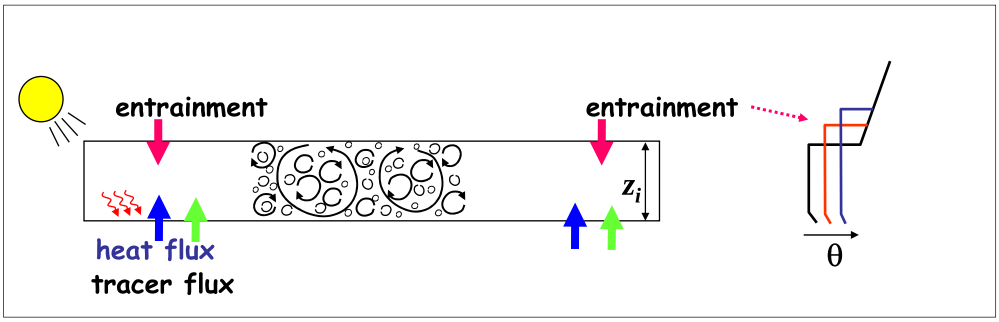
- what is the origin (mechanism) ?

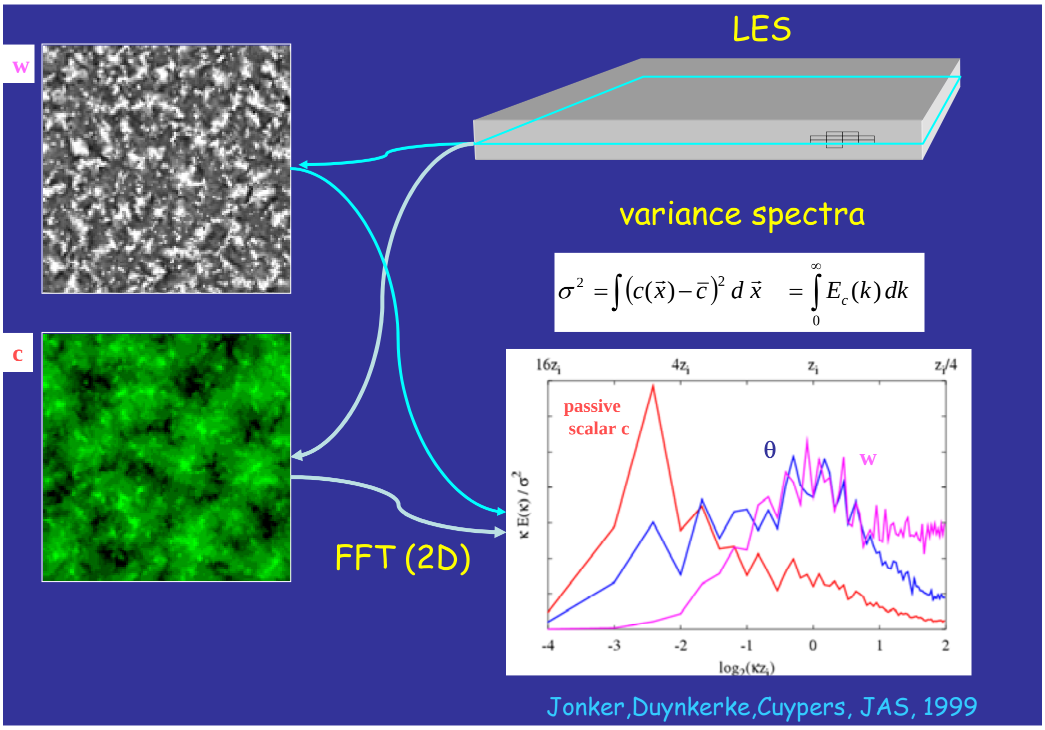
  - latent heat release
  - radiative cooling
  - entrainment
  - inverse cascade

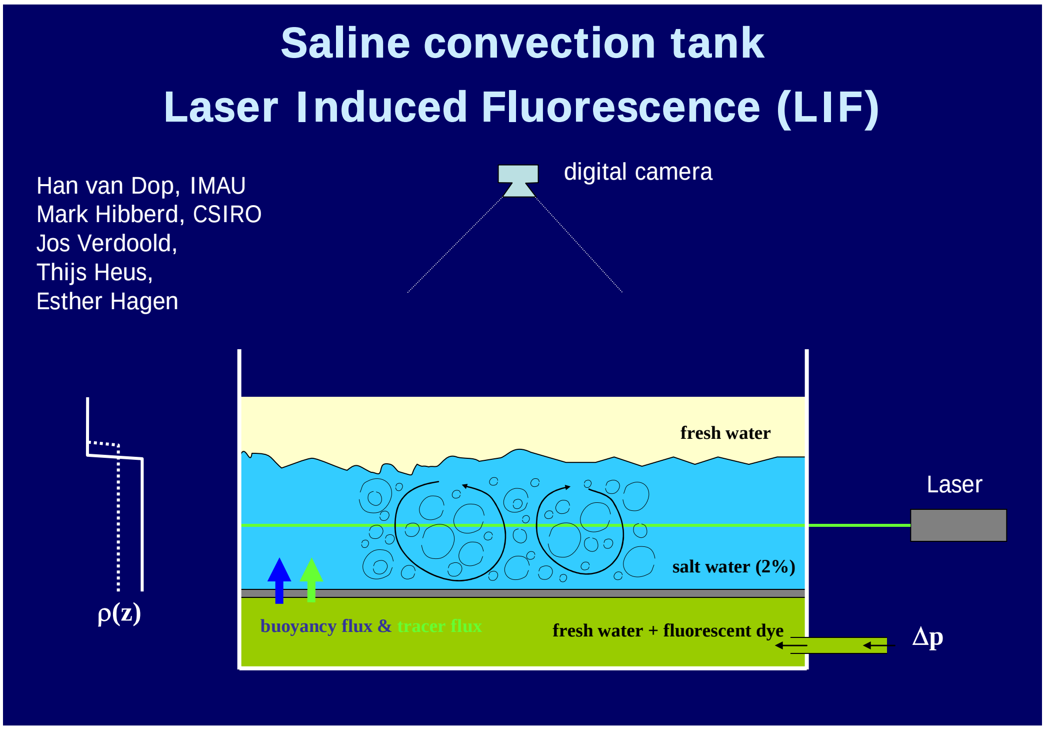
Atkinson and Zhang
Fiedler, van Delden,
Muller and Chlond,
Randall and Shao,
Dornbrack, ……

Convective Atmospheric Boundary Layer

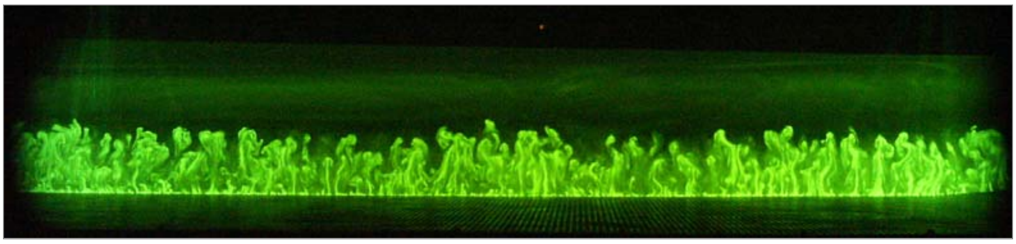
penetrative convection

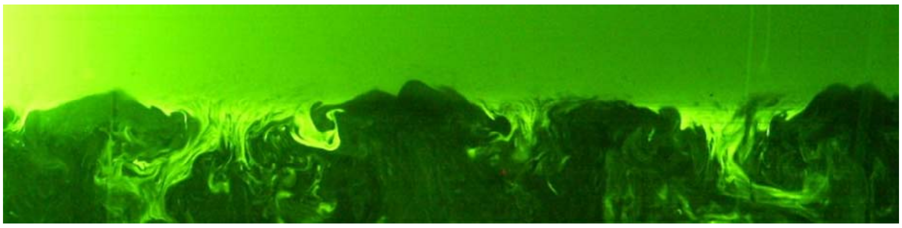



LES
w
c
variance spectra
$\sigma^2 = \int (c(\vec{x}) - \bar{c})^2 \, d\vec{x} \quad = \int_0^\infty E_c(k)\, dk$
FFT (2D)
passive scalar c
θ
w
κ E(κ) / σ²
log₂(κz_i)
Jonker,Duynkerke,Cuypers, JAS, 1999


Saline convection tank
Laser Induced Fluorescence (LIF)
Han van Dop, IMAU
Mark Hibberd, CSIRO
Jos Verdoold,
Thijs Heus,
Esther Hagen
digital camera
fresh water
Laser
salt water (2%)
ρ(z)
buoyancy flux & tracer flux
fresh water + fluorescent dye
Δp

Laser Induced Fluorescence

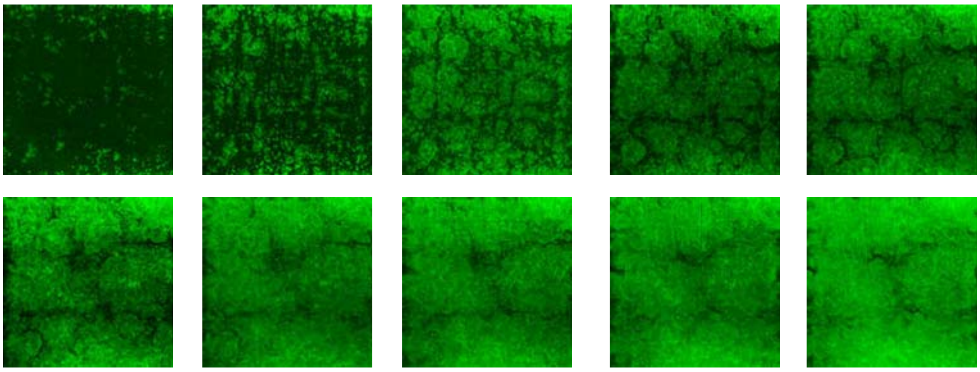




Laser Induced Fluorescence (LIF)

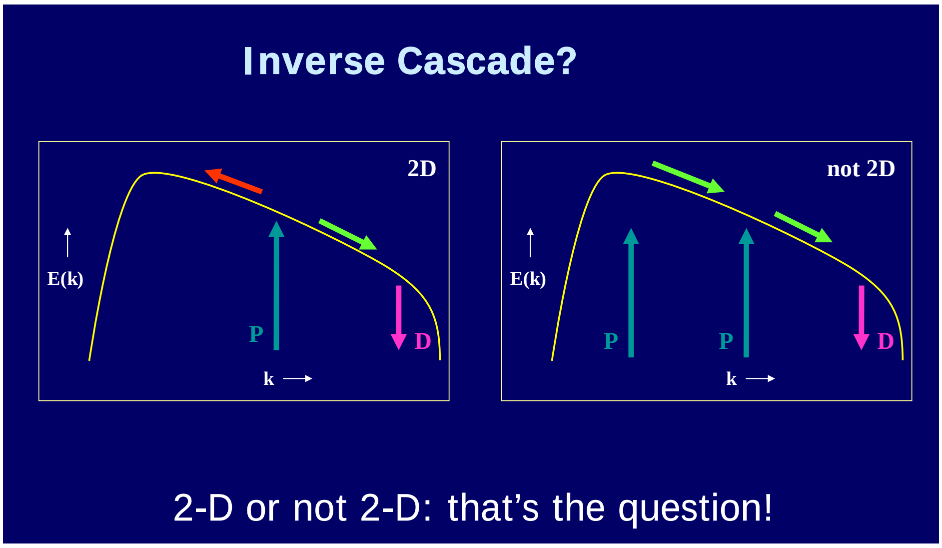
“bottom-up” tracer

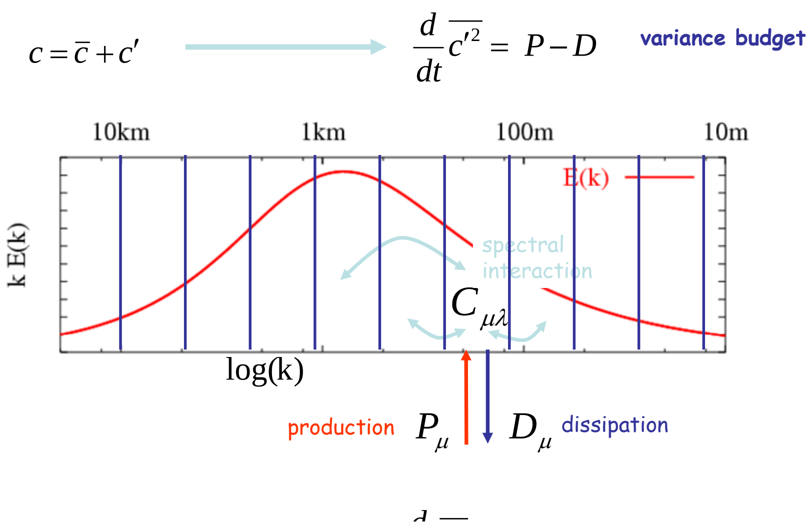
○ **boundary layer depth structure**

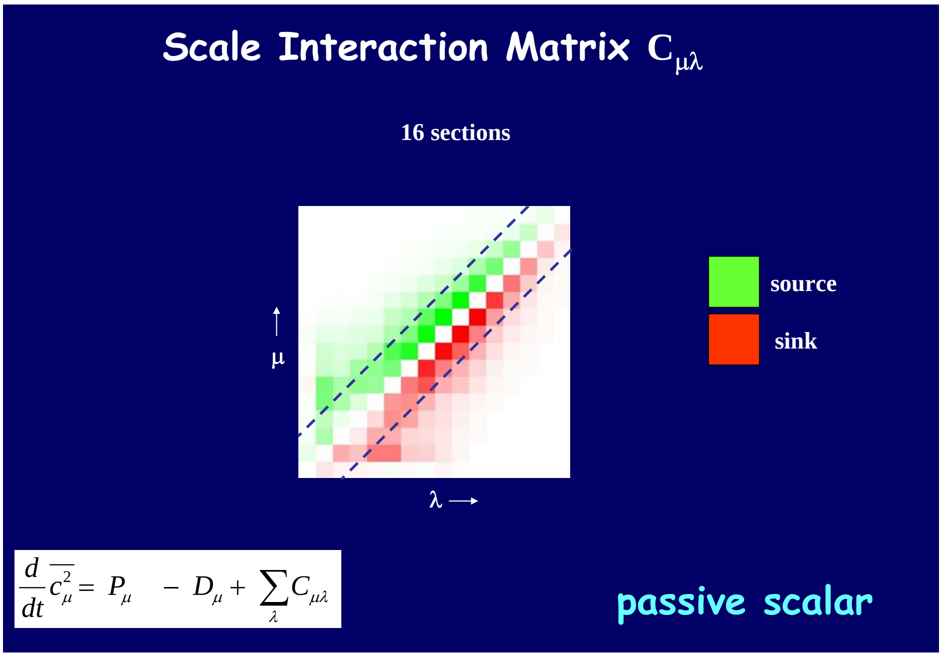


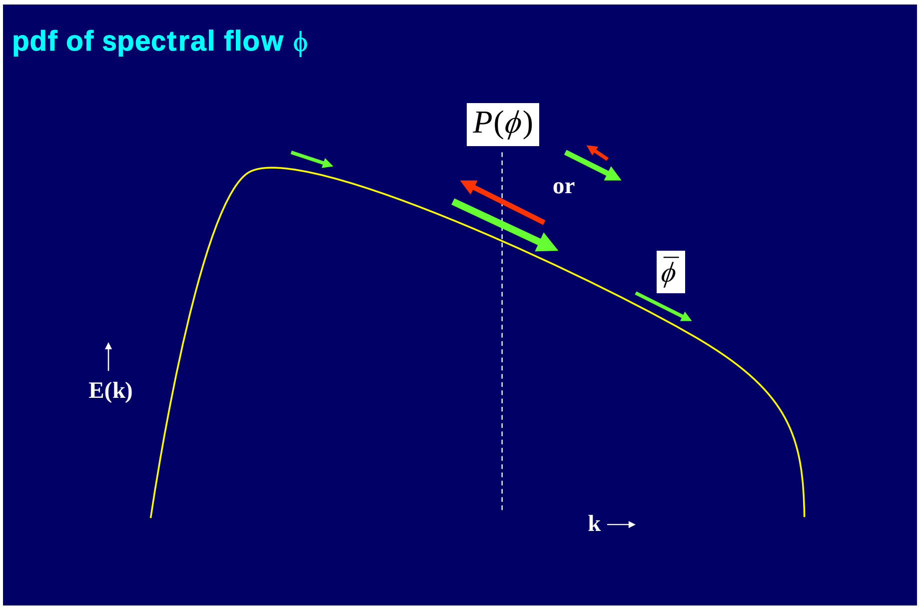
(see also van Dop, et al. BLM 2005)

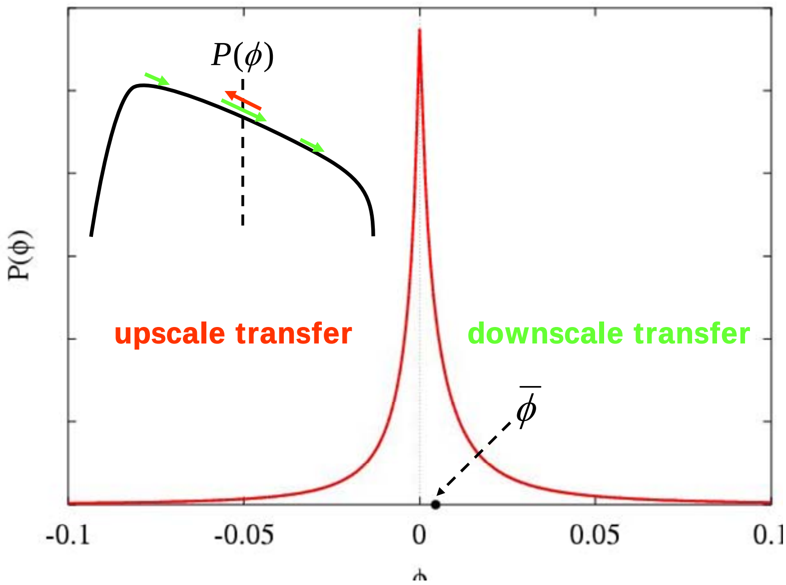
(Verdoold, Delft, 2001)

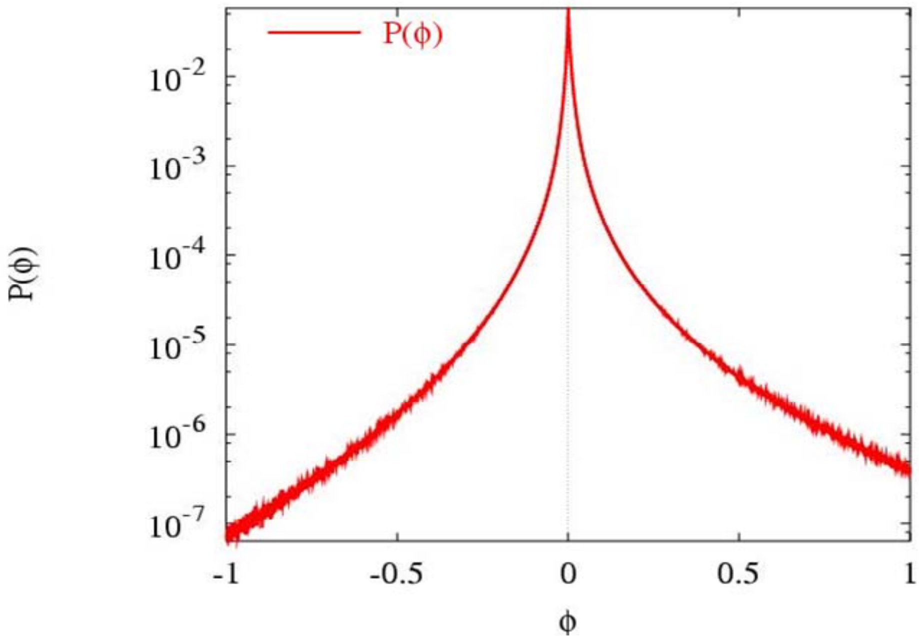

Inverse Cascade?
2D
E(k)
P
D
k
not 2D
E(k)
P
P
D
k
2-D or not 2-D: that's the question!

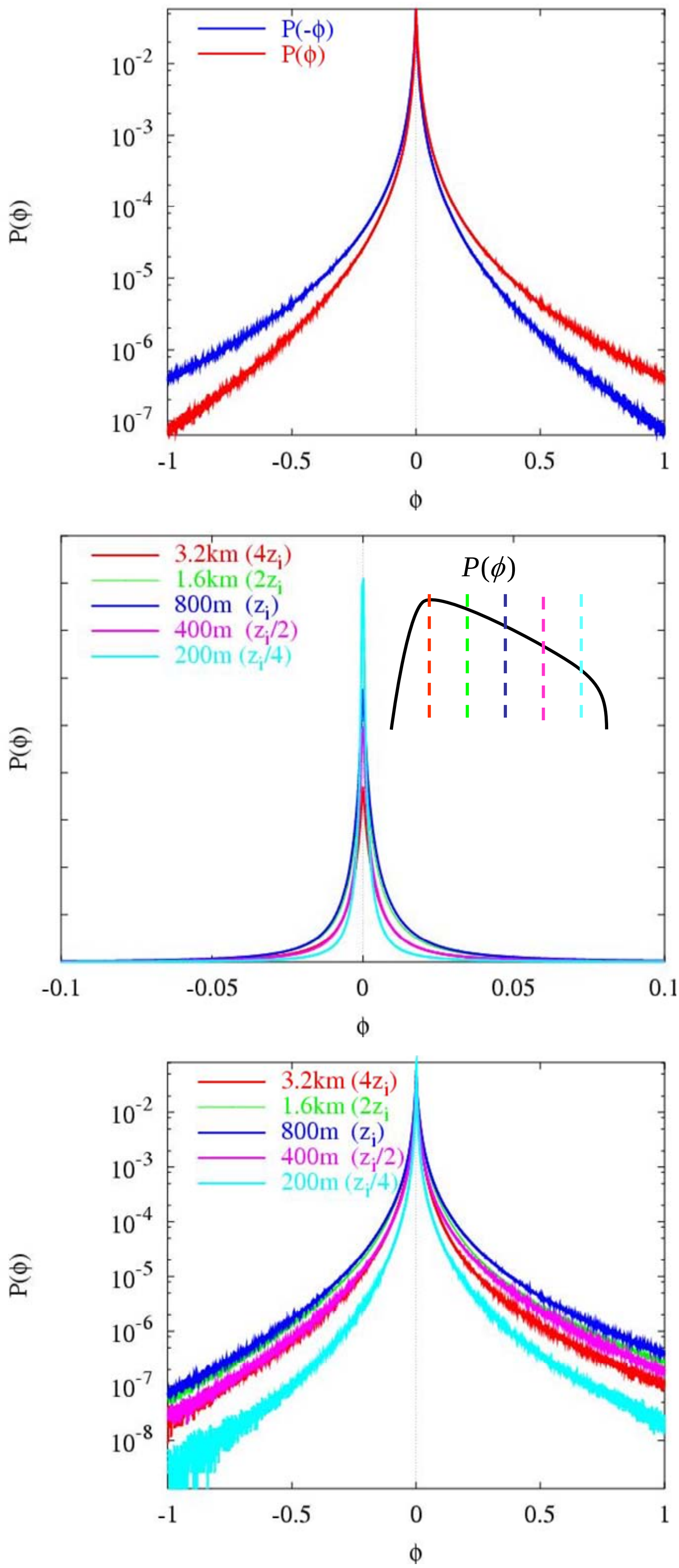

$c = \bar{c} + c'$
$\frac{d}{dt}\overline{c'^2} = P - D$
variance budget
10km
1km
100m
10m
E(k)
k E(k)
spectral interaction
$C_{\mu\lambda}$
log(k)
production
P_μ
D_μ
dissipation


Scale Interaction Matrix $C_{\mu\lambda}$
16 sections
μ
λ
source
sink
$\frac{d}{dt}\overline{c_\mu^2} = P_\mu - D_\mu + \sum_\lambda C_{\mu\lambda}$
passive scalar


pdf of spectral flow ϕ
P(ϕ)
or
ϕ̄
E(k)
k


P(ϕ)
upscale transfer
downscale transfer
ϕ̄
-0.1
-0.05
0
0.05
0.1
P(ϕ)


P(ϕ)
10^-2
10^-3
10^-4
10^-5
10^-6
10^-7
-1
-0.5
0
0.5
1
ϕ
P(ϕ)


P(-ϕ)
P(ϕ)
P(ϕ)
ϕ
3.2km (4z_i)
1.6km (2z_i
800m (z_i)
400m (z_i/2)
200m (z_i/4)
P(ϕ)
ϕ
3.2km (4z_i)
1.6km (2z_i
800m (z_i)
400m (z_i/2)
200m (z_i/4)
P(ϕ)
ϕ

Intermediate Conclusions

1) the formation of **dominating** mesoscale fluctuations is an integral part of PBL dynamics!

2) latent heat and radiation are **not** essential

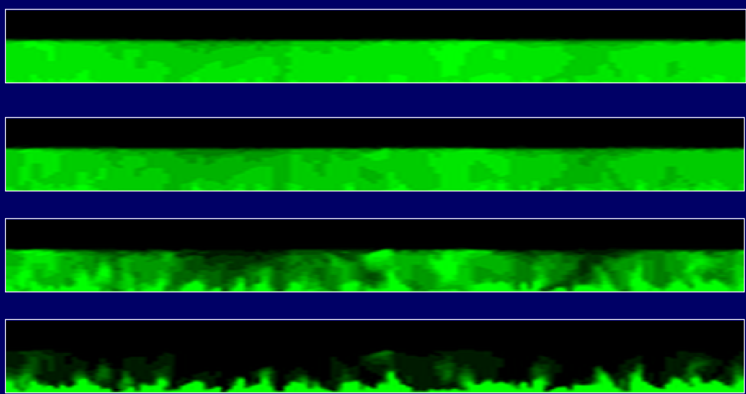
3) budgets show: no inverse cascade
(significant backscatter on all scales)

~~- latent heat release~~
~~- radiative cooling~~
~~- entrainment~~
~~- inverse cascade~~

$$\frac{d}{dt}c = -j\,c$$

LES of reacting species:
Side view at **t = 40 t**$_*$ (10hr)

$$\mathrm{Da} = \frac{t_{\mathrm{turb}}}{t_{\mathrm{chem}}} = j\,t_*$$



Da=10^{-2}

Da=10^{-1}

Da=10^{0}

Da=10^{1}

(Jonker, Vila, Duynkerke, JAS 2004)

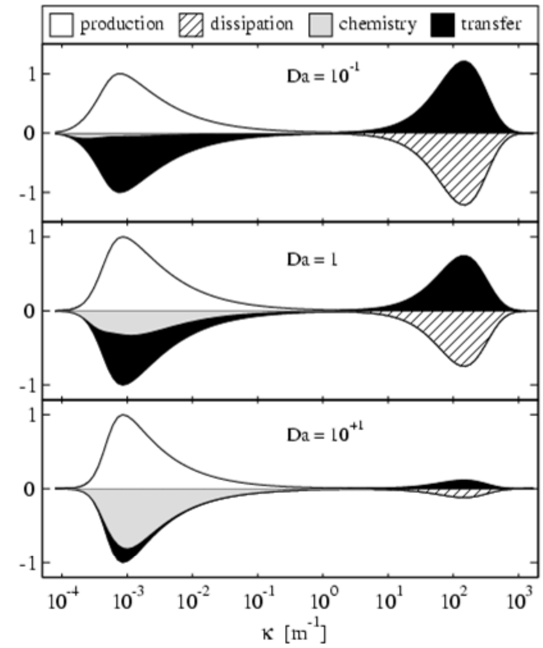
Spectral Model

$$\frac{d}{dt}E_c(k) = -E_{wc}(k)\frac{\partial \bar{c}}{\partial z} - D_c\,k^2 E_c(k) - j\,E_c(k) - S(k)$$

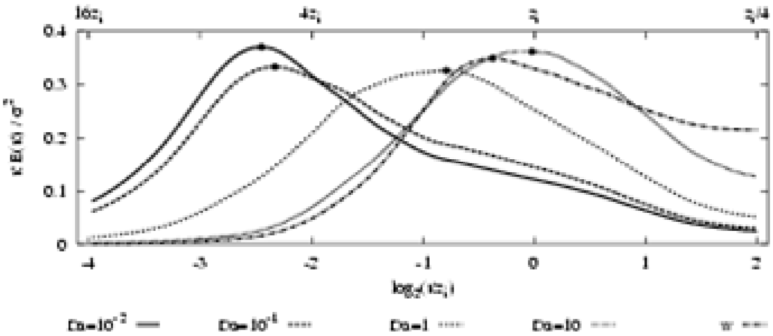
production **dissipation** **chemistry** **spectral transfer**

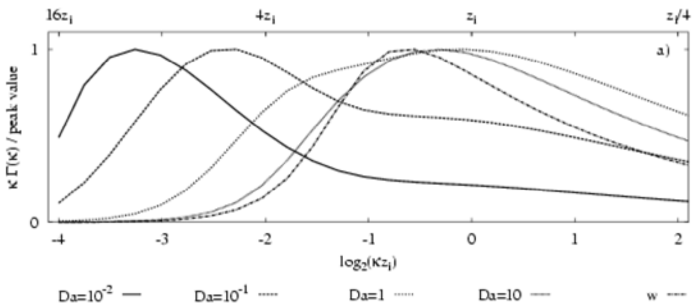
Leith (1967)

$$S(k) = -\frac{d}{dk}\left[k^{13/2}\frac{d}{dk}\left(k^{-3}\sqrt{W(k)}E_c(k)\right)\right]$$



(Jonker, Vila, Duynkerke, JAS 2004)



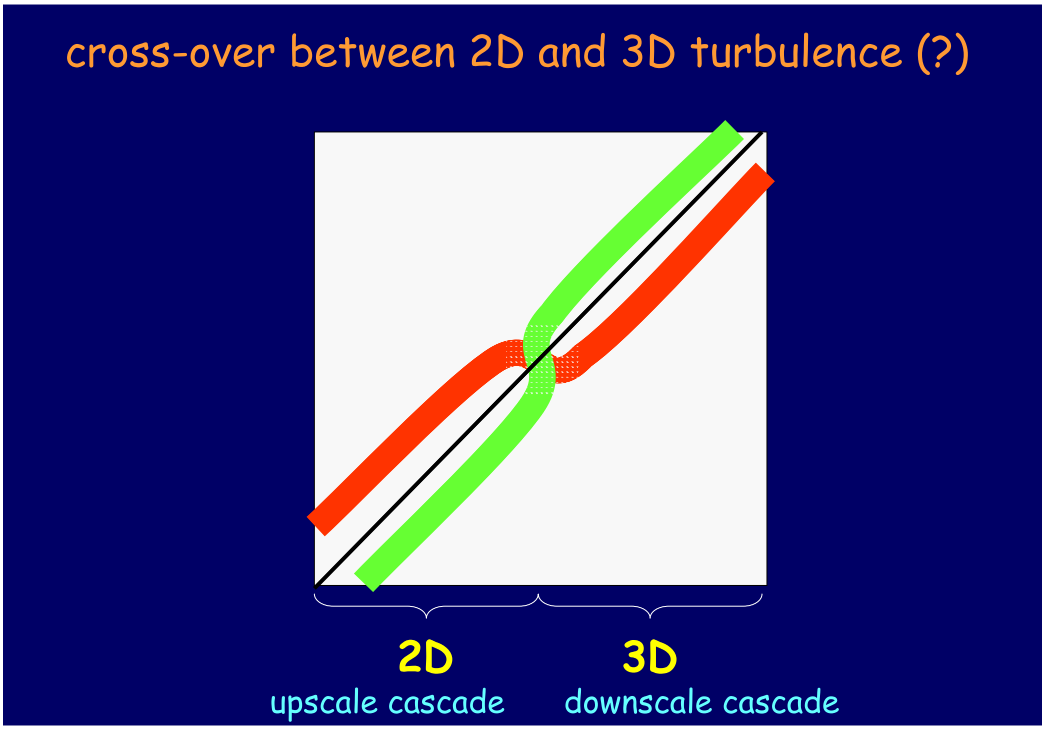


$$\frac{d}{dt}E_c(k) = -E_{wc}(k)\frac{\partial\overline{c}}{\partial z} - D_c k^2 E_c(k) - j\,E_c(k) - S(k)$$

production **dissipation** **chemistry** **spectral transfer**

$$P(k) \sim \sqrt{W(k)E_c(k)}\,\frac{c_*}{z_i} \quad = \quad kE_c(k)\sqrt{kW(k)} \sim S(k)$$

$$\Rightarrow \qquad E_c(k) \sim k^{-3} \qquad t(k) \sim \left(k^3 W(k)\right)^{-1/2}$$



Conclusions

1) the formation of **dominating** mesoscale fluctuations is an integral part of PBL dynamics!

2) latent heat and radiation are **not** essential (but speed up the process considerably)

3) budgets: no inverse cascade on average.
significant backscatter (on all scales)

4) production: ineffective (slow), but spectral transfer is just as ineffective

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TUDelft