Simulations of a Convective Boundary Layer with a Dynamic Smagorinsky Scheme

Modelling the Greyzone Boundary Layers (GreyBLs)

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Modelling Turbulence with grid spacing (Δ)

BL resolved
·Δ of O~50m
·Used for research purposes
·Assumption: Δ<<ℓ
·Resolves large eddies
·Small eddies parametrized

Greyzones
·Δ of O~1km
·Starting to be used in NWP
·Situation: Δ≈ℓ
·LEM and low resolution parametrizations not suitable

BL not resolved
·Δ > 1km
·Used over many years for weather forecasting and climate modelling
·Assumption: Δ>>ℓ
·BL- parametrized fully

Δ

- Convective Boundary Layer in grey zones because large eddies scale with boundary layer height
- Dynamic model – considered as one possible model suitable for greyzones.
- Stretch grid length towards coarse resolution to determine point where the subgrid model choice makes a difference.

Smagorinsky-Lilly in LEM

$$\frac{Du_i}{Dt} = -\frac{\partial}{\partial x_i}\left(\frac{p'}{\rho_s}\right) + \delta_{i3}B' + \frac{1}{\rho_s}\frac{\partial \tau_{ij}}{\partial x} - 2\epsilon_{ijk}\Omega_j u_k$$

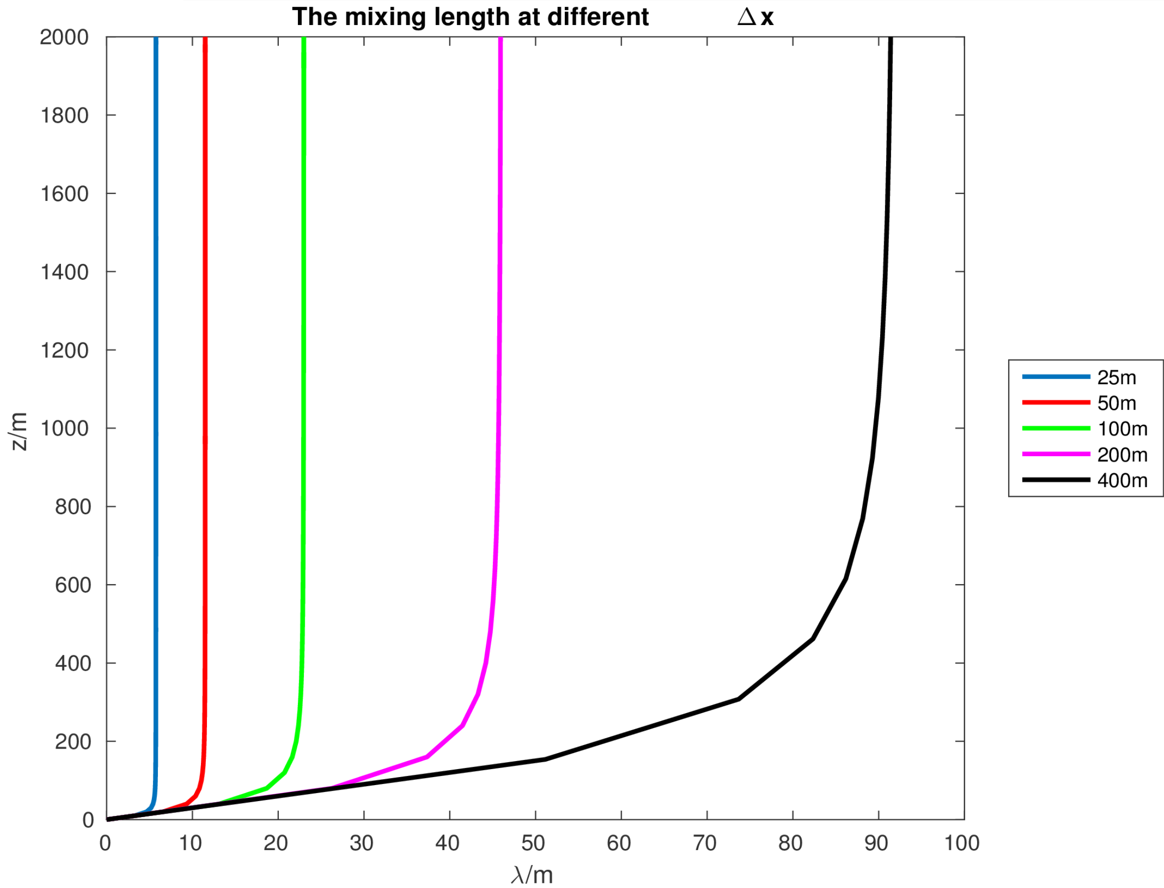
$$\tau_{ij} = \rho_s \lambda^2 f_m(Ri_p)\, S S_{ij}$$

$$S_{ij} = \frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i}$$

$$S = \left(\frac{1}{2}\sum_{i,j=1,3} S_{ij}^2\right)^{1/2}$$

$$\frac{1}{\lambda^2} = \frac{1}{\lambda_0^2} + \frac{1}{[k(z+z_0)]^2}$$

$$\lambda_0 = c_s \Delta$$



Dynamic Model

- Number of studies determined c_s
  - Flow dependent and suggested values include 0.1, 0.2 and 0.23.
  - Germano 1991 introduced a method that allows c_s to be determined from the flow

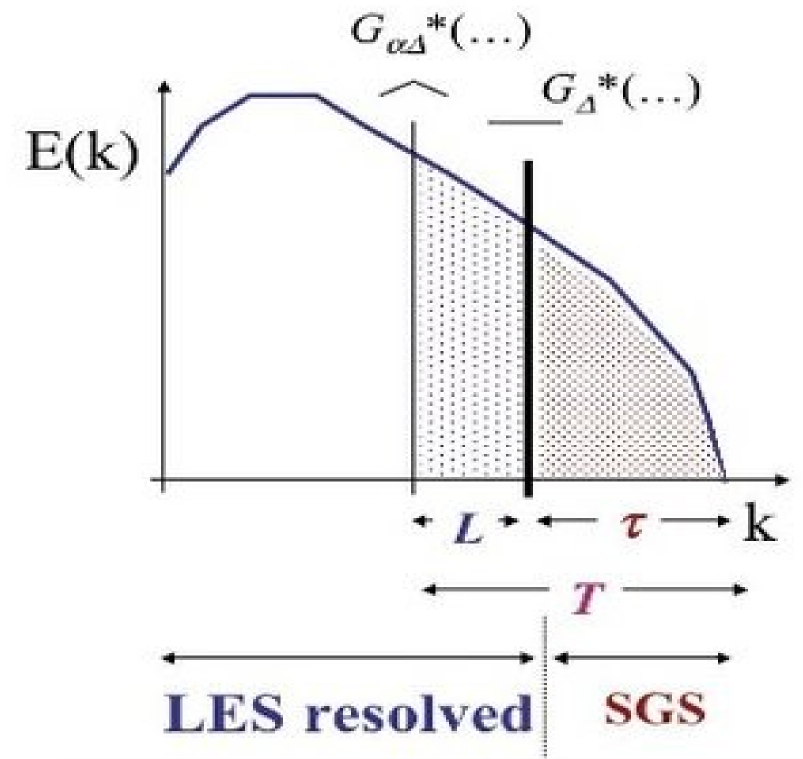
$$\tau_{ij} = -2c_{s,\Delta}^2 \Delta^2 |\tilde{S}| \tilde{S}_{ij}$$

$$T_{ij} = -2c_{s,\alpha\Delta}^2 (\alpha\Delta)^2 \overline{|\bar{S}| \bar{S}_{ij}}$$

$$L_{ij} = \overline{\tilde{u}_i \tilde{u}_j} - \bar{u}_i \bar{u}_j$$

$$L_{ij} - \left(\overline{T_{ij}} - \overline{\tilde{\tau}_{ij}}\right) = e = L_{ij} - c_{s,\Delta}^2 M_{ij}$$

$$M_{ij} = -2\Delta^2 \left(\overline{|\tilde{S}|\tilde{S}_{ij}} - \alpha^2 \beta \overline{|\bar{S}|\bar{S}_{ij}}\right), \beta = c_{s,\alpha\Delta}^2 / c_{s,\Delta}^2$$



Variations of the dynamic model

- Germano (1991) – plane averaged
  - Suitable for horizontally homogeneous flows
- Meneveau et al (1996) – Lagrangian averages
  - Suitable for inhomogeneous flows and complex geometries
- Bou-Zeid et al. (2005) – Lagrangian averaged scale variant
  - Uses a second test scale to determine $ß=c^2_{s,4\Delta}/c^2_{s,2\Delta}$
  - Proposed as a procedure that could be suitable for the grey zone

Simulations

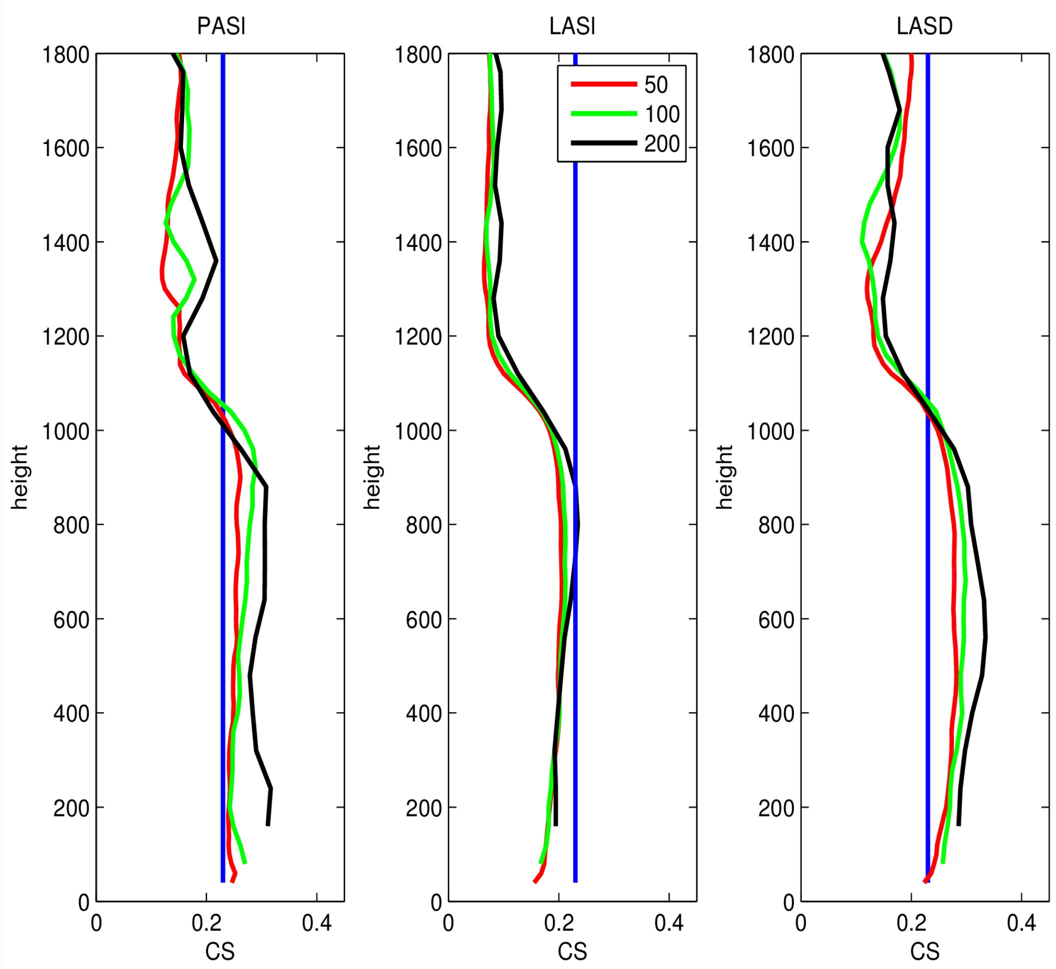
- Met Office Large Eddy Model
- Convection atmosphere
  - Constant sensible heat flux : 241Wm^{-2}
  - Constant temp of 300K up to 1km, and a sharp jump of 8K is imposed over a depth of 100m near the top of the BL.
  - 1K amplitude perturbations, 4 hour simulations
  - Weak geostrophic winds $(U_g,V_g)=(1,0)$m/s
- Domain size 9600x9600x2000m

Δx	Δz=0.4*Δx	Λ_0=0.23*Δx	Grid points
25	10	5.75	384x384x200
50	20	11.5	192x192x100
100	40	23.	96x96x50
200	80	18.4	48x48x25
400	160	36.8	24x24x13

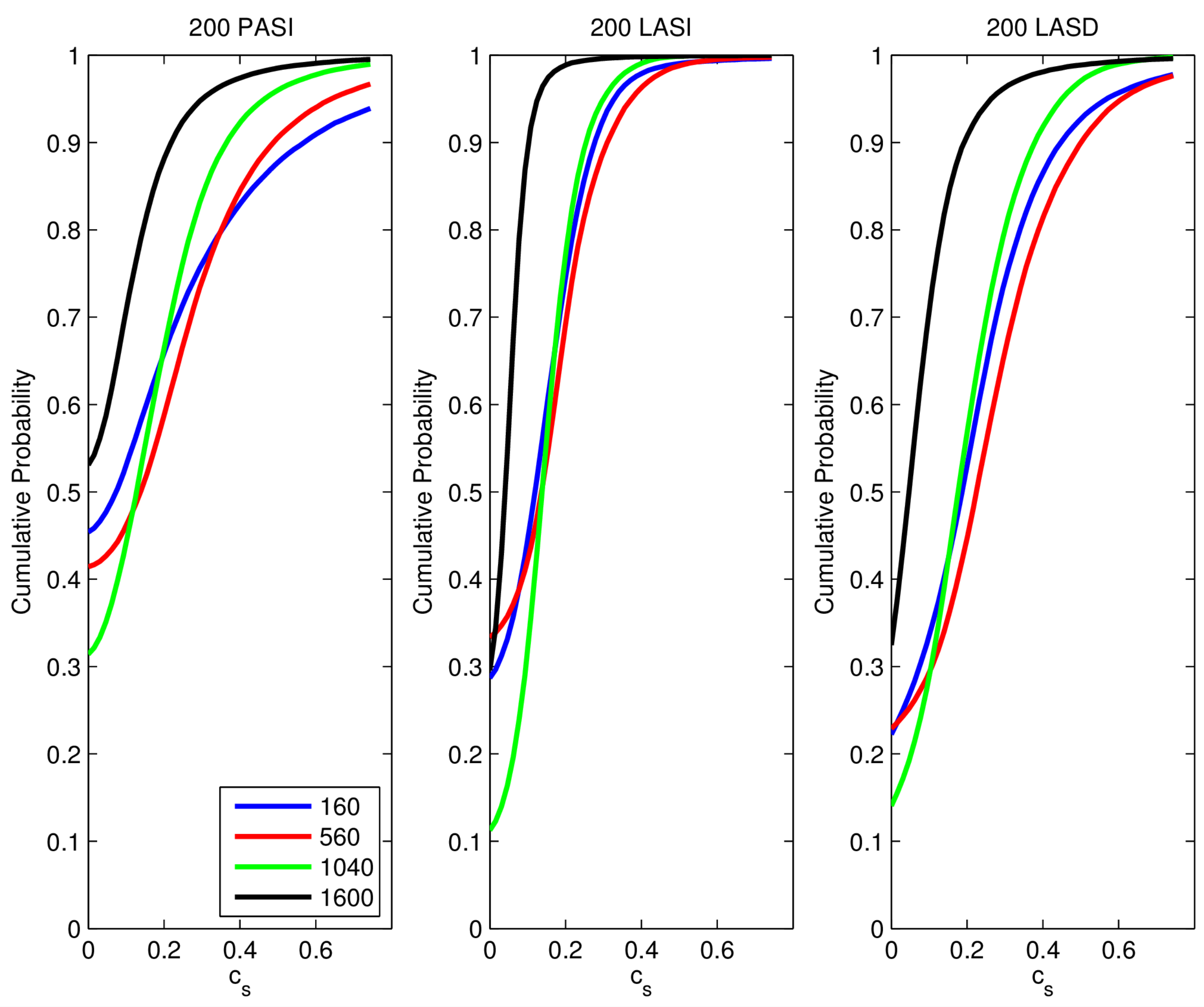
Only Smag

Dynamic model variations

- Plane-averaged scale invariant (PASI)
- Lagrangian-averaged scale-invariant (LASI)
- Lagrangian-averaged scale-dependent (LASD)

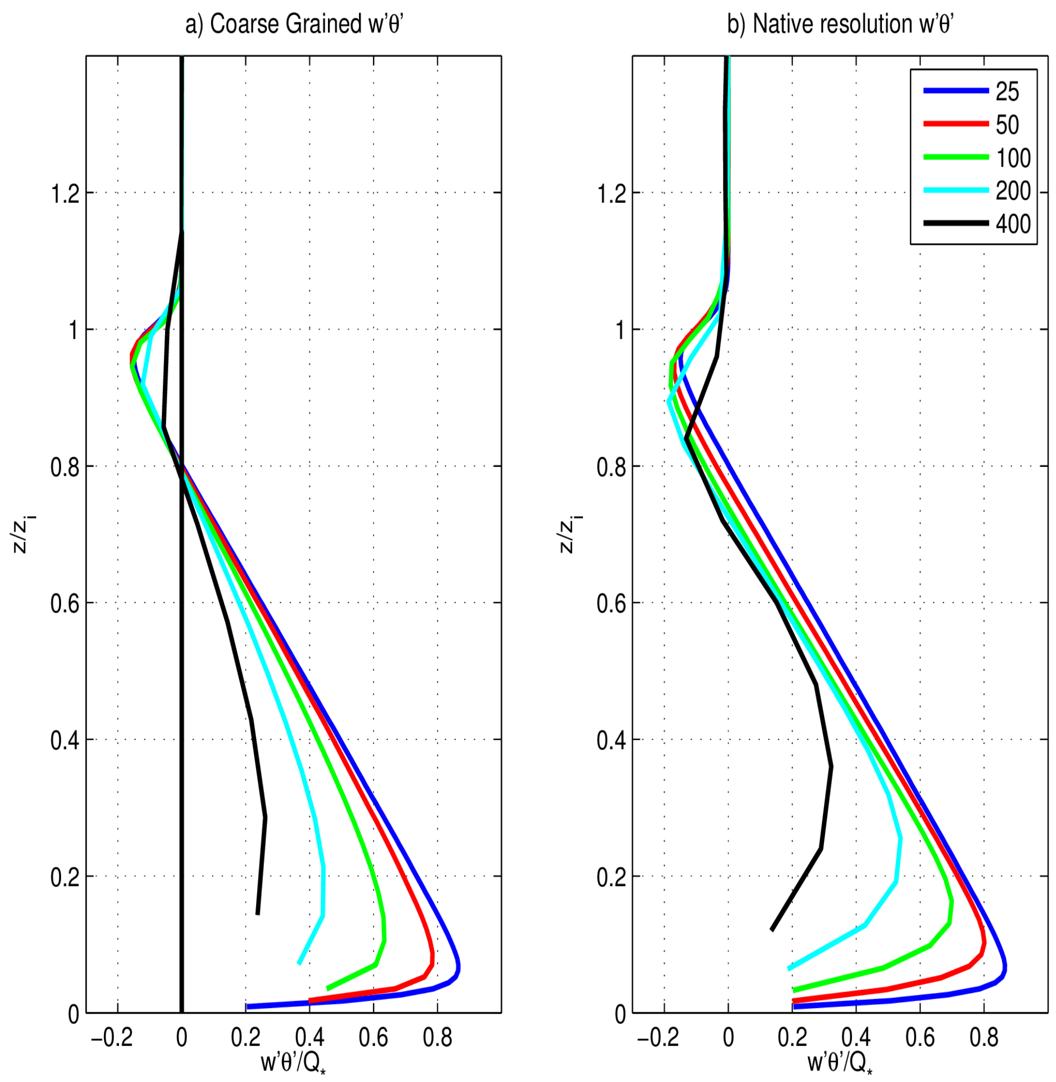


CS probability distribution



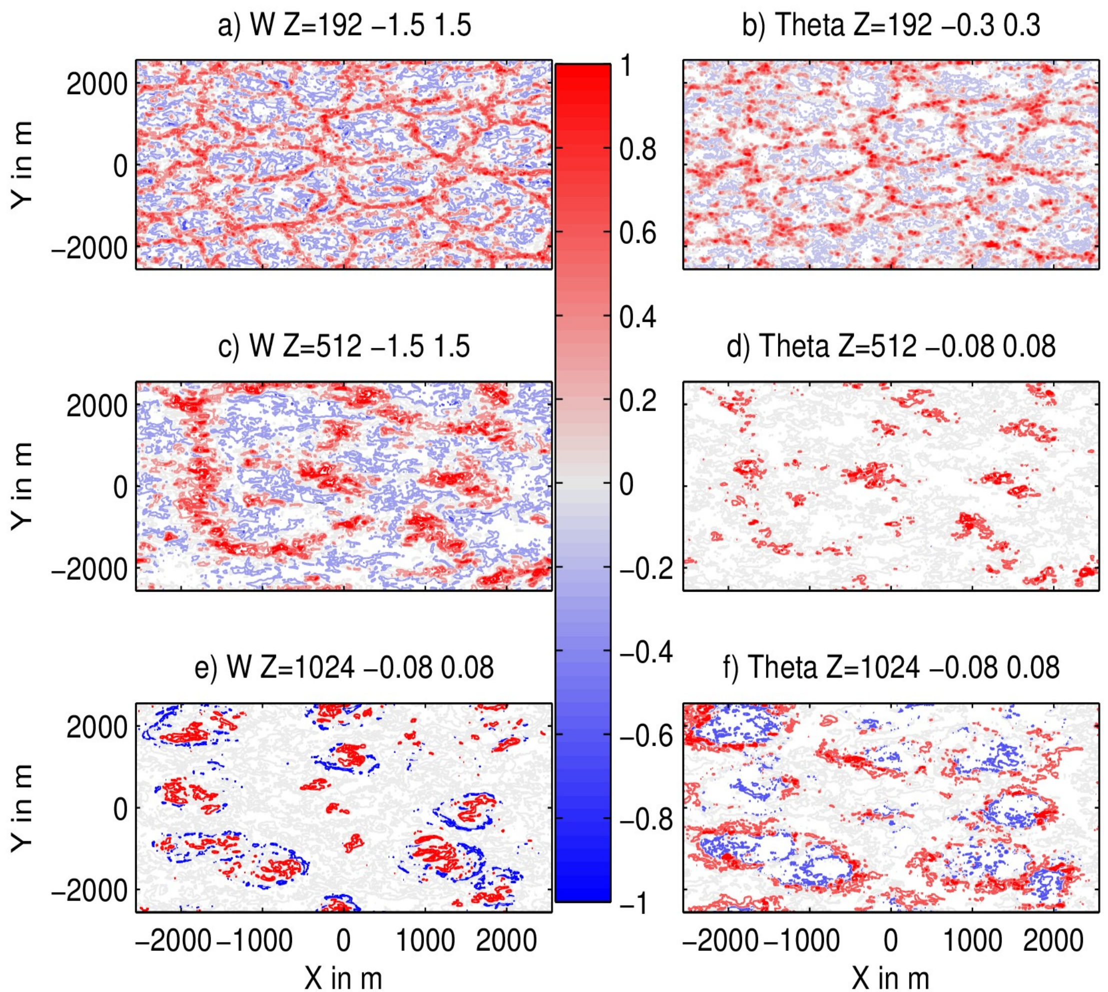
- 200 m resolution
- As resolution is decreased more clipping occurs

Resolved Potential temperature flux



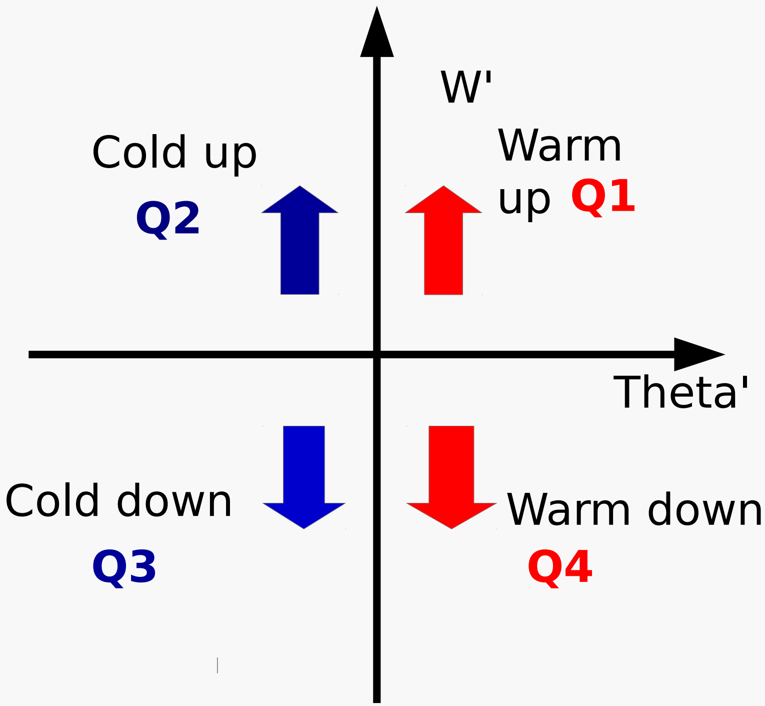
- Decrease with height to a minimum
- Negative region = entrainment zone
- Minimum – lower height with low resolution
- CG data is more converged below zi

Structures at different heights



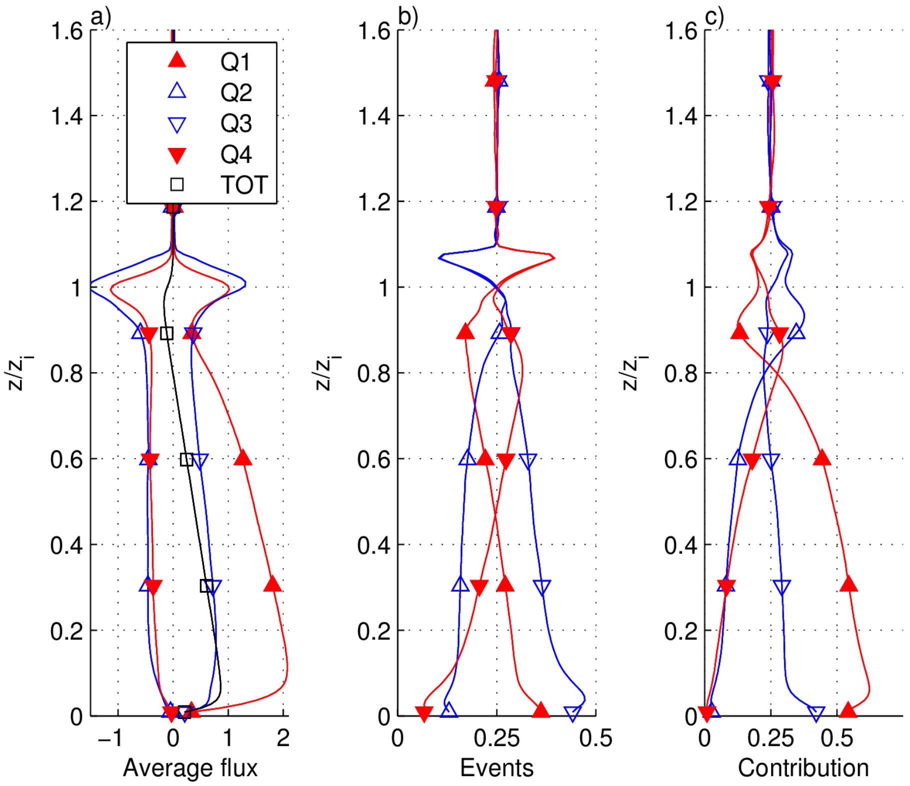
- Thermals rise
- Join those in adjacent regions to form larger structures.
- Theta' gets smaller due to mixing
- Closer to BL height – negative theta' associated with positive w'

Temperature flux
Quadrant analysis



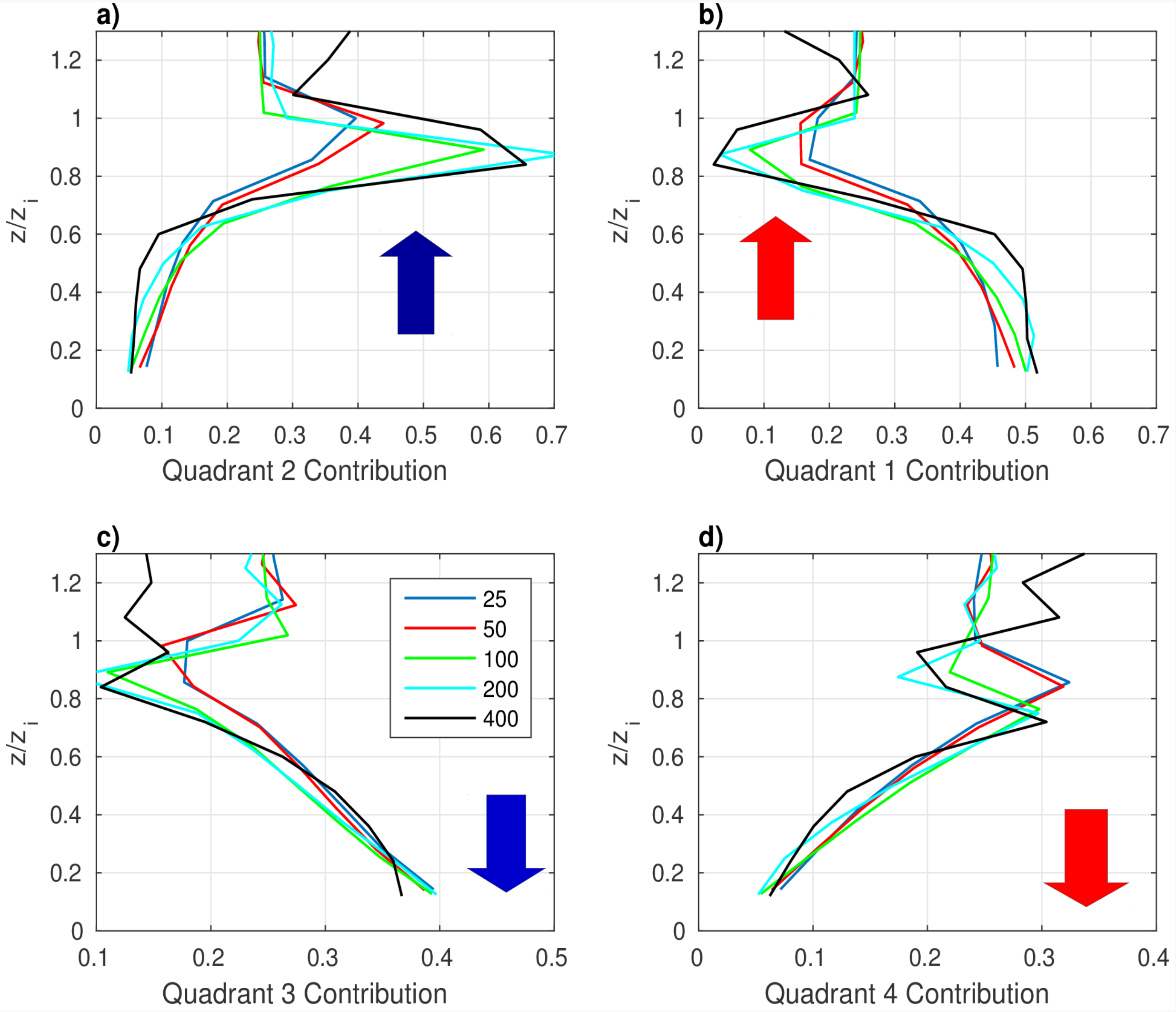
- Disentangle the temperature flux.
- e.g.Sullivan et al., 1998; Coceal et al 2007, Park and Baik 2014
- Theta'>0,W'>0 : Q1
- Theta'<0,W'>0 : Q2
- Theta'<0,W'<0 : Q3
- Theta'>0,W'<0 : Q4
- Number of events and contribution of each quadrant to the total flux.

25m resolution Quadrant analyses



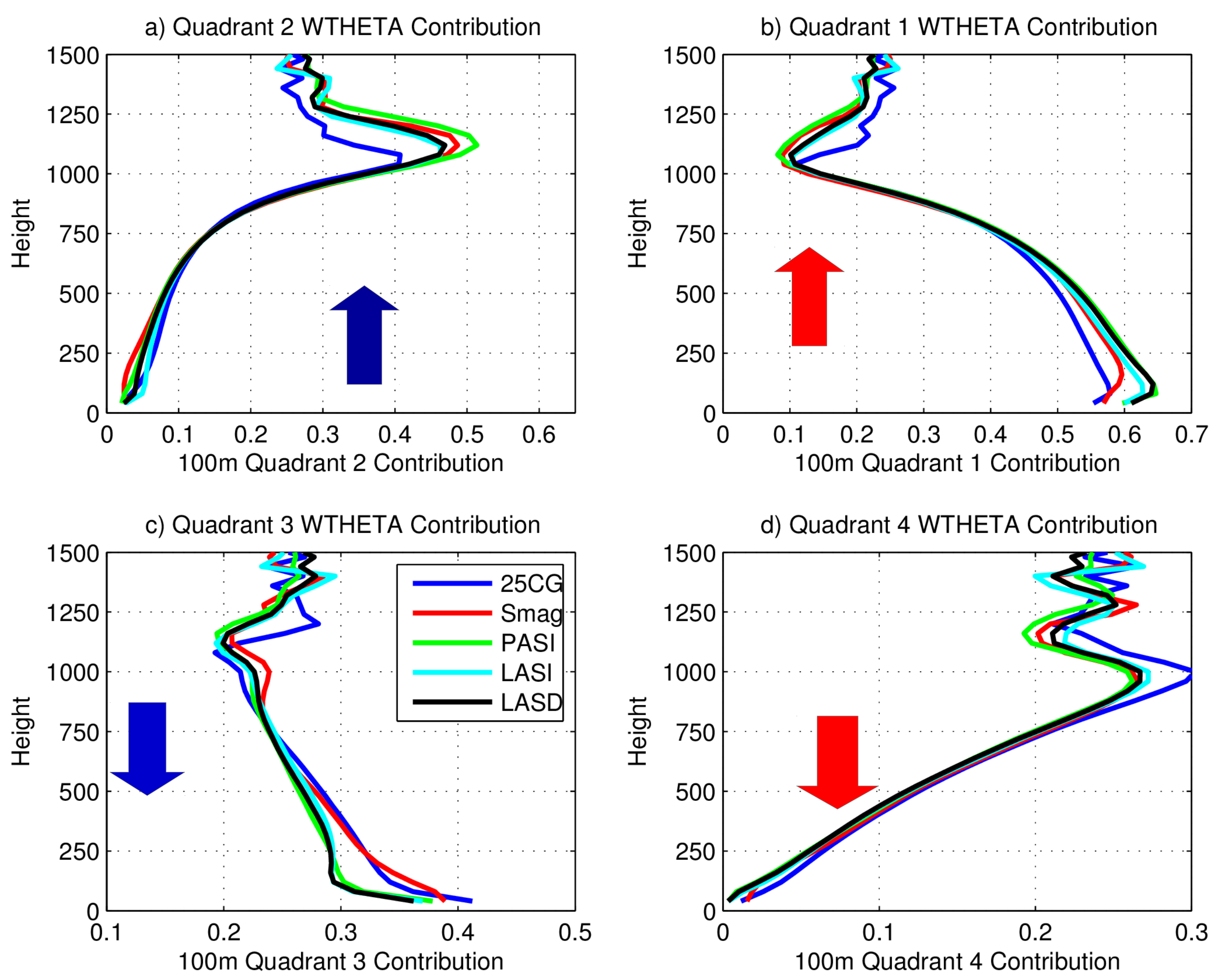
- Thermals rise – mix with environment-get colder
- Some join Q3 closer to the surface, most become Q2
- Q2 – bigger contribution theta'w'
- More Q4 events close to inversion layer- entrainment – contribution is about ¼.
- Q4 events mix with the environmental air- become cold - Q3

Grid size comparison for Smag



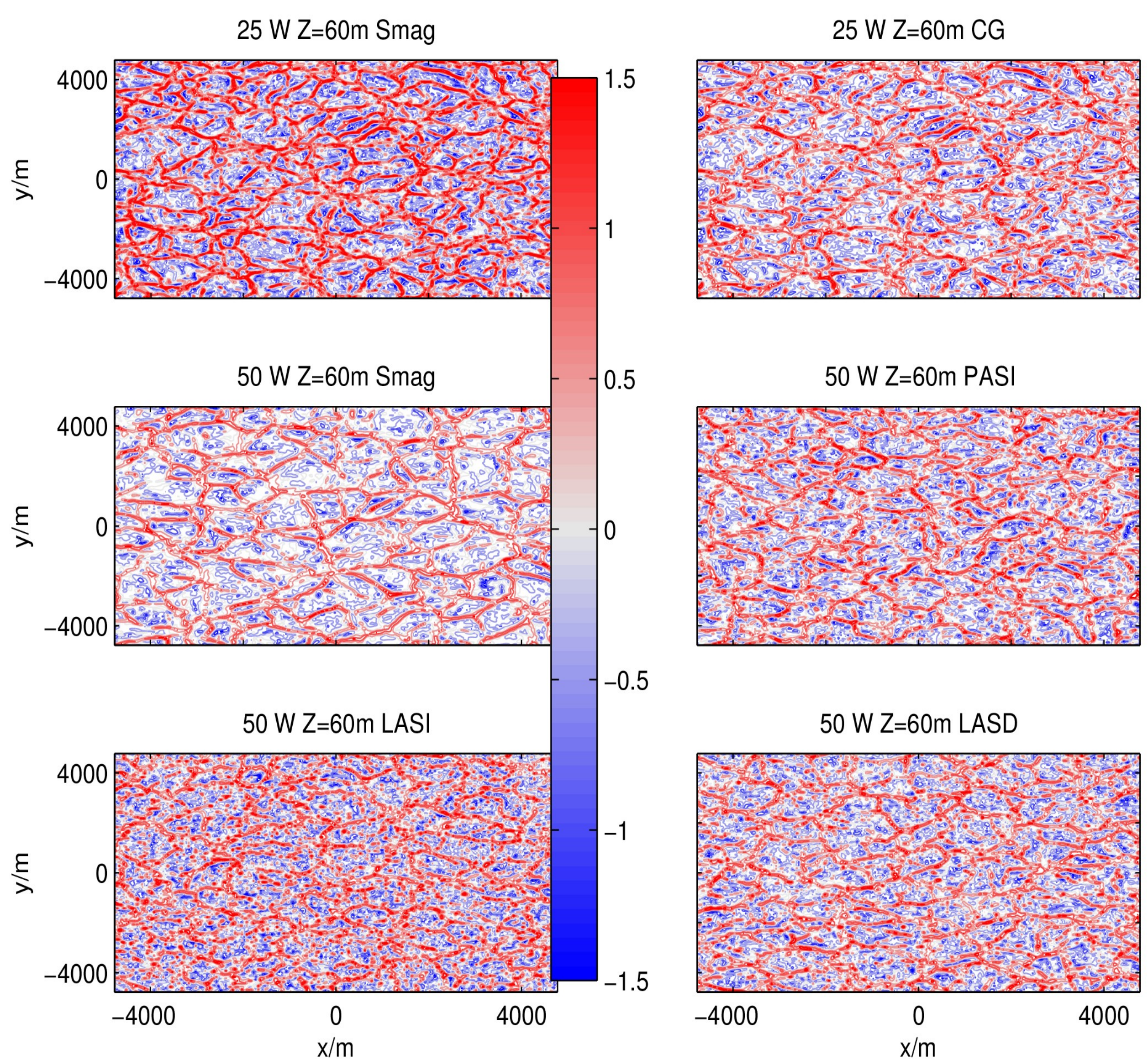
- NO evidence of large entrainment with low resolution
- Q2 contribution much larger than the rest with increased grid length

Contribution at 100m resolution – no f(Ri)



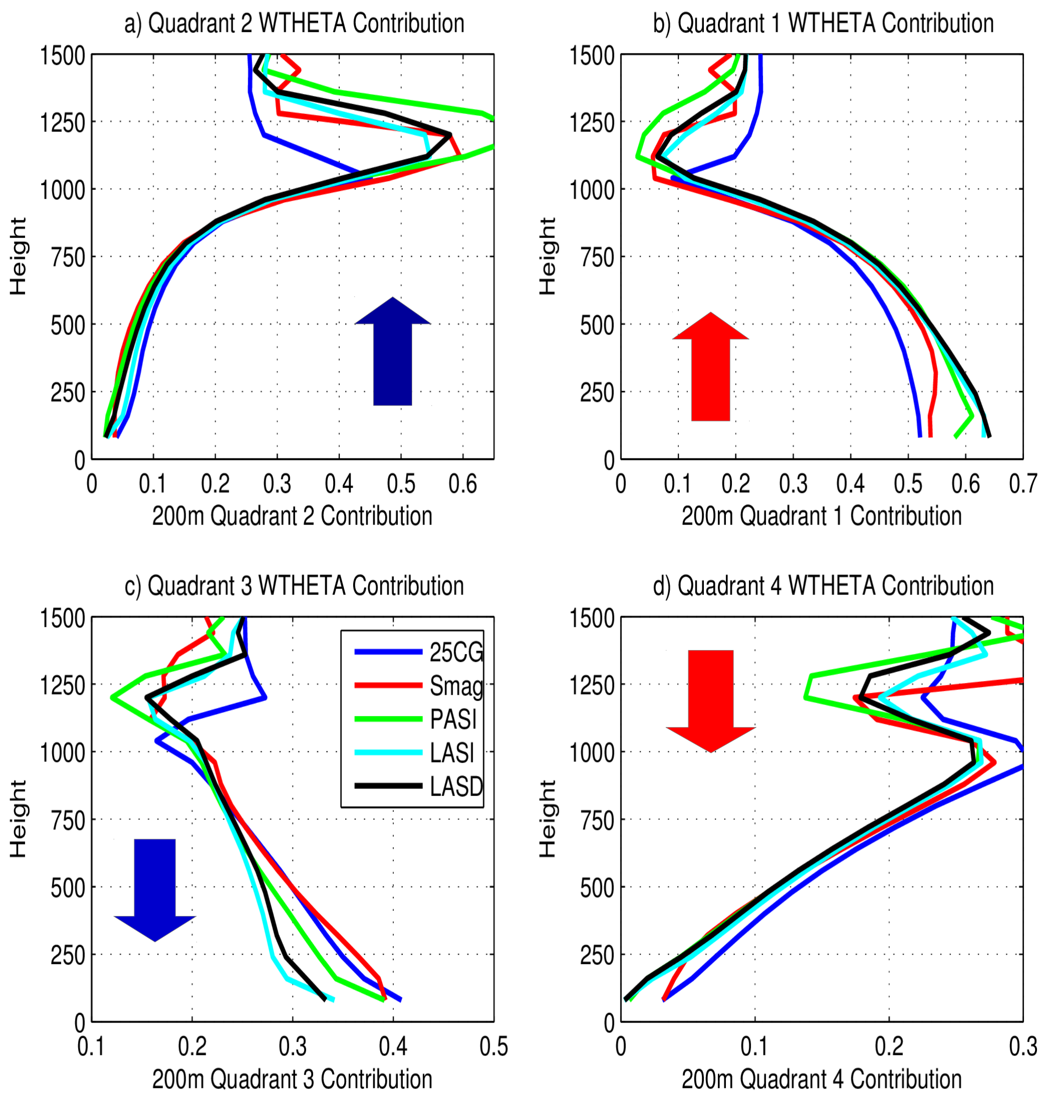
- Similar at higher resolution.
- More similar with stability functions.

W' at Z=60m deltax=50



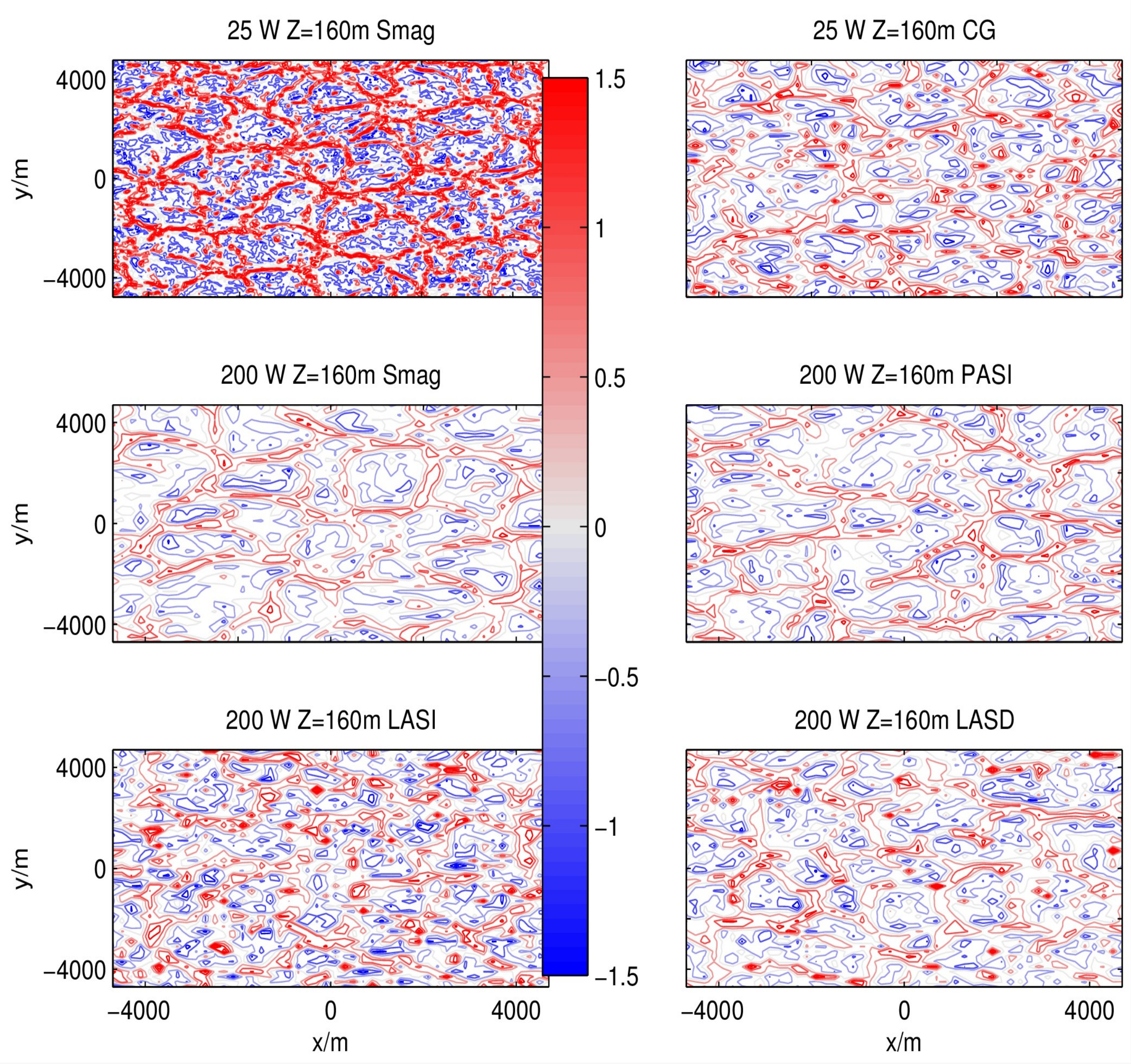
- Mean variables are almost the same.
- Structures look different
- LASI is more broken – too noisy
- Smag is too smooth

Qaudrant analyses – 200 m no f(Ri)



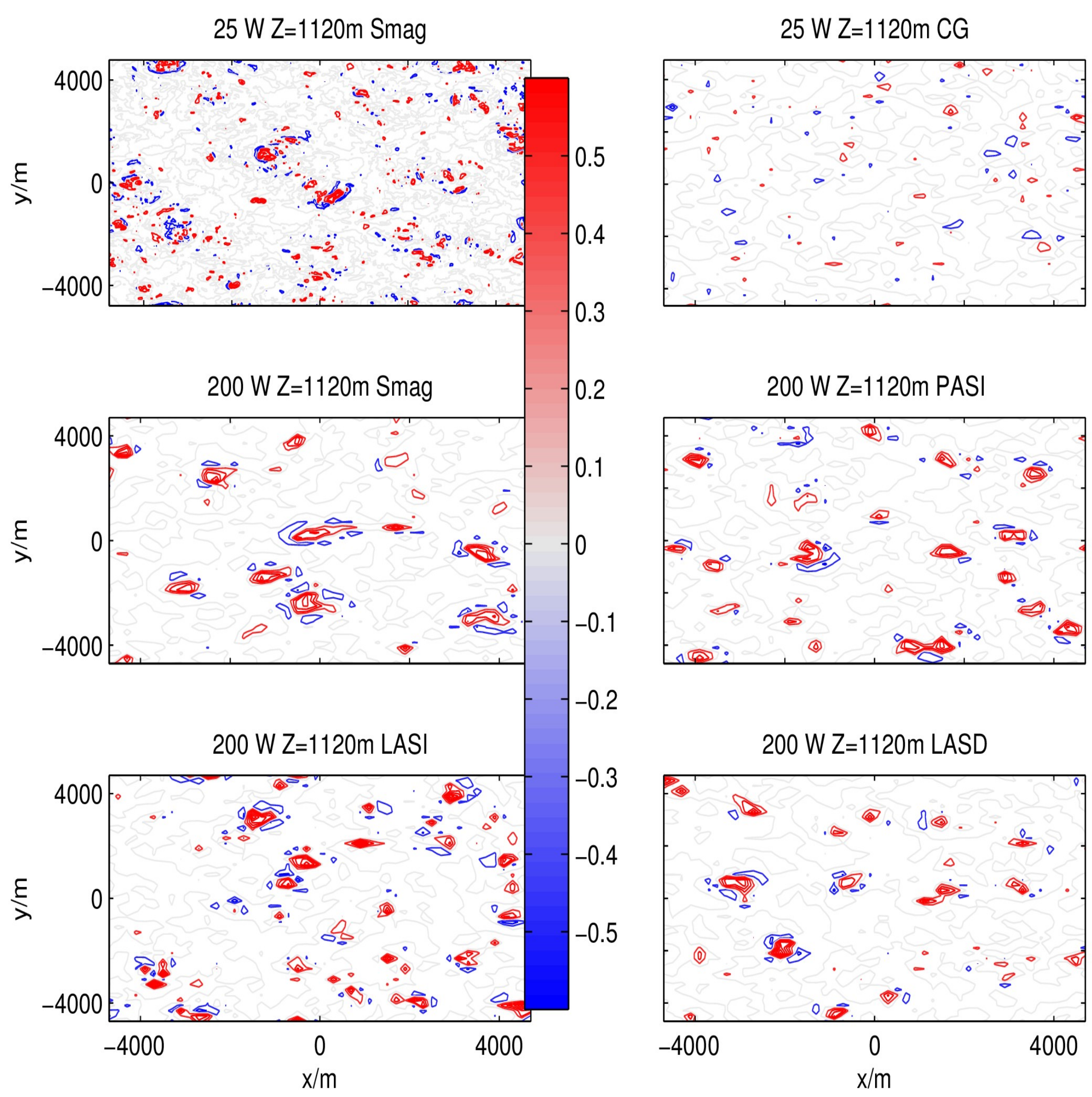
- Lines more divergent than without stability functions.

Z=160m Smag deltax=200m



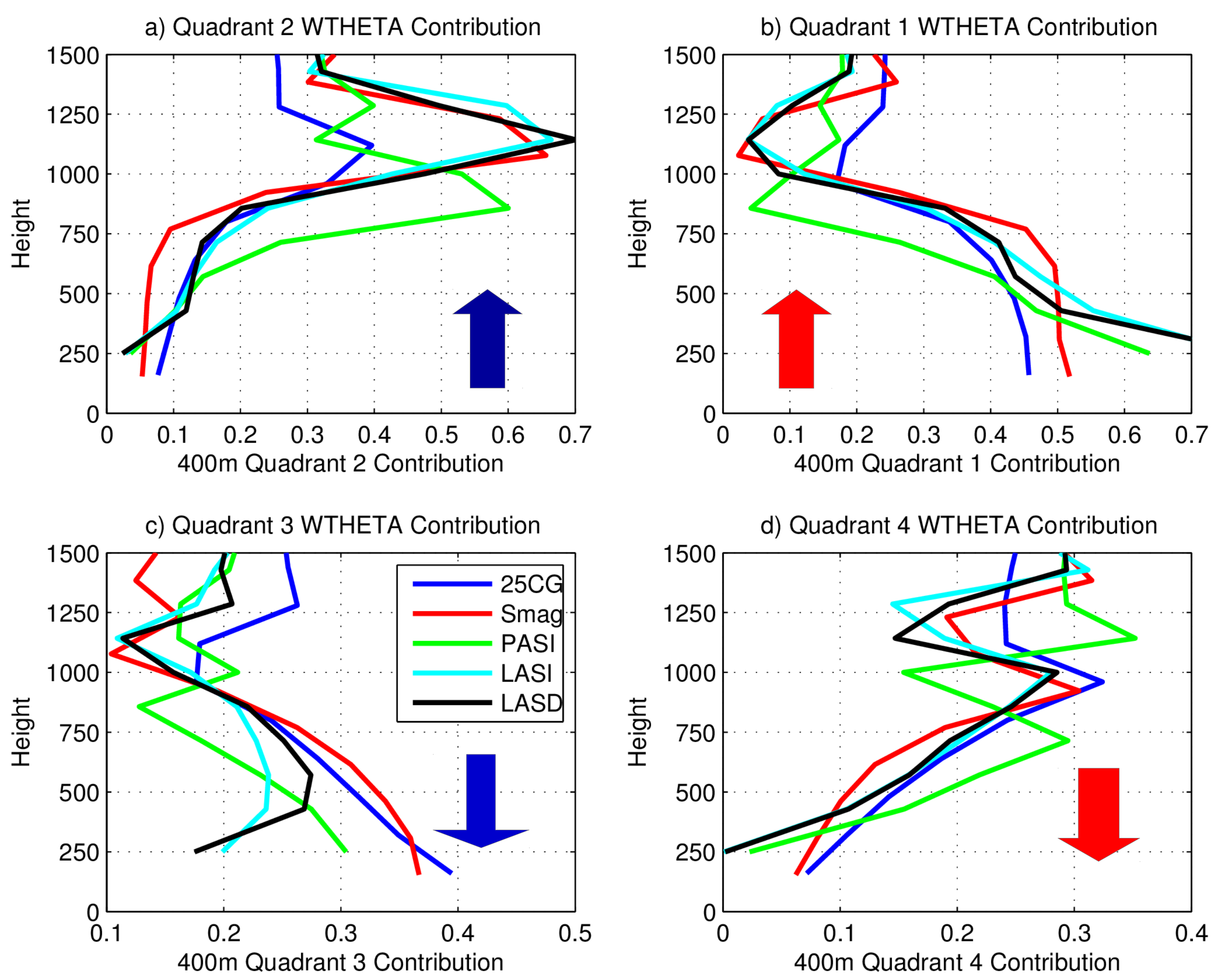
- Smag and PASI are smooth.
- Lagrangian models look slightly better

Z=1120 deltax=200m



- Strong w' in all subgrid models.
- Lagrangian models make no improvement here

Contribution at 400m resolution



- Run without stability functions crashes
- Simulations much more divergent.

Summary

- Stability functions make a large difference from 200m and higher.
- Subgrid model choice make a small difference from 200m grid spacing and higher.
- No subgrid choice is better, or worse in the Convective BL when considering domain means.
- Improvements were found using the dynamic model for the morning transition (in progress).

Thank you for your attention