SBL workshop FMI 3 – 5 December 2012

The role of snow-surface coupling, radiation and turbulent mixing in modeling a stable boundary layer over Arctic sea-ice

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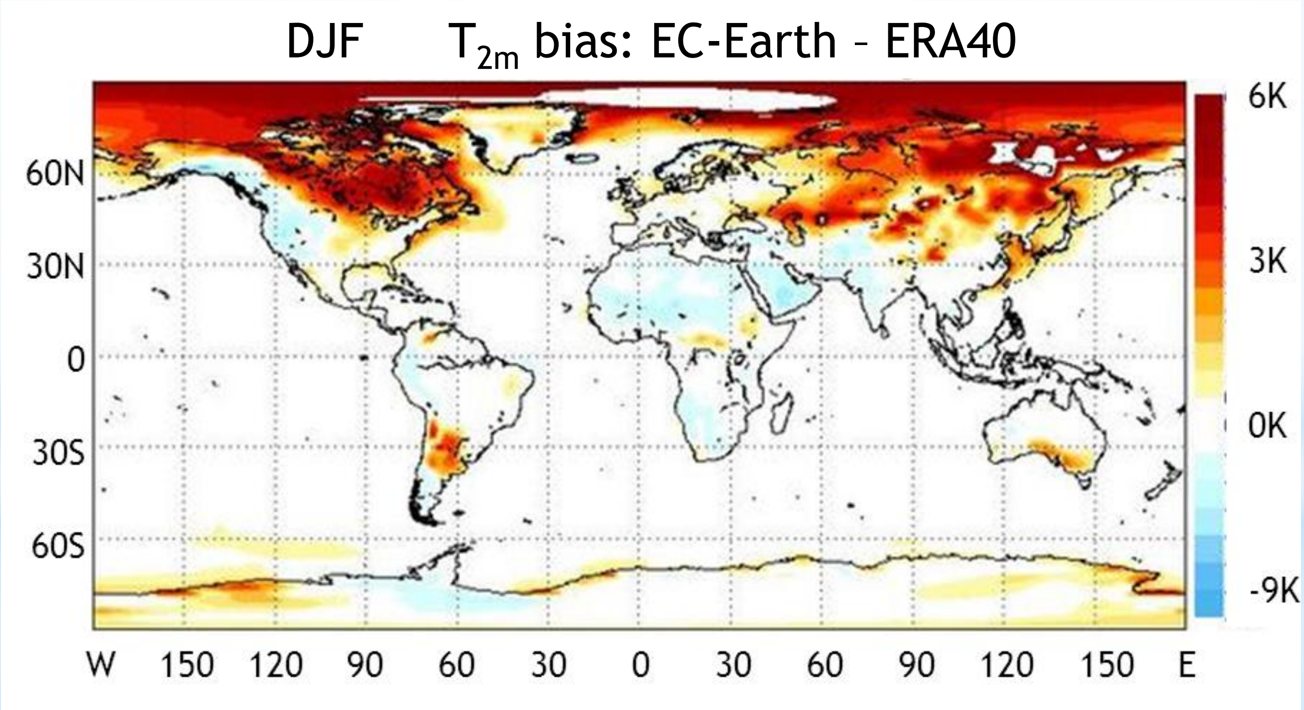
METEOROLOGY AND AIR QUALITY

Motivation

- Evaluate knowledge gaps in Stable Boundary Layer (SBL) physics



ecearth.knmi.nl (CY33R1 H-tessel)

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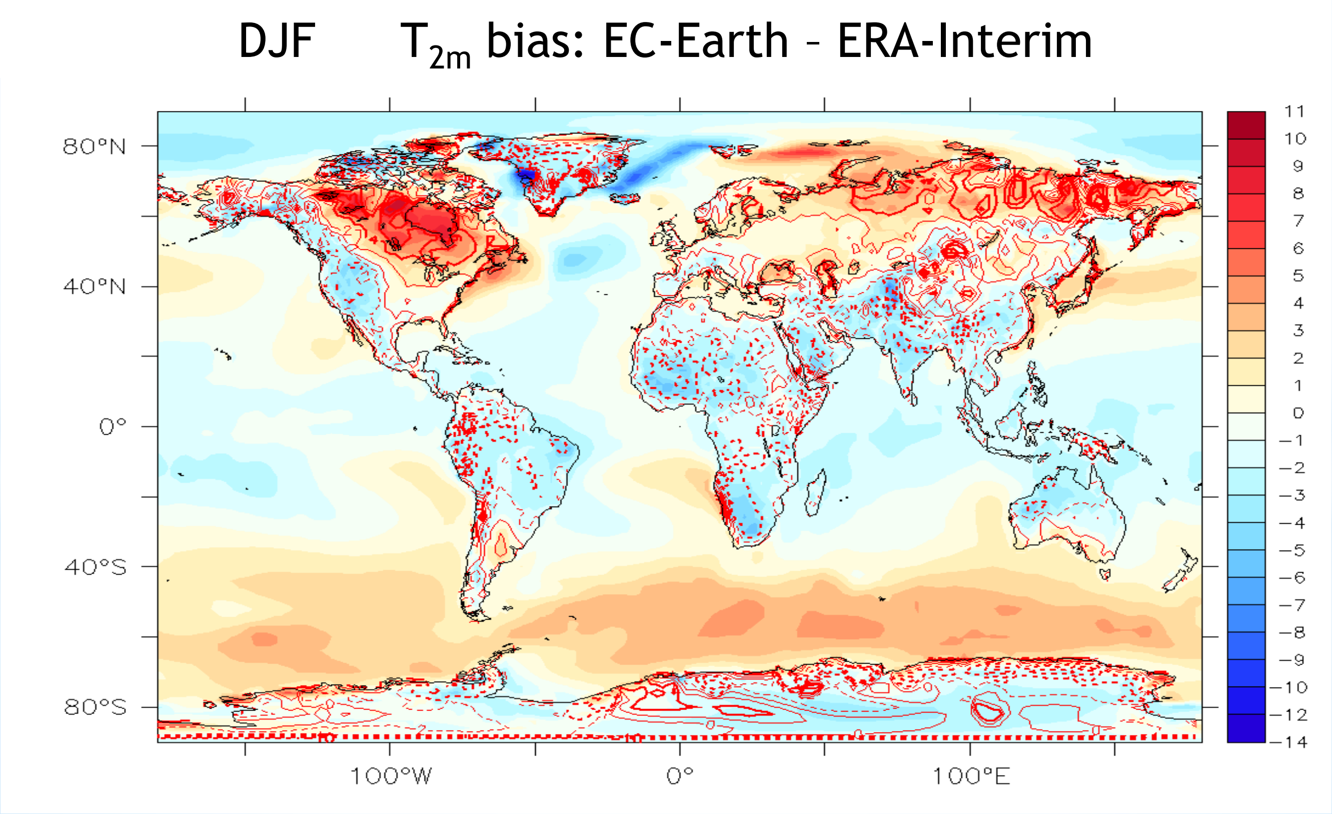
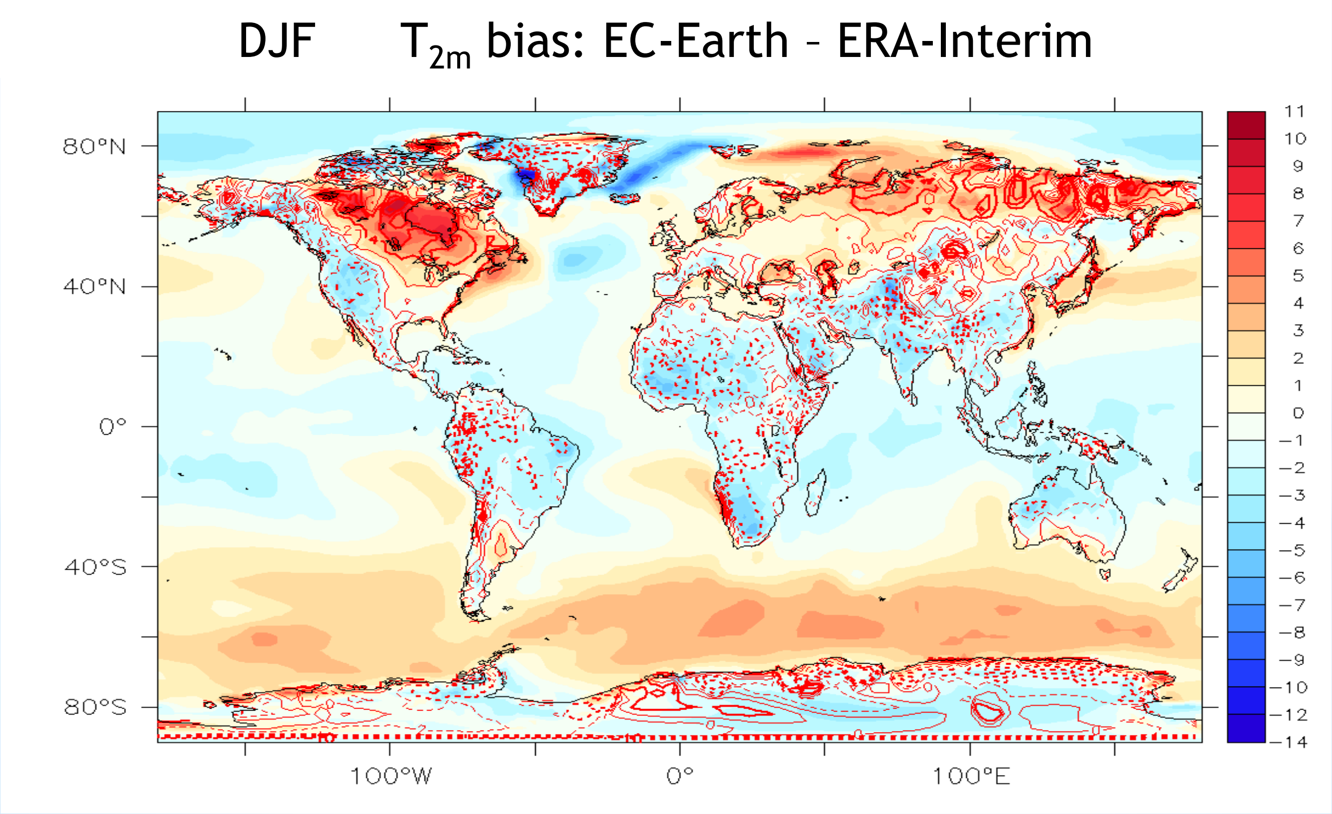


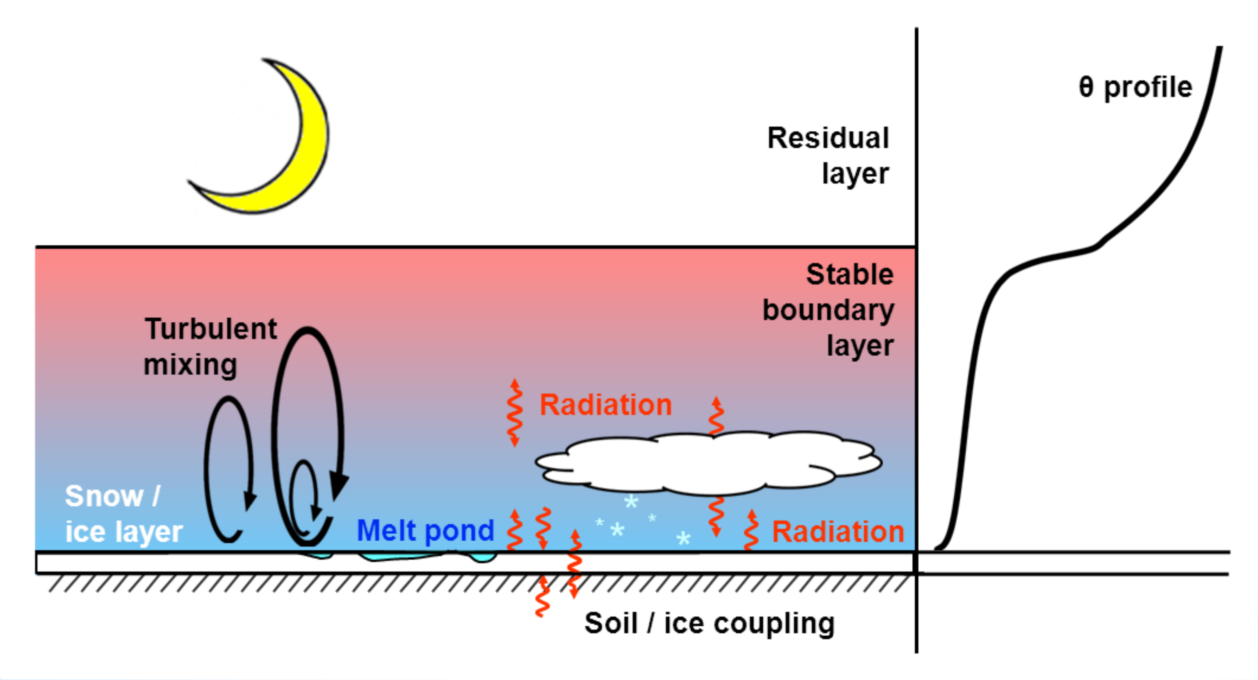
Motivation

- Evaluate knowledge gaps in Stable Boundary Layer (SBL) physics
- Which physical processes can cause these biases?



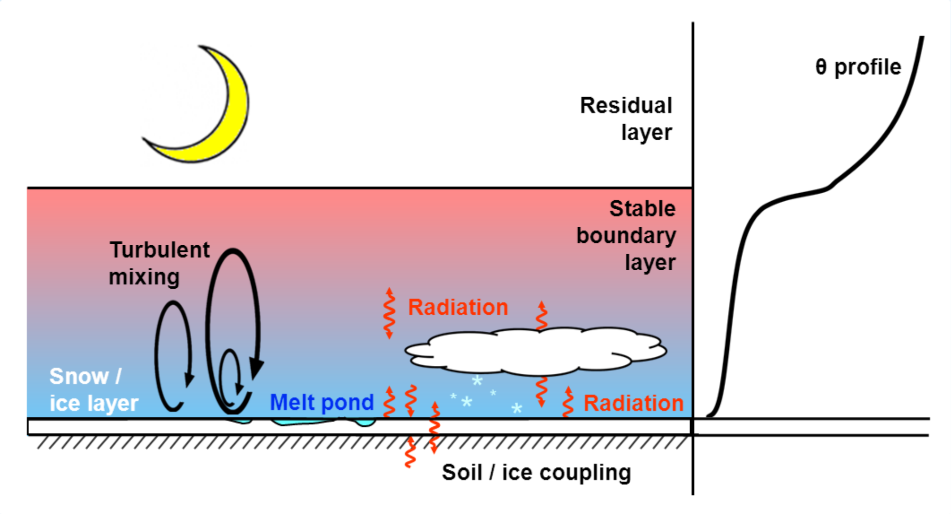
Physical processes

- Possible physical processes for bias:



- Vertical exchanges (turbulent mixing)
- Atmosphere – soil / ice interactions (coupling)
- Radiative effects (radiation)
- Non-linear feedbacks

Strategy



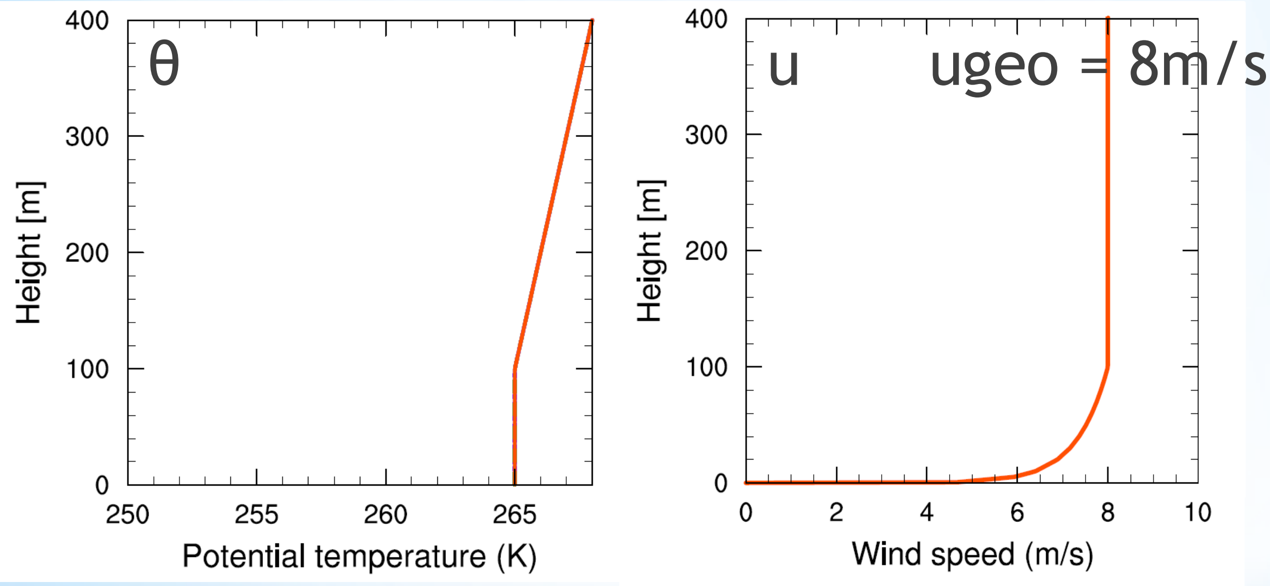
1. Study variability within the model using different schemes for physical processes
2. Perform sensitivity analysis by changing parameter settings

   Use single column model

   - high vertical resolution possible, easier controllable, fast runs

WRF SCM study inspired by GABLS1

- Initial idealized SBL case



- q = 0.5 g/kg up to 4 km
- T_{ice} = 265 K
- 9h forecast, night time

Beare et al., 2006
Cuxart et al., 2006
Kosovic and Curry, 2000
BASE

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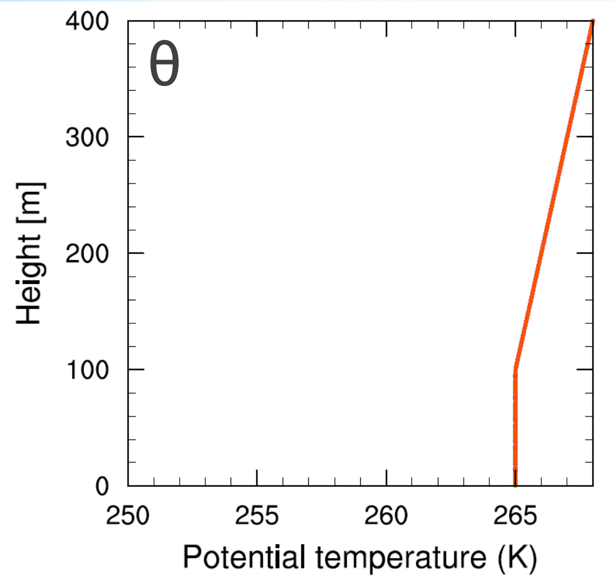

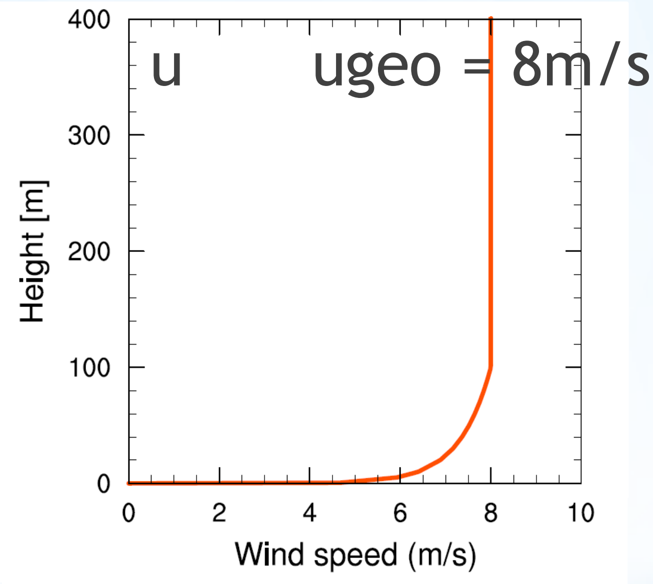

- q = 0.5 g/kg up to 4 km
- T_{ice} = 265 K
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- Extend GABLS1 case:
  - Coupled surface, radiation included
  - 200 atmospheric layers, 4 ice layers
  - z_0 = 0.5mm

Beare et al., 2006
Cuxart et al., 2006
Kosovic and Curry, 2000
BASE

Model intercomparison

Vary main schemes of SBL: simple ⟷ more complex

- BL: YSU, MYJ, QNSE
- LWrad: GFDL, RRTM, CAM
- LSM: NOAH

Model intercomparison

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Adjustments in YSU:

- Limit to u_*: 0.1 → 0.001 (Jiménez et al., 2011)
- Stability function: 1 + 5 z/L (Troen and Mahrt, 1986)

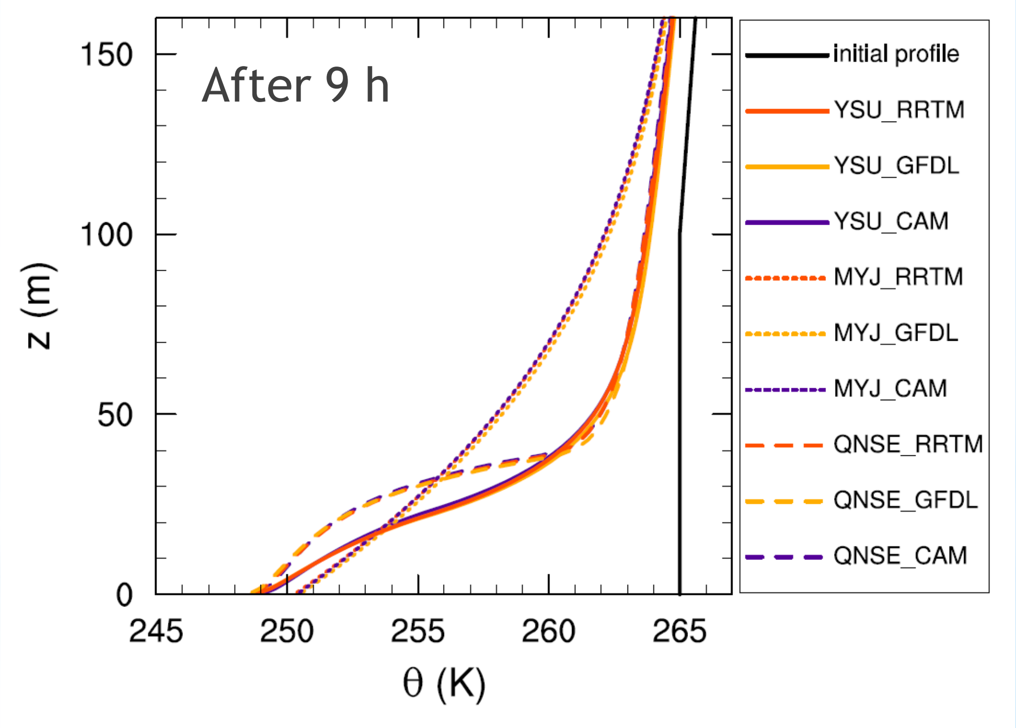
Model intercomparison

Vary main schemes of SBL: simple ⟷ more complex

- BL: YSU, MYJ, QNSE
- LWrad: GFDL, RRTM, CAM
- LSM: NOAH

Results θ profile

- Large differences between the BL-schemes
- Different profile shapes



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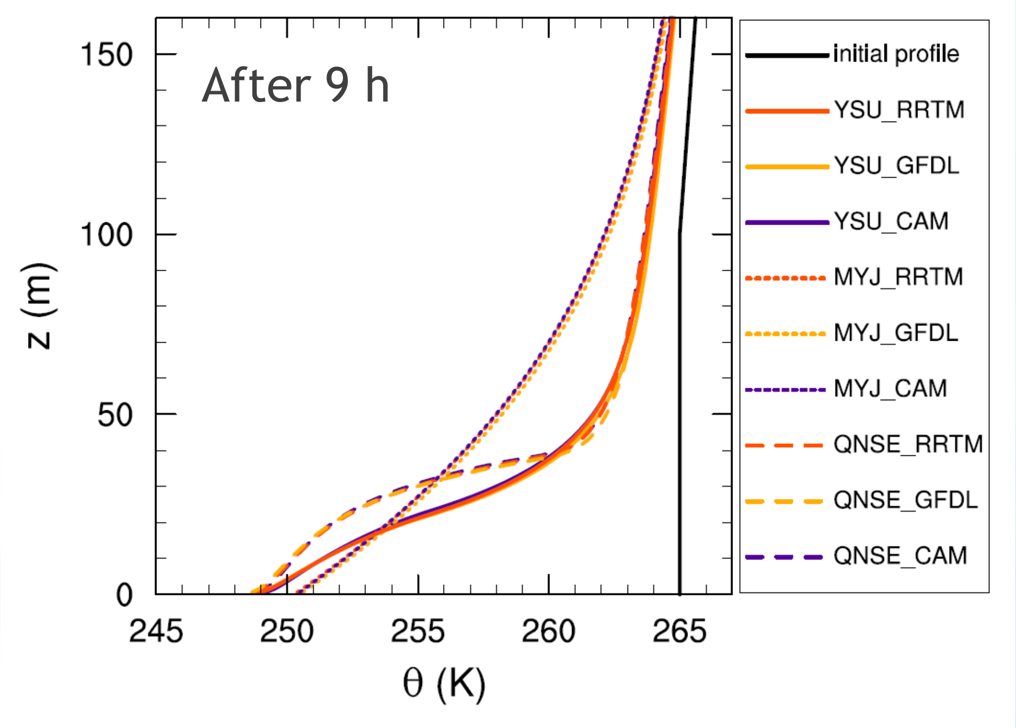


At first sight BL scheme seems most important

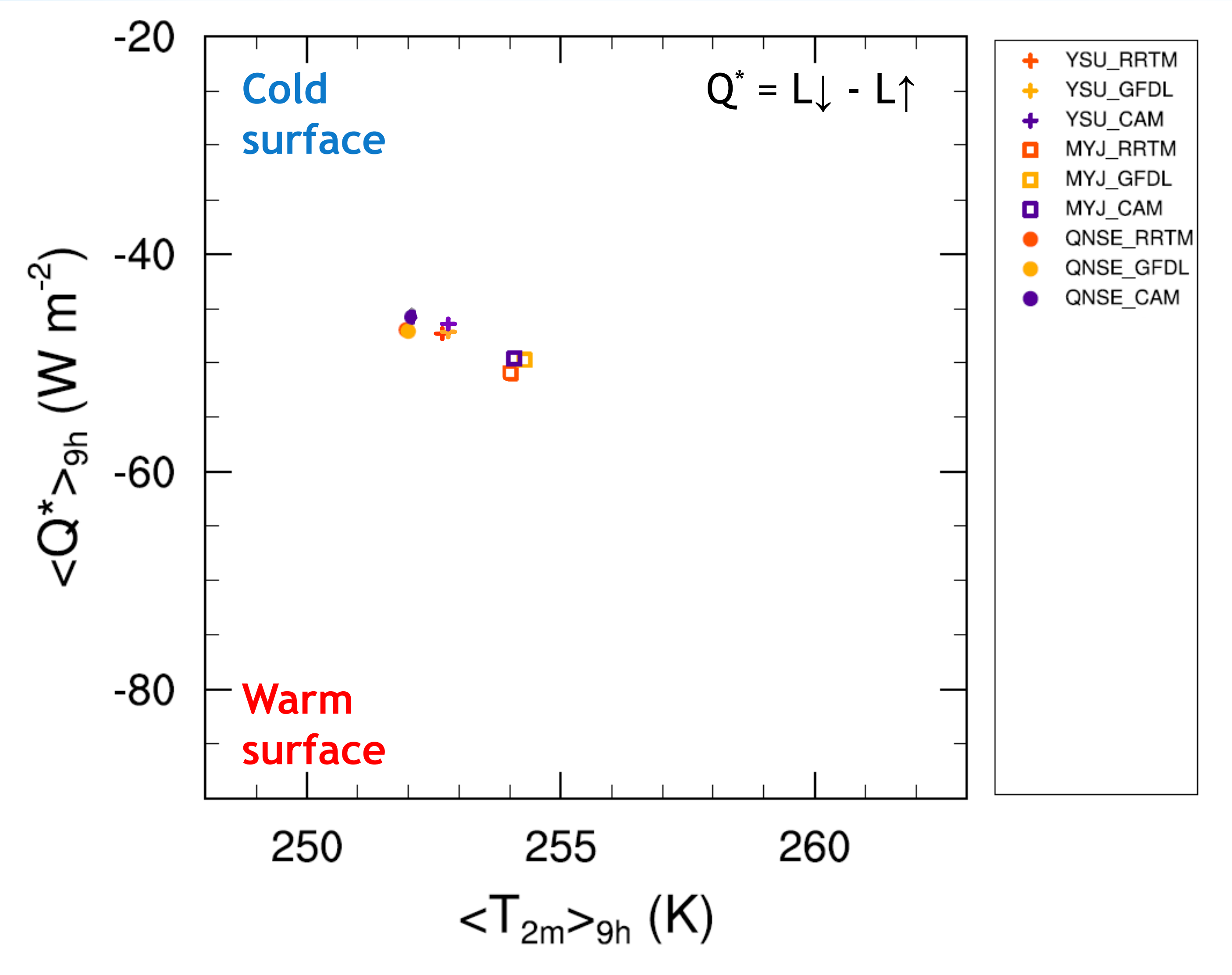
Sensitivity analysis

- For the YSU-RRTM runs vary parameter settings

Run	Process	Parameter
K	Mixing in BL only	Eddy diffusivity K
K_Chm	Mixing in BL and surface layer	Eddy diffusivity K, exchange coefficients C
λ	Coupling	Ice conductivity λ
q	Radiation	Specific humidity q to influence L↓

- Multiply parameters by:
  - K, K_Chm, *λ*: 0.25, 0.5, 2 and 4
  - q: 0.5, 0.67, 1.5 and 2

Results - Process diagram u_{geo} = 8 m/s



Plots as in Bosveld et al. (submitted)

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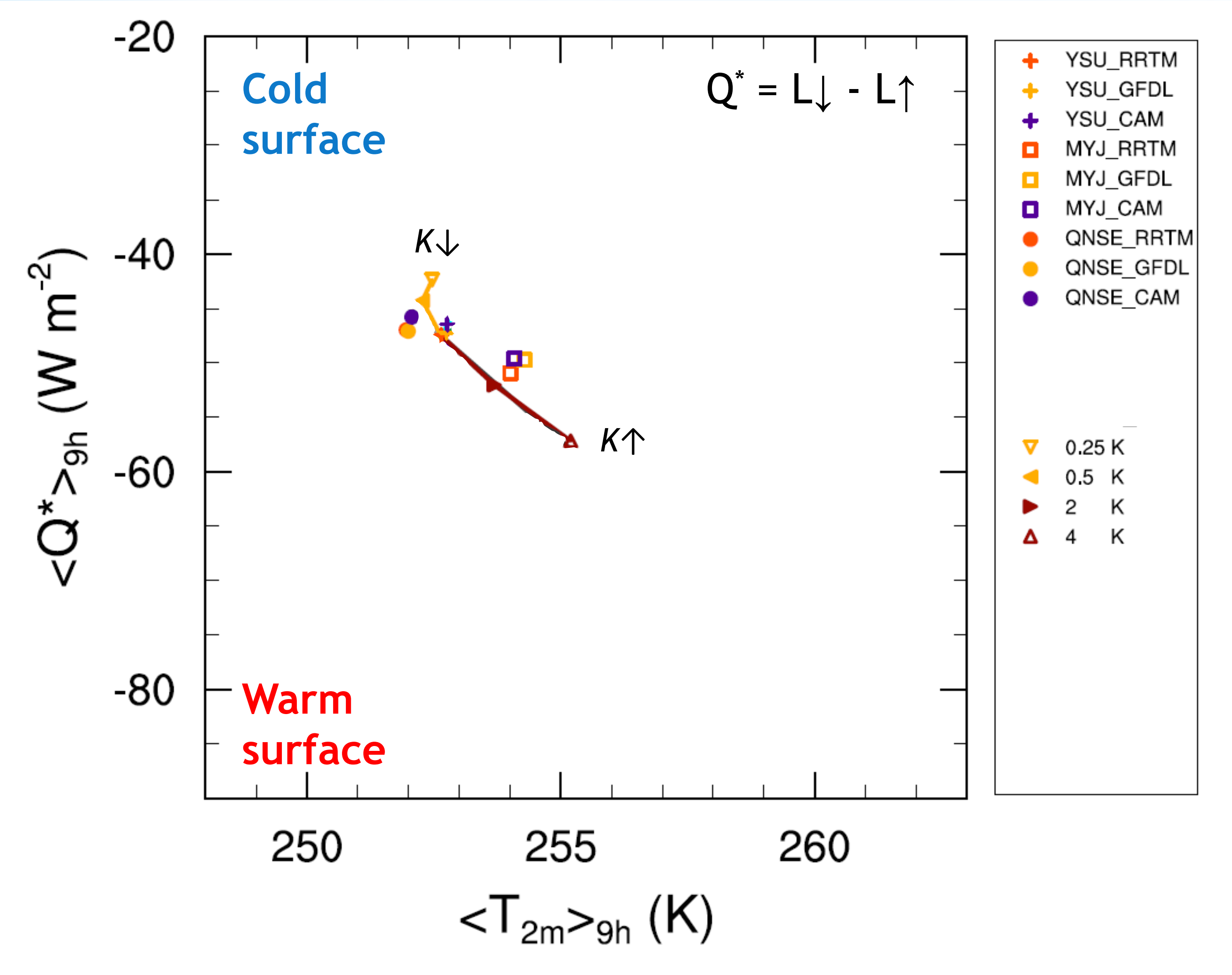

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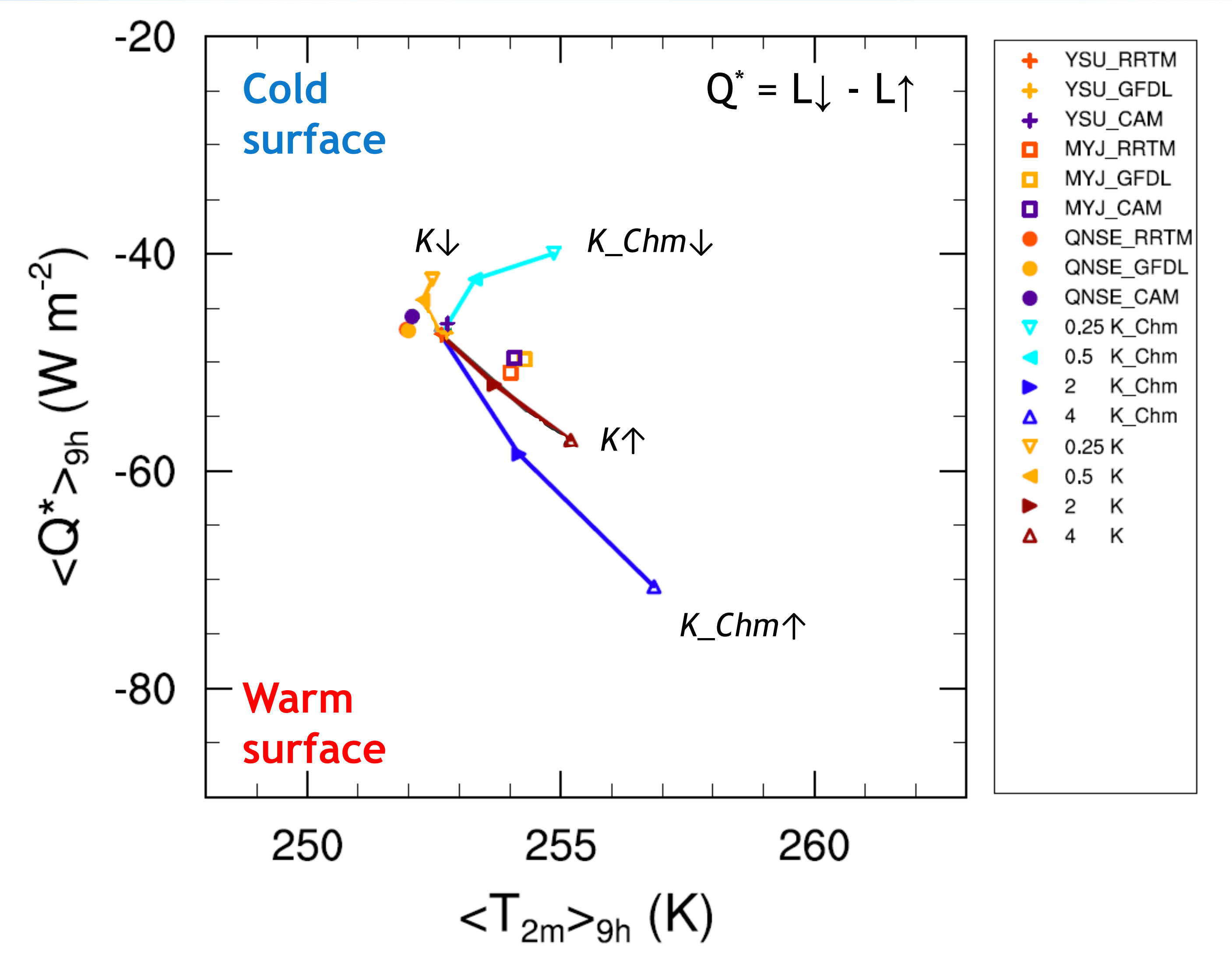

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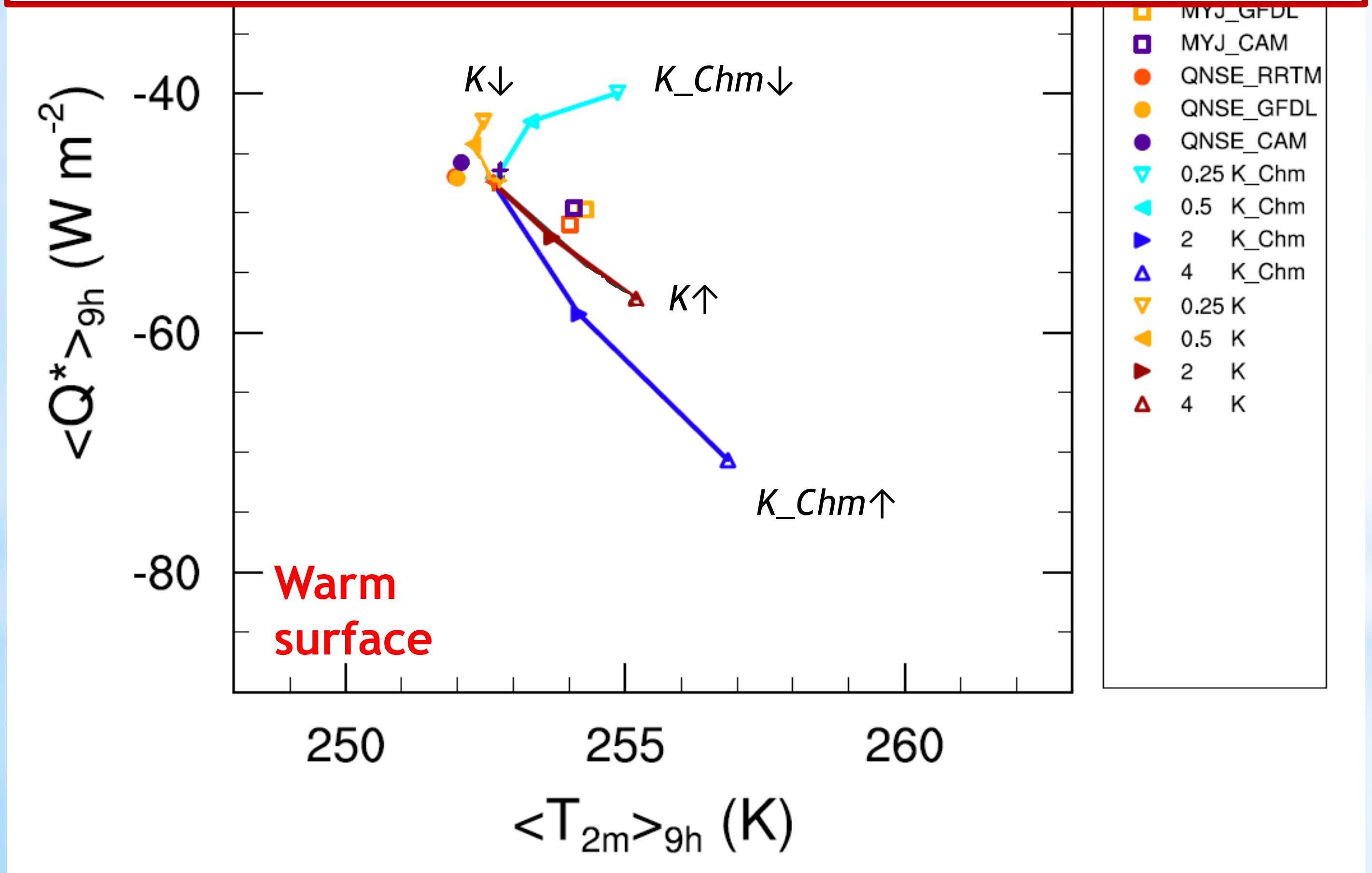
Result sensitive to consistently linking surface layer and boundary layer



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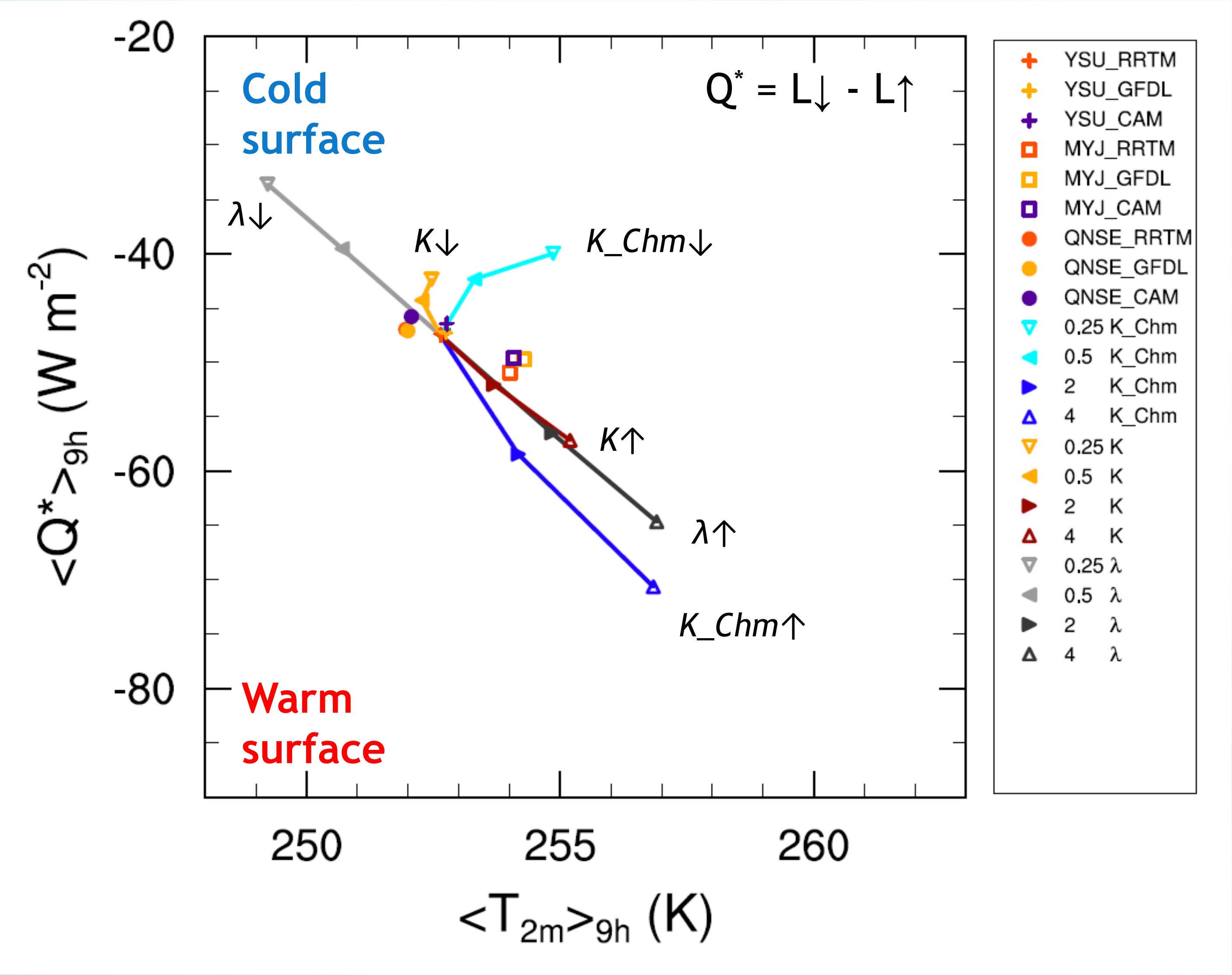

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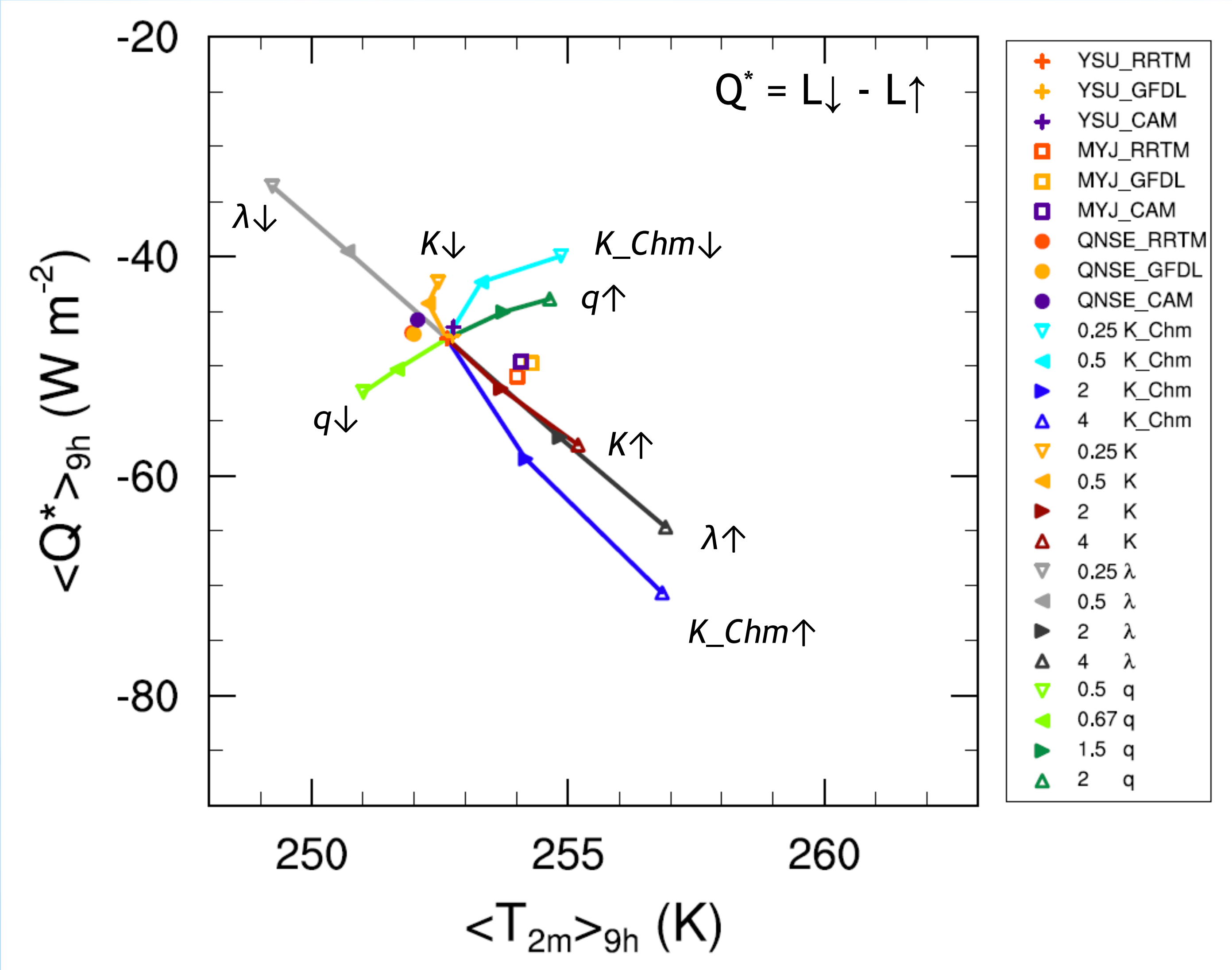

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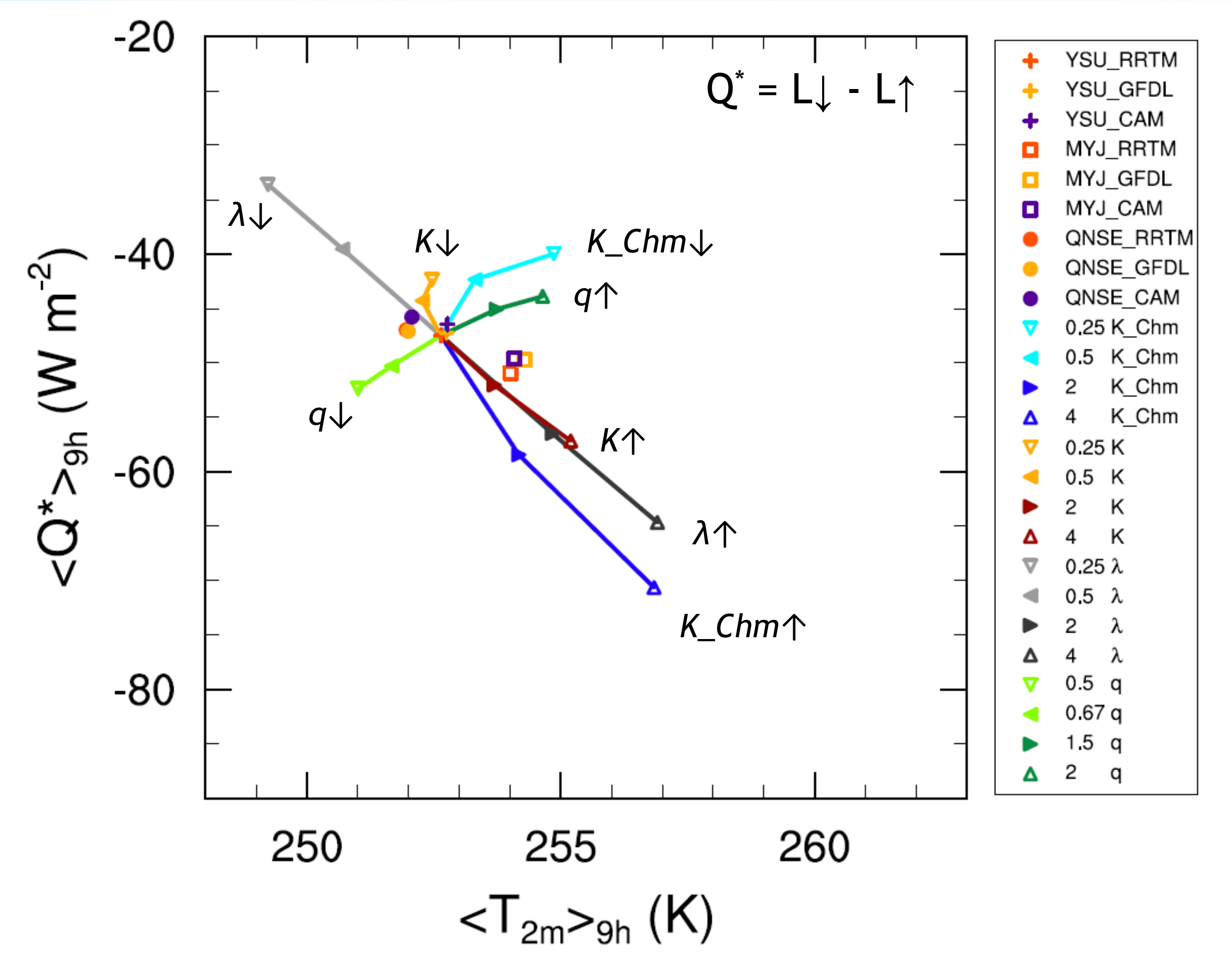


Mixing and coupling processes overlap

Plots as in Bosveld et al. (submitted)

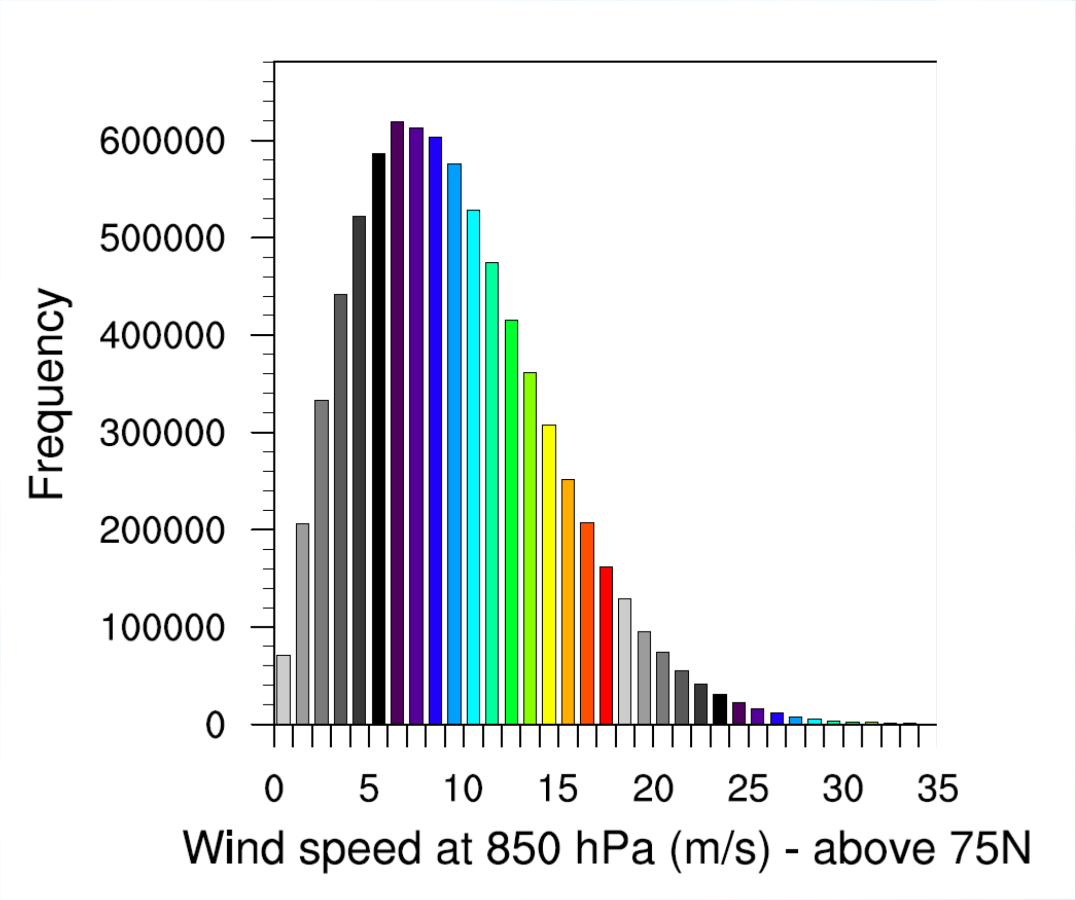
Results - Process diagram u_{geo} = 8 m/s

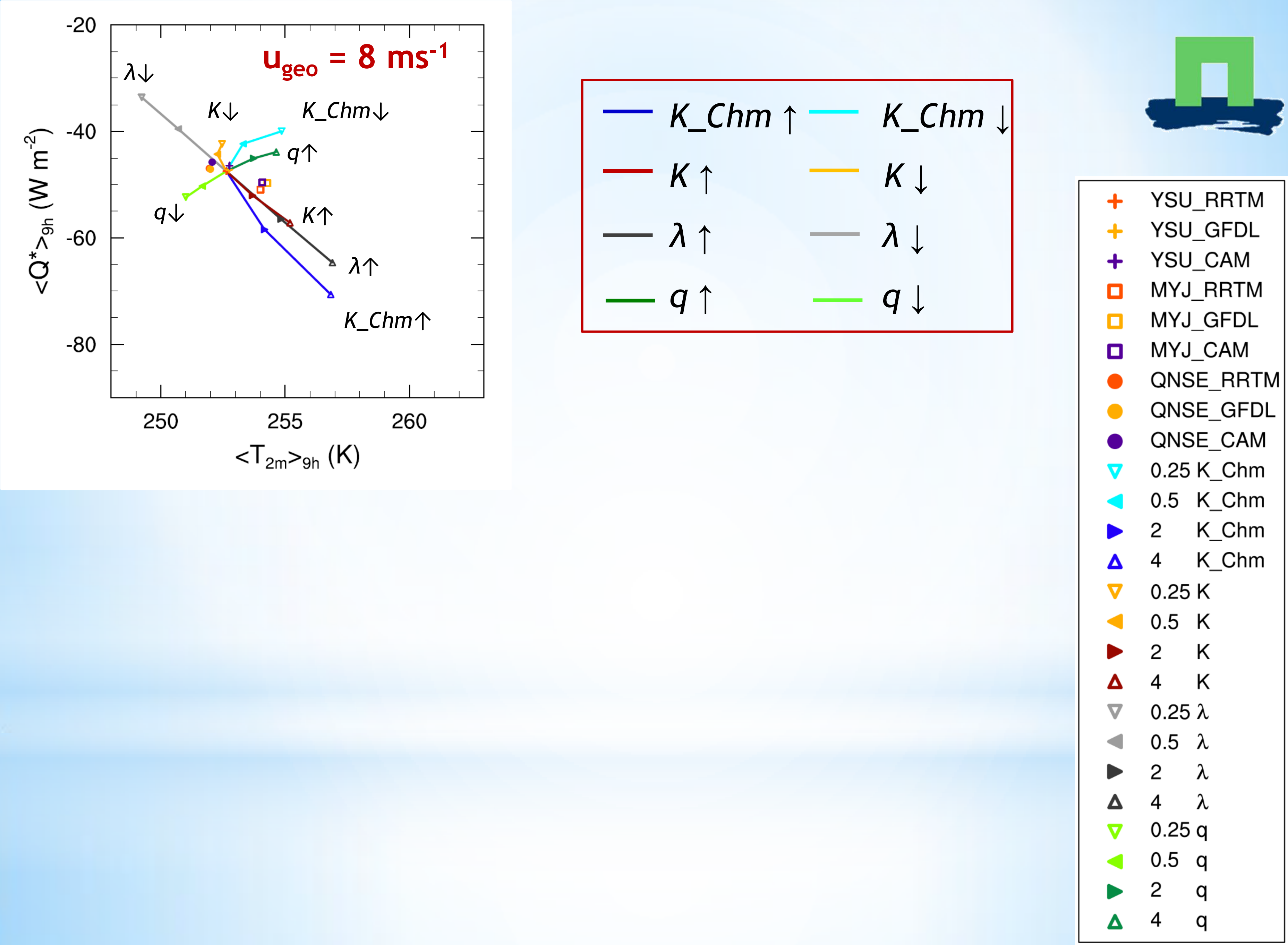
The overlapping processes are not the same for various sets of variables!!

→ Processes should not be studied in isolation

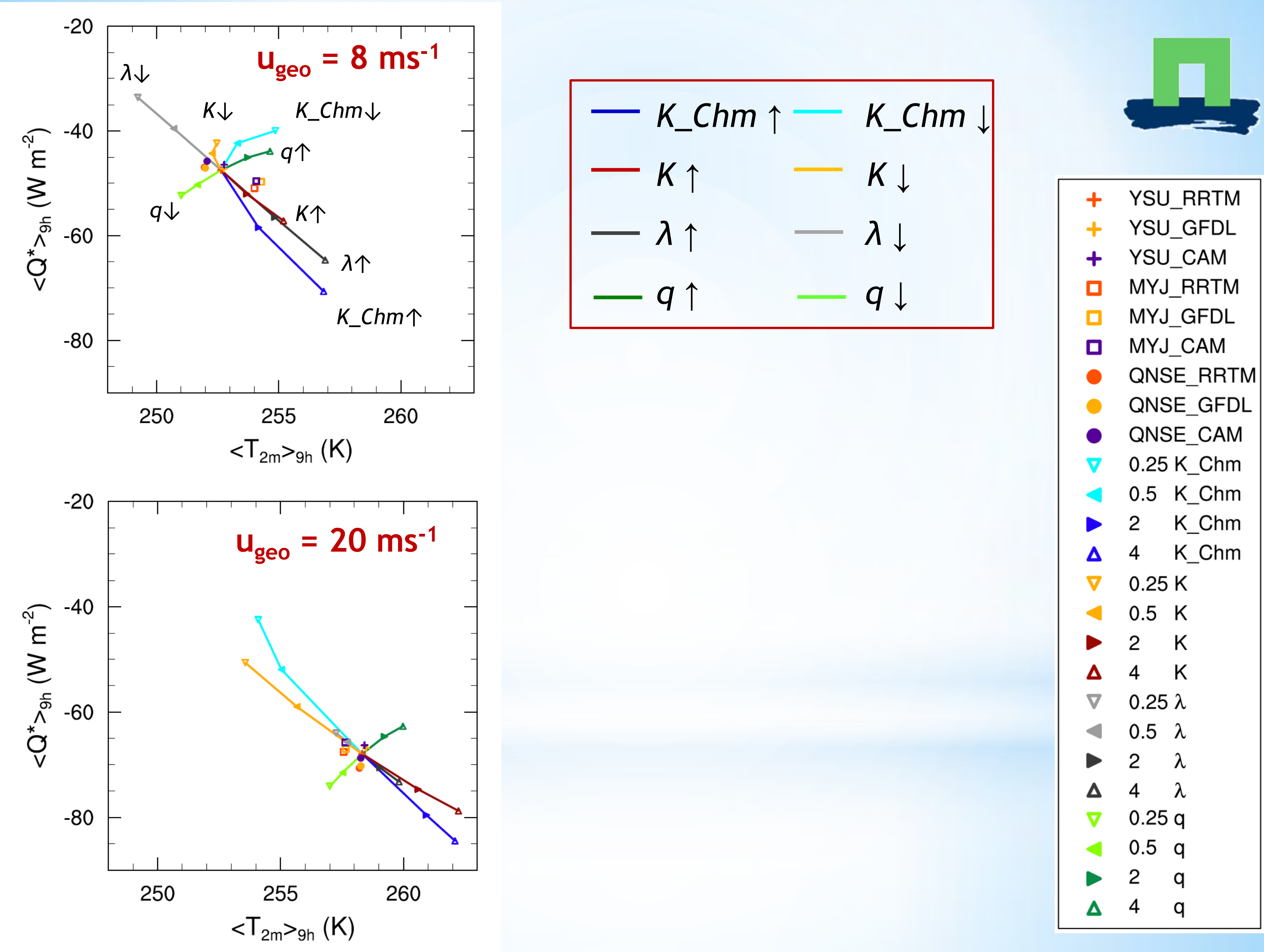
Geostrophic winds in the Arctic

- ERA-Interim reanalysis data:
  - Latitudes > 75ºN
  - Winter: DJF
  - Years 1979 - 2010

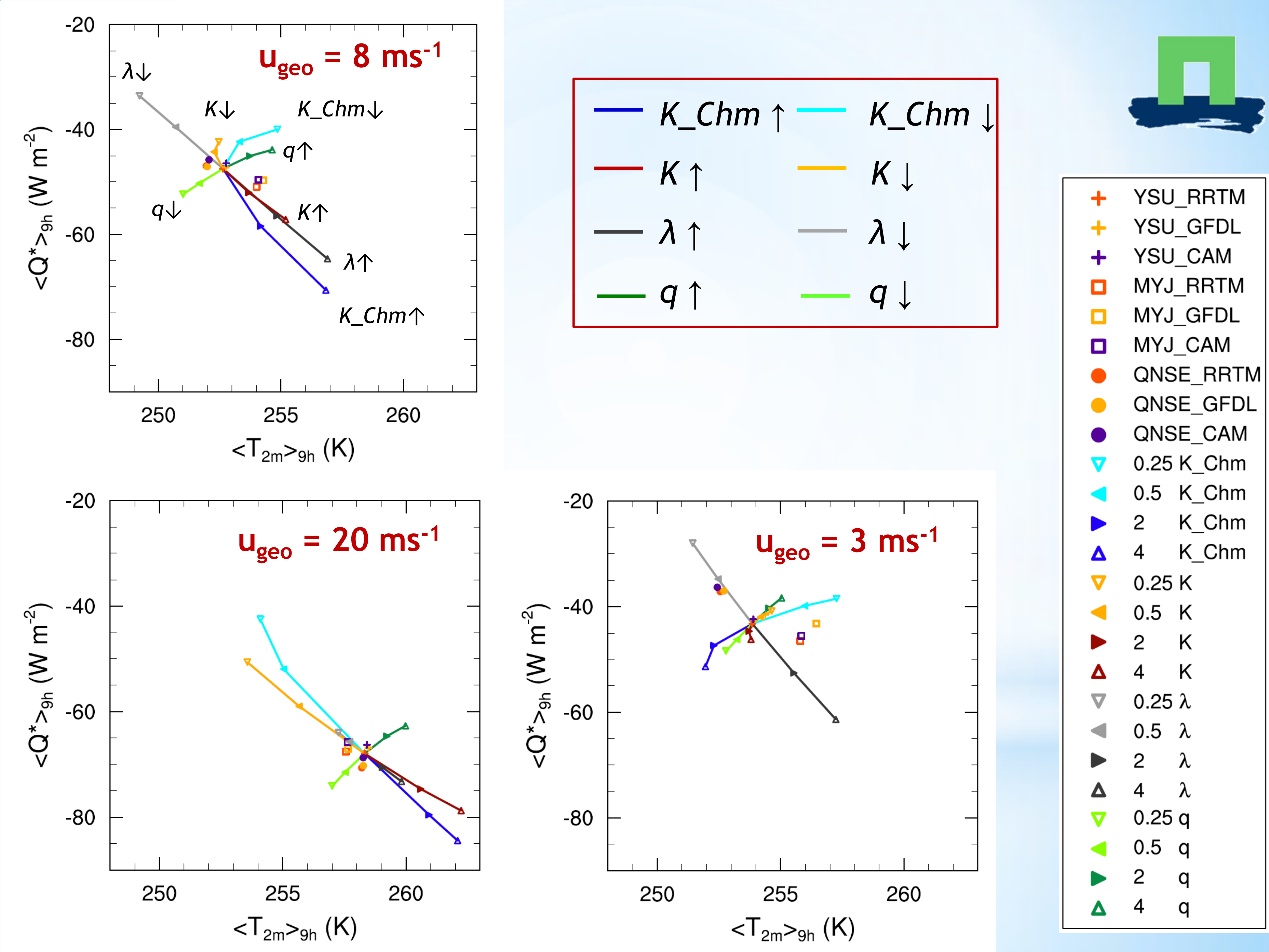




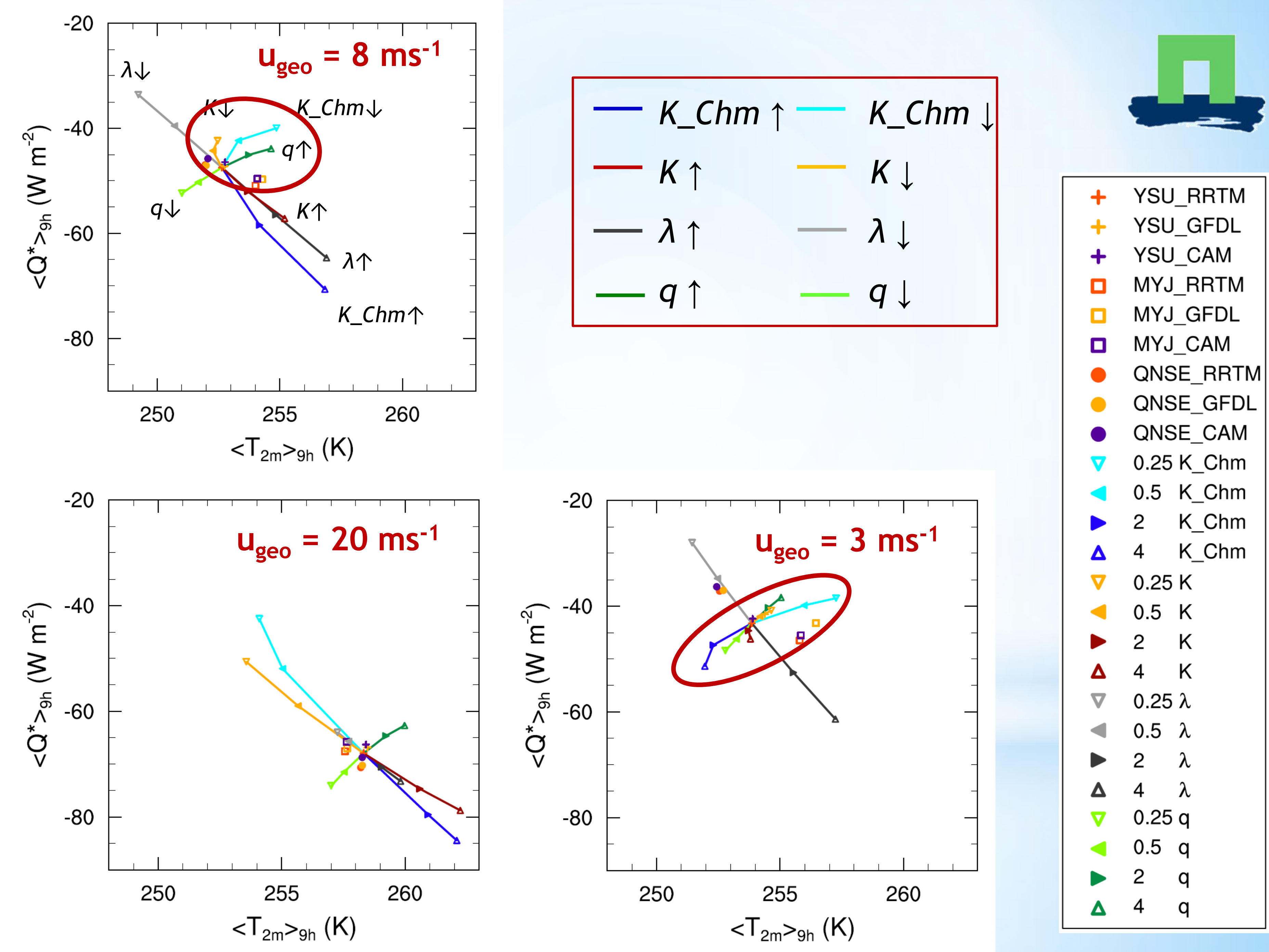
u_geo = 8 ms-1
<Q*>9h (W m-2)
<T2m>9h (K)
-20
-40
-60
-80
250
255
260
λ↓
K↓
K_Chm↓
q↑
q↓
K↑
λ↑
K_Chm↑
K_Chm ↑
K_Chm ↓
K ↑
K ↓
λ ↑
λ ↓
q ↑
q ↓
YSU_RRTM
YSU_GFDL
YSU_CAM
MYJ_RRTM
MYJ_GFDL
MYJ_CAM
QNSE_RRTM
QNSE_GFDL
QNSE_CAM
0.25 K_Chm
0.5 K_Chm
2 K_Chm
4 K_Chm
0.25 K
0.5 K
2 K
4 K
0.25 λ
0.5 λ
2 λ
4 λ
0.25 q
0.5 q
2 q
4 q



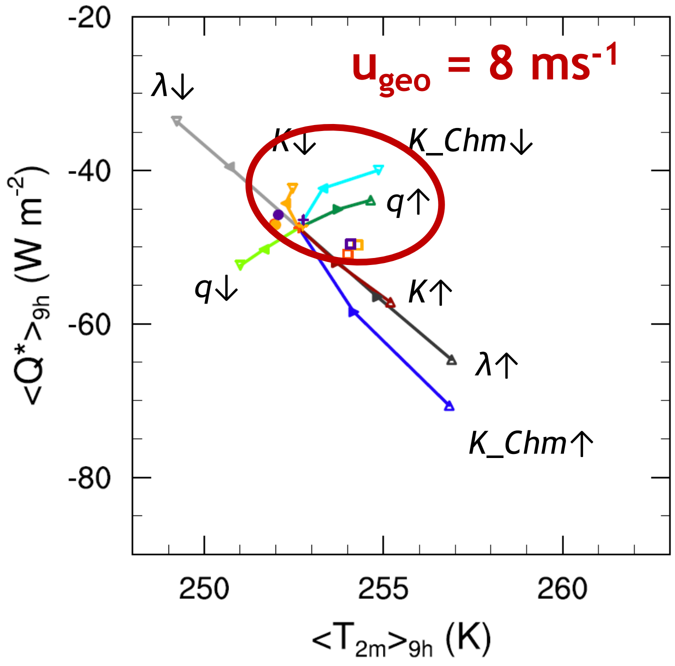
u_geo = 8 ms^-1
u_geo = 20 ms^-1
<Q*>_9h (W m^-2)
<T_2m>_9h (K)
-20
-40
-60
-80
250
255
260
λ↓
K↓
K_Chm↓
q↑
q↓
K↑
λ↑
K_Chm↑
K_Chm ↑
K_Chm ↓
K ↑
K ↓
λ ↑
λ ↓
q ↑
q ↓
YSU_RRTM
YSU_GFDL
YSU_CAM
MYJ_RRTM
MYJ_GFDL
MYJ_CAM
QNSE_RRTM
QNSE_GFDL
QNSE_CAM
0.25 K_Chm
0.5 K_Chm
2 K_Chm
4 K_Chm
0.25 K
0.5 K
2 K
4 K
0.25 λ
0.5 λ
2 λ
4 λ
0.25 q
0.5 q
2 q
4 q



u_geo = 8 ms-1
λ↓
K↓
K_Chm↓
q↑
q↓
K↑
λ↑
K_Chm↑
-20
-40
-60
-80
250
255
260
<Q*>9h (W m-2)
<T2m>9h (K)
K_Chm ↑
K_Chm ↓
K ↑
K ↓
λ ↑
λ ↓
q ↑
q ↓
u_geo = 20 ms-1
u_geo = 3 ms-1
YSU_RRTM
YSU_GFDL
YSU_CAM
MYJ_RRTM
MYJ_GFDL
MYJ_CAM
QNSE_RRTM
QNSE_GFDL
QNSE_CAM
0.25 K_Chm
0.5 K_Chm
2 K_Chm
4 K_Chm
0.25 K
0.5 K
2 K
4 K
0.25 λ
0.5 λ
2 λ
4 λ
0.25 q
0.5 q
2 q
4 q



u_{geo} = 8 ms^{-1}
λ↓
K↓
K_Chm↓
q↑
q↓
K↑
λ↑
K_Chm↑
u_{geo} = 20 ms^{-1}
u_{geo} = 3 ms^{-1}
<Q*>$_{9h}$ (W m^{-2})
<T$_{2m}$>$_{9h}$ (K)
-20
-40
-60
-80
250
255
260
K_Chm ↑
K_Chm ↓
K ↑
K ↓
λ ↑
λ ↓
q ↑
q ↓
YSU_RRTM
YSU_GFDL
YSU_CAM
MYJ_RRTM
MYJ_GFDL
MYJ_CAM
QNSE_RRTM
QNSE_GFDL
QNSE_CAM
0.25 K_Chm
0.5 K_Chm
2 K_Chm
4 K_Chm
0.25 K
0.5 K
2 K
4 K
0.25 λ
0.5 λ
2 λ
4 λ
0.25 q
0.5 q
2 q
4 q

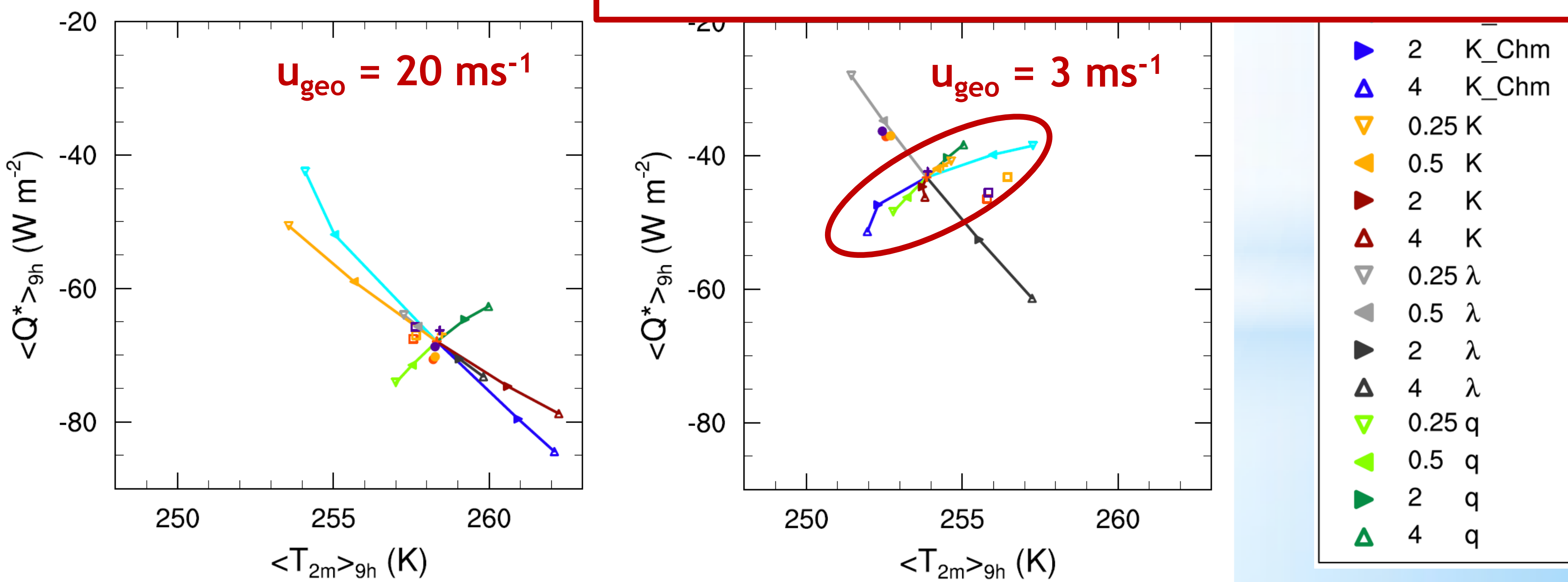


Somewhat counter intuitive:

- More mixing → lower T_{2m}
- Less mixing → higher T_{2m}

BUT:

T_{skin} is higher for more mixing, lower for less mixing



Results - non-linear behavior

- At very light wind speeds, little cold is lifted due to mixing → low T_{skin}

- *Similar results found by McNider et al. (2012) for various geostrophic wind speeds*

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- Exponential θ profile:

  When mixing increases, cold air from the surface is mixed aloft → T_{skin}↑, T_{2m}↓

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Results - non-linear behavior

- At very light wind speeds, little cold is lifted due to mixing → low T_{skin}
- Exponential θ profile:

  When mixing increases, cold air from the surface is mixed aloft → T_{skin}↑, T_{2m}↓
- Mixed θ profile:

  When mixing increases, warm air from aloft is able to reach lower layers → T_{2m}↑

- *Similar results found by McNider et al. (2012) for various geostrophic wind speeds*

Summary / conclusion

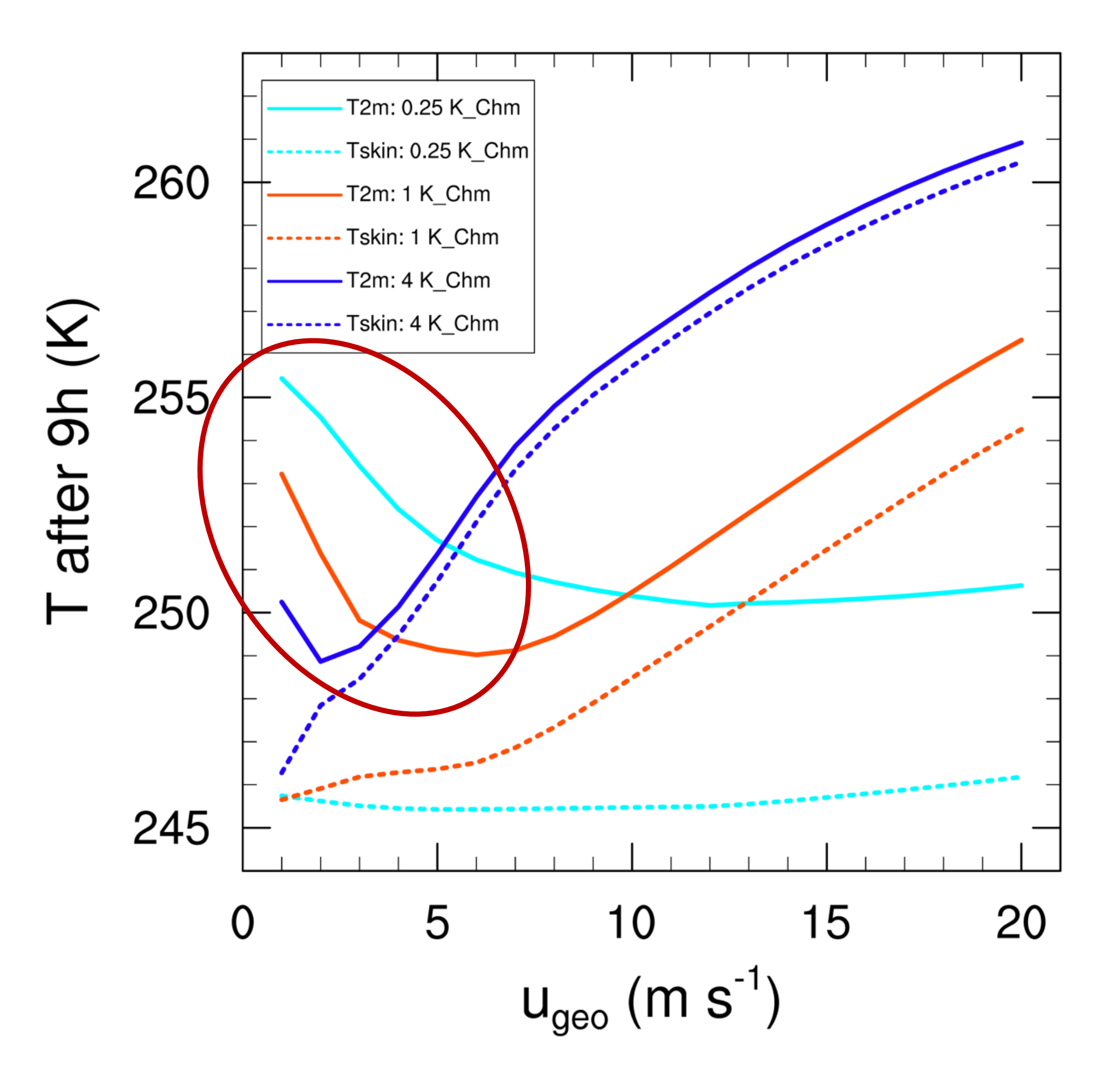
- Which are the most dominating processes for different wind regimes?
  - Low wind speed: thermal coupling and radiative effect appear more important (mixing if also in surface layer)
  - High wind speed: turbulent mixing becomes more significant

Summary / conclusion

- Which are the most dominating processes for different wind regimes?
  - Low wind speed: thermal coupling and radiative effect appear more important (mixing if also in surface layer)
  - High wind speed: turbulent mixing becomes more significant
- Non-linearity for low and most freq. occurring u_{geo}
  - Temperature close to the surface decreases with increased mixing
  - Related to the shape of the potential temperature profile

Thank you for your attention!

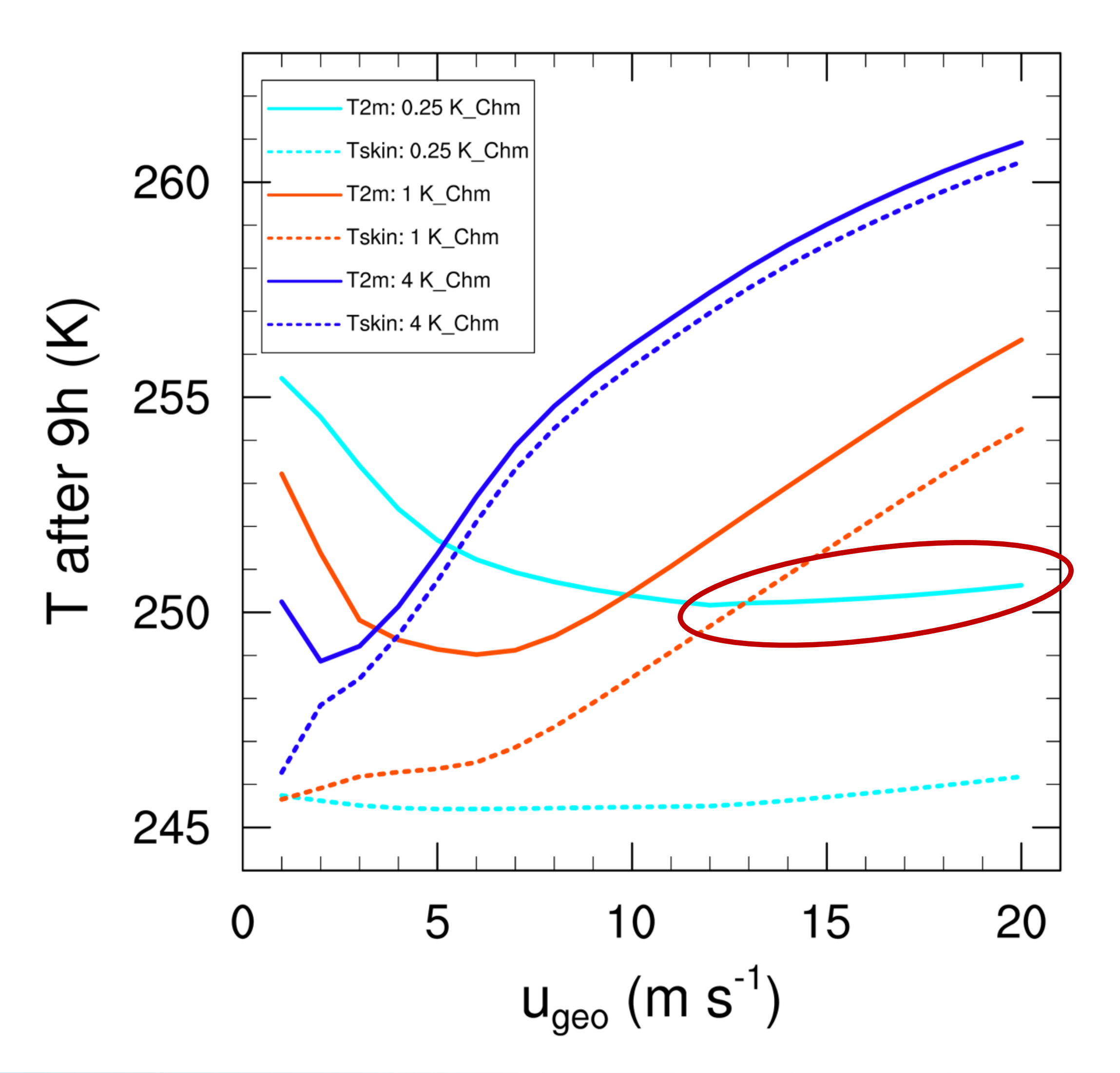
Results - wind speed / mixing



Low wind speeds:

- All mixing strengths show this behavior
- Appears dependent on vertical θ profile:
  - Left of T_{min}: exponential
  - Right of T_{min} (for 1 and 4 K_Chm): better mixed

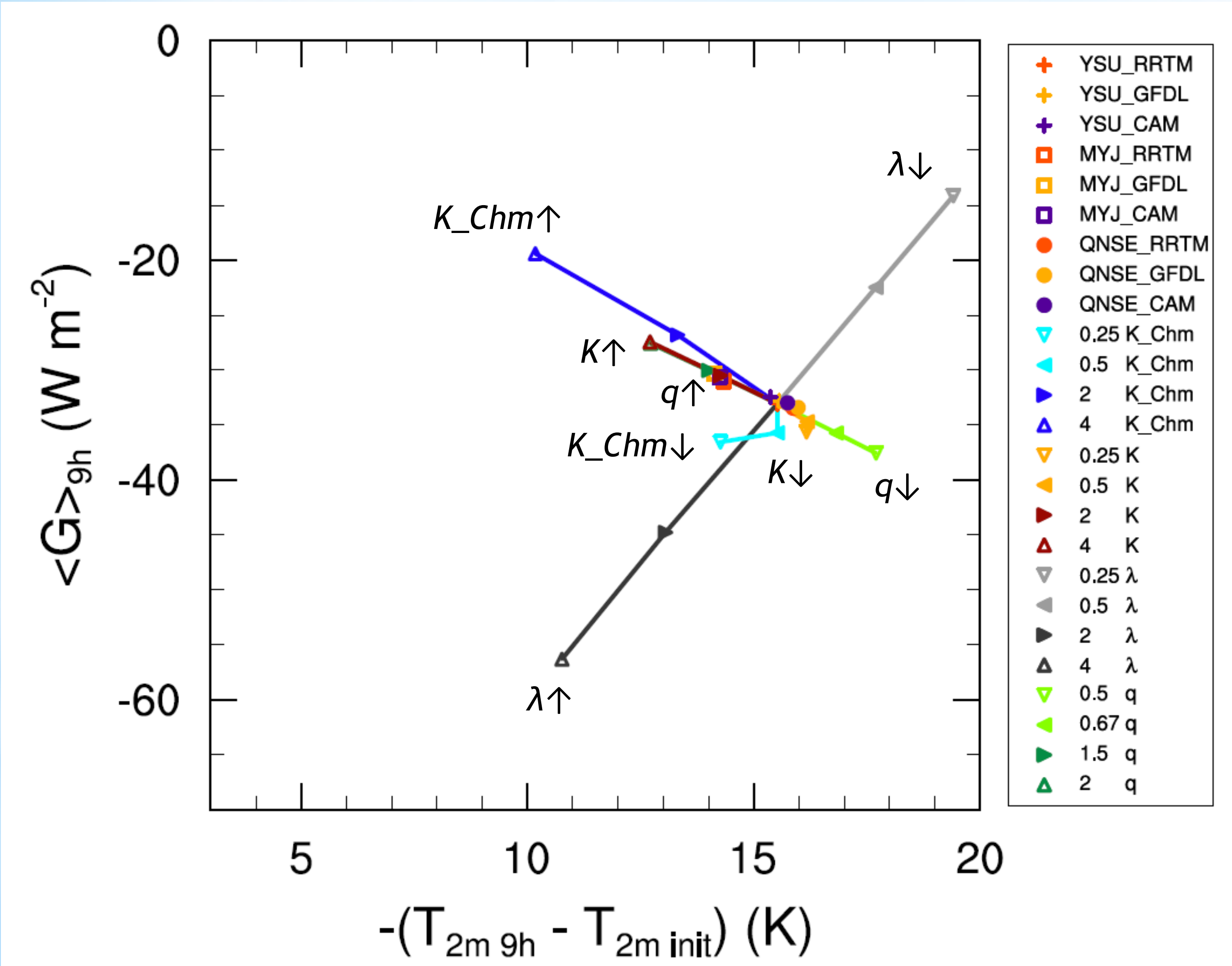
Results - wind speed / mixing



For decreased mixing strength:

- Difference in profile shape not clear
- Though temperature gradient decreases for increasing u_{geo} and more efficient downward mixing from higher levels

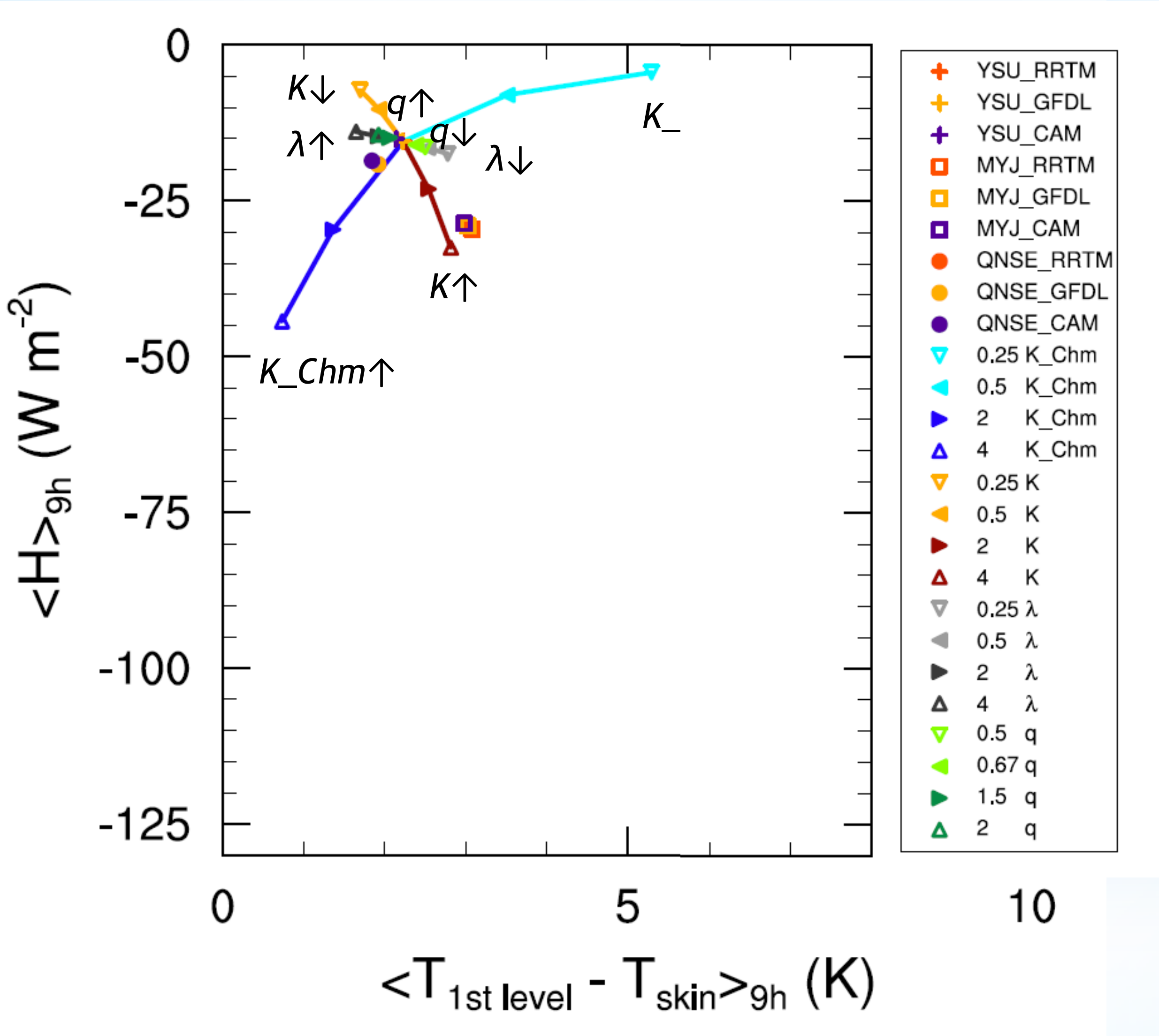
Results - Process diagram u_{geo} = 8 m/s



$$G = -\lambda \frac{dT}{dz}$$

Mixing and radiation processes overlap

Results - Process diagram u_{geo} = 8 m/s



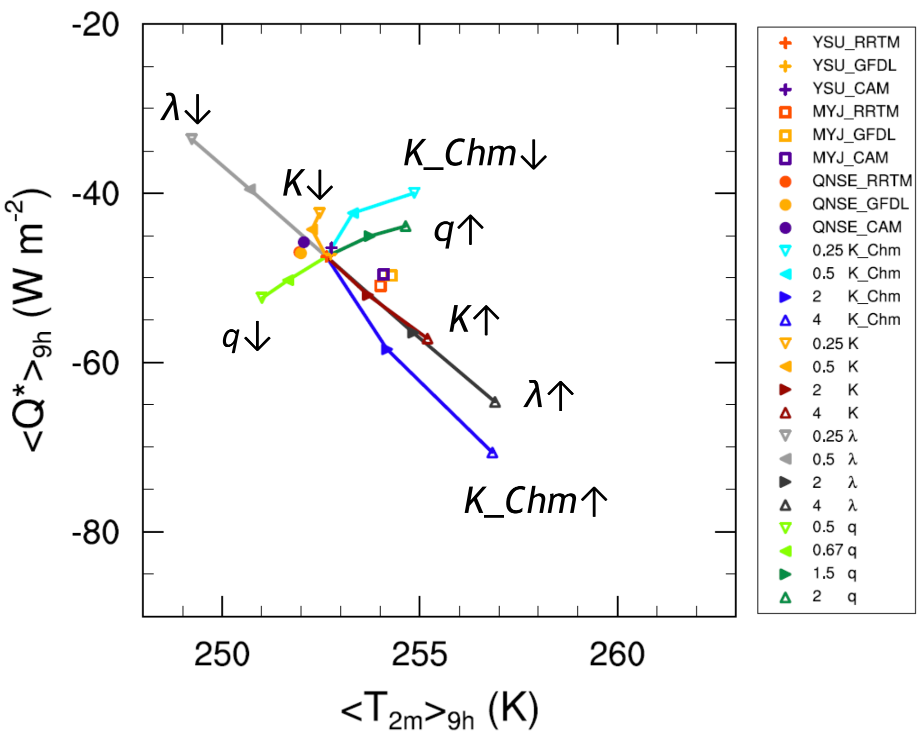
$$H = -\rho c_p K_h \frac{\partial \theta}{\partial z}$$

$$H = -\rho c_p C_h u(\theta_1 - \theta_s)$$

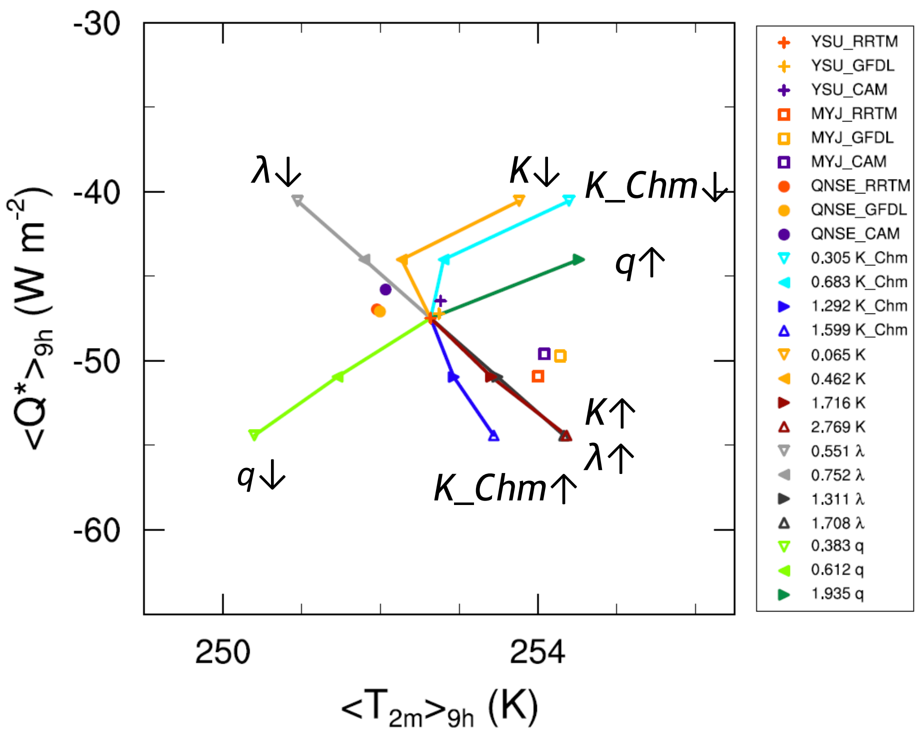
Coupling and radiation processes overlap

Results - Process diagram u_{geo} = 8 m/s

- Change in surface net radiation (ΔQ^*) is kept similar

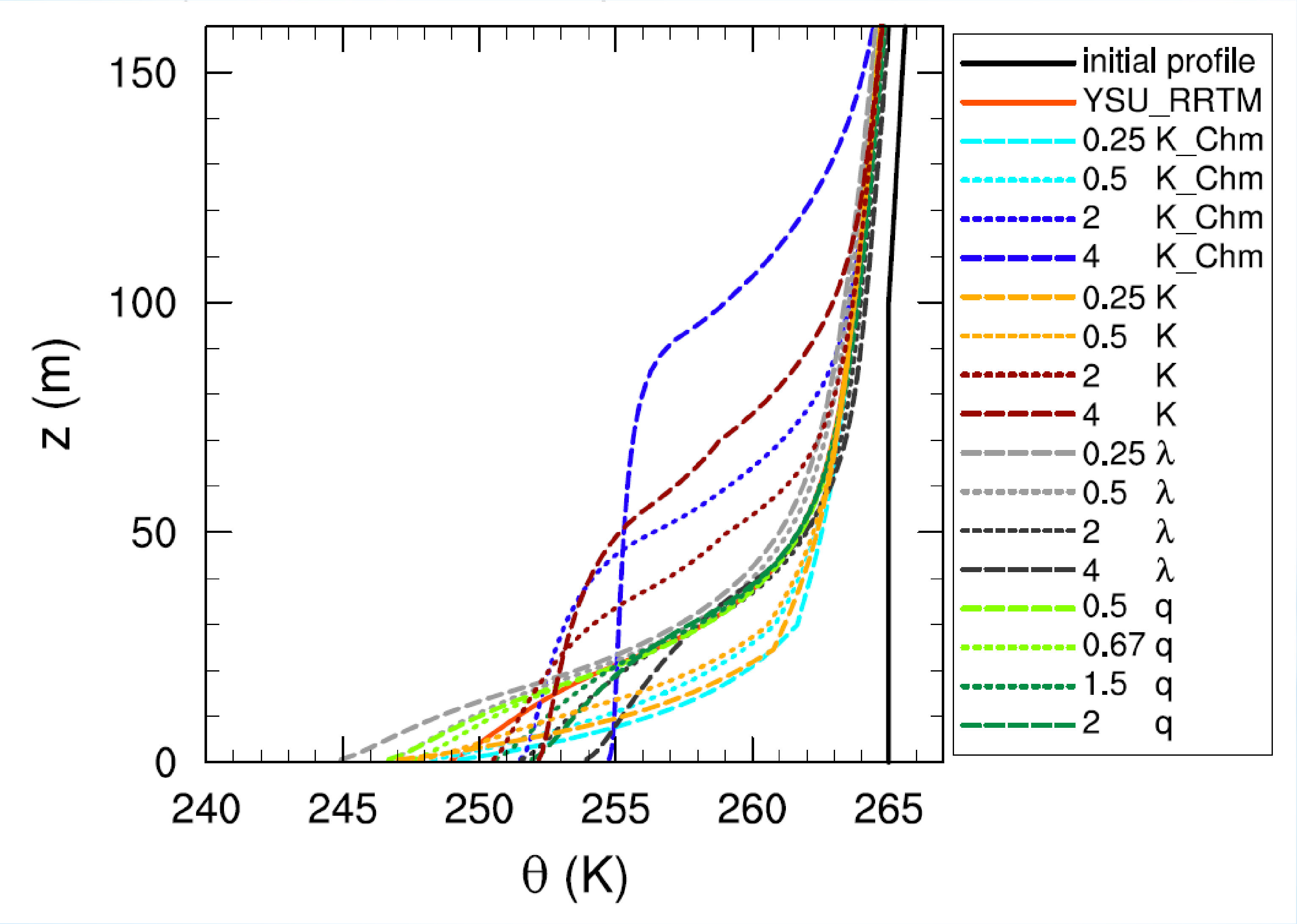


OLD

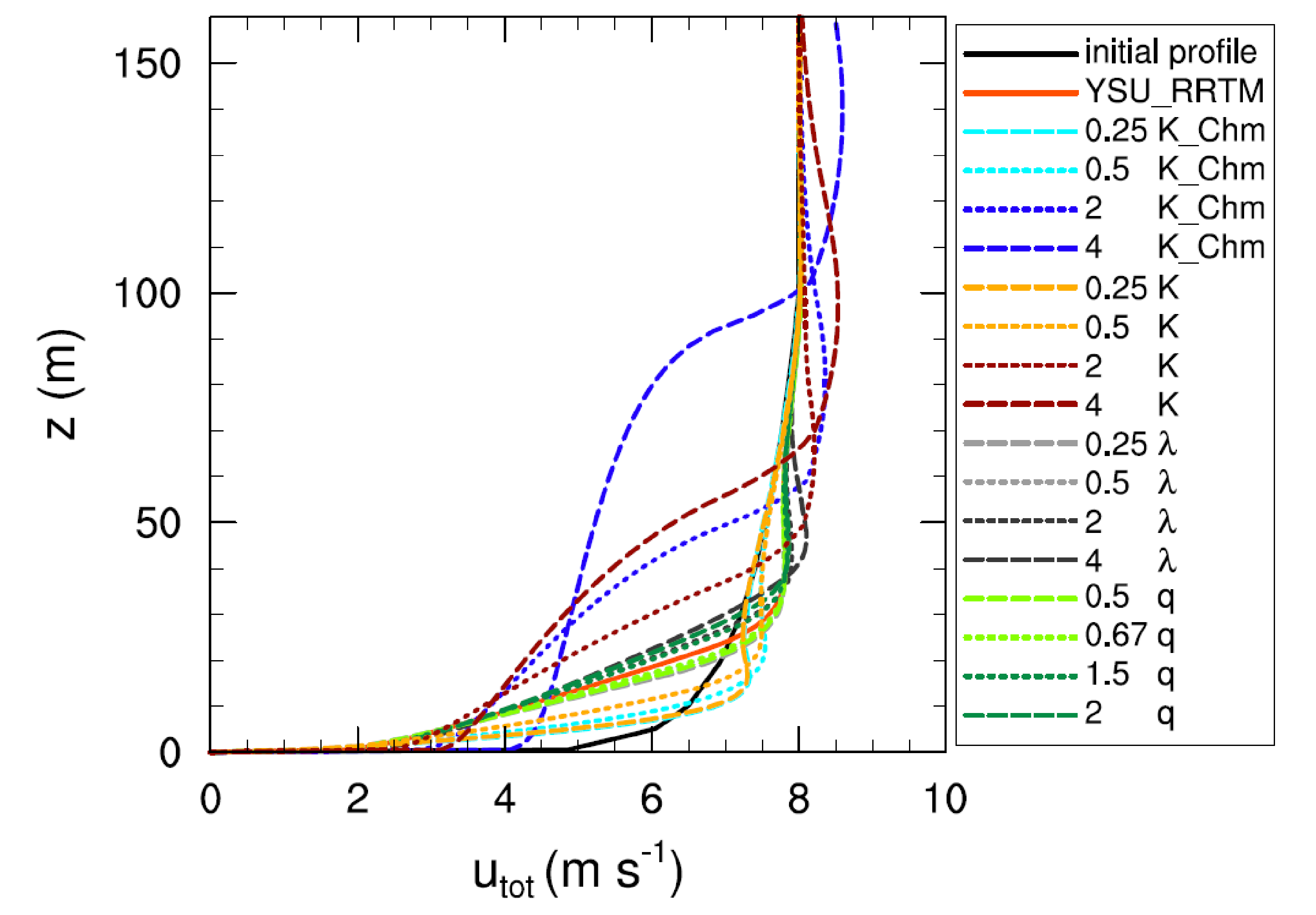


NEW

Results - θ profile: u_{geo} = 8 m/s



Results - u_{tot} profile: u_{geo} = 8 m/s



Non-linearity in observations

- Lüpkes et al. (2008) using SHEBA data:
  - Minimum T at 10m not observed for very calm conditions, but for wind speeds of 4 m/s
- Acevedo and Fitzjarrald (2003) using SBL measurements in Albany:
  - Wind below 1.5 m/s only mix air downward → cooling
  - Higher wind speeds mix with higher levels → warming