WAVES TO WEATHER

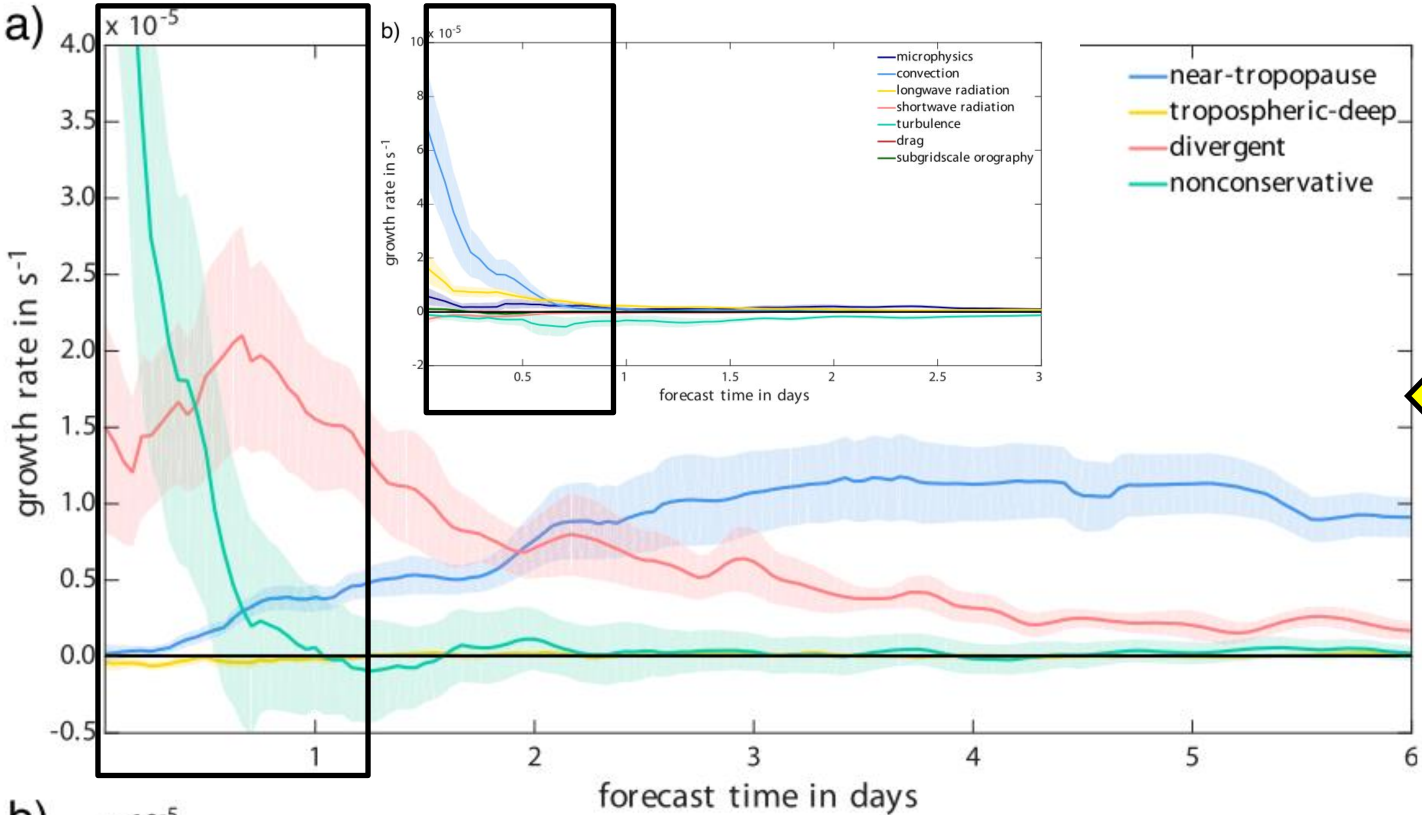
Which processes control upper tropospheric divergent outflow of deep convection?

Edward Groot, Holger Tost
Institute of atmospheric physics
Johannes Gutenberg University, Mainz, Germany

ECMWF workshop on model uncertainties
May 2022 Reading

Motivation

- Deep moist convective UT divergence as mediator of errors (uncertainty) from convective scale to large scales (Baumgart et al. 2019)
- PV based UT error: convection → divergent mode → non-linear near-tropopause



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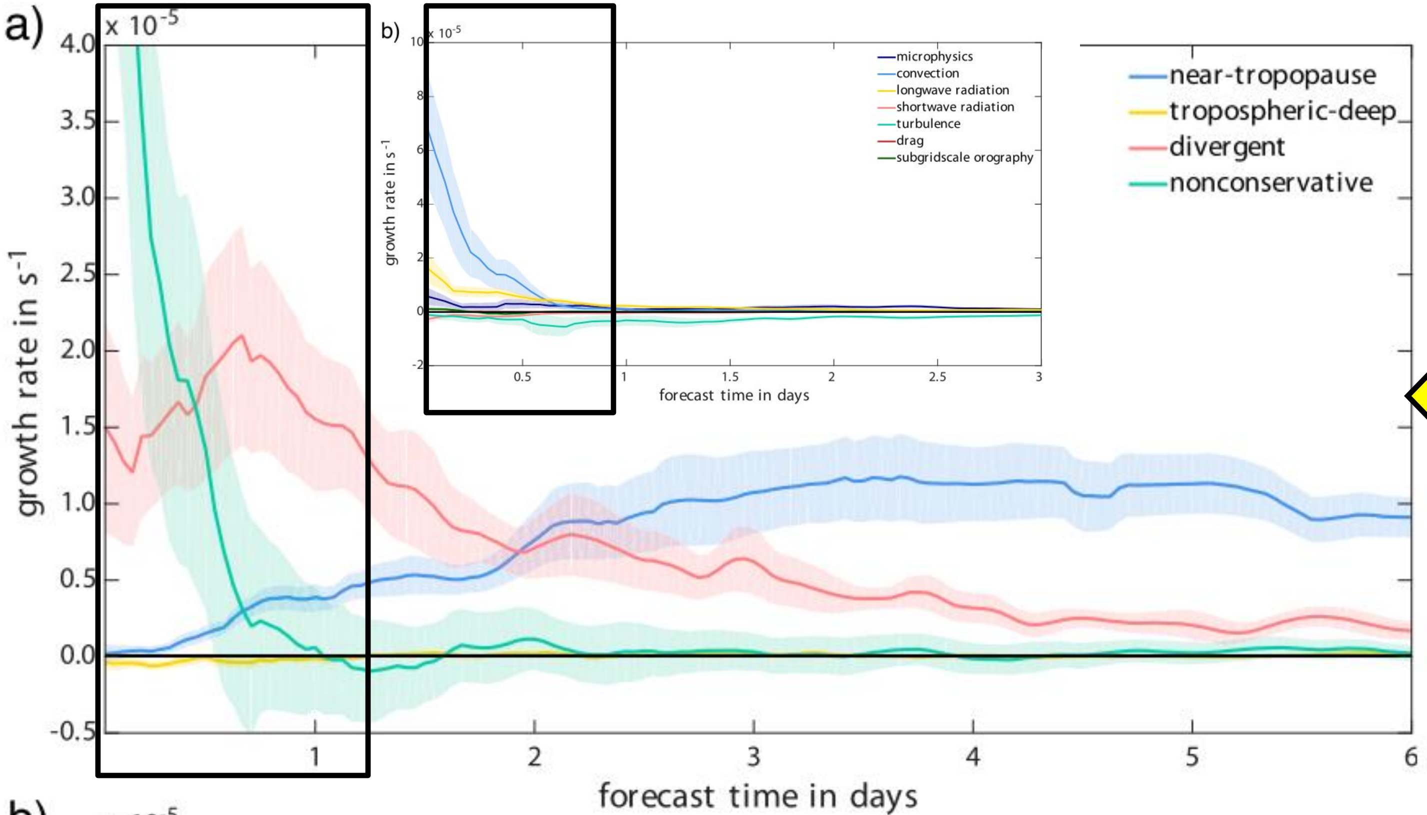

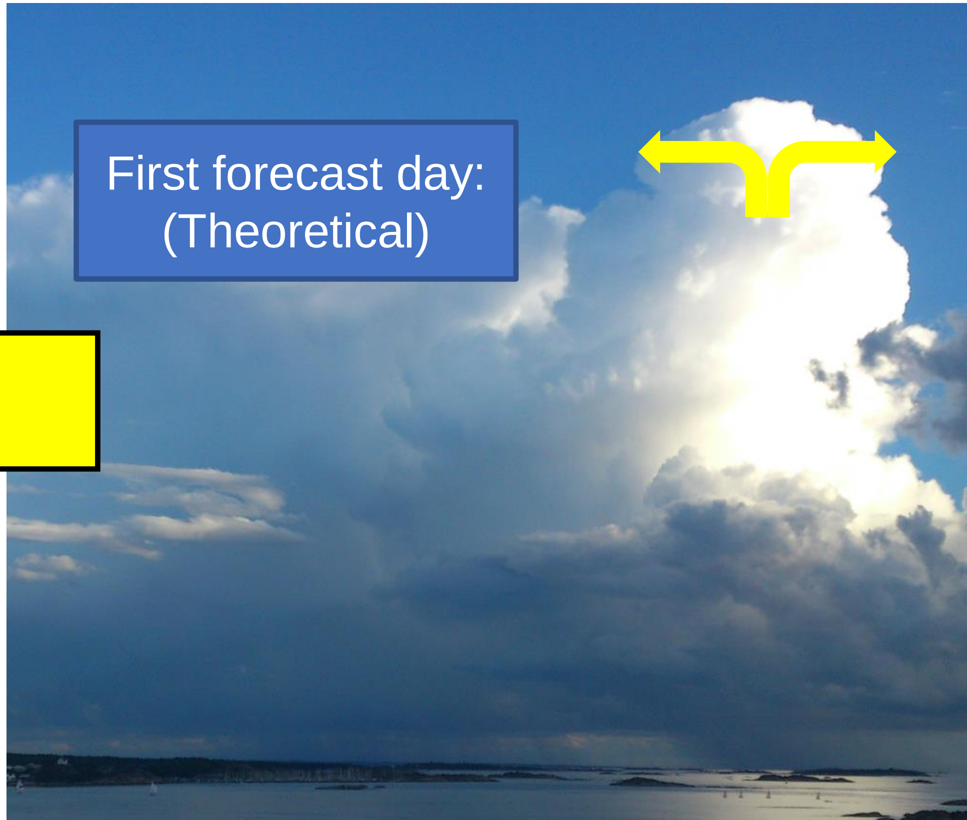

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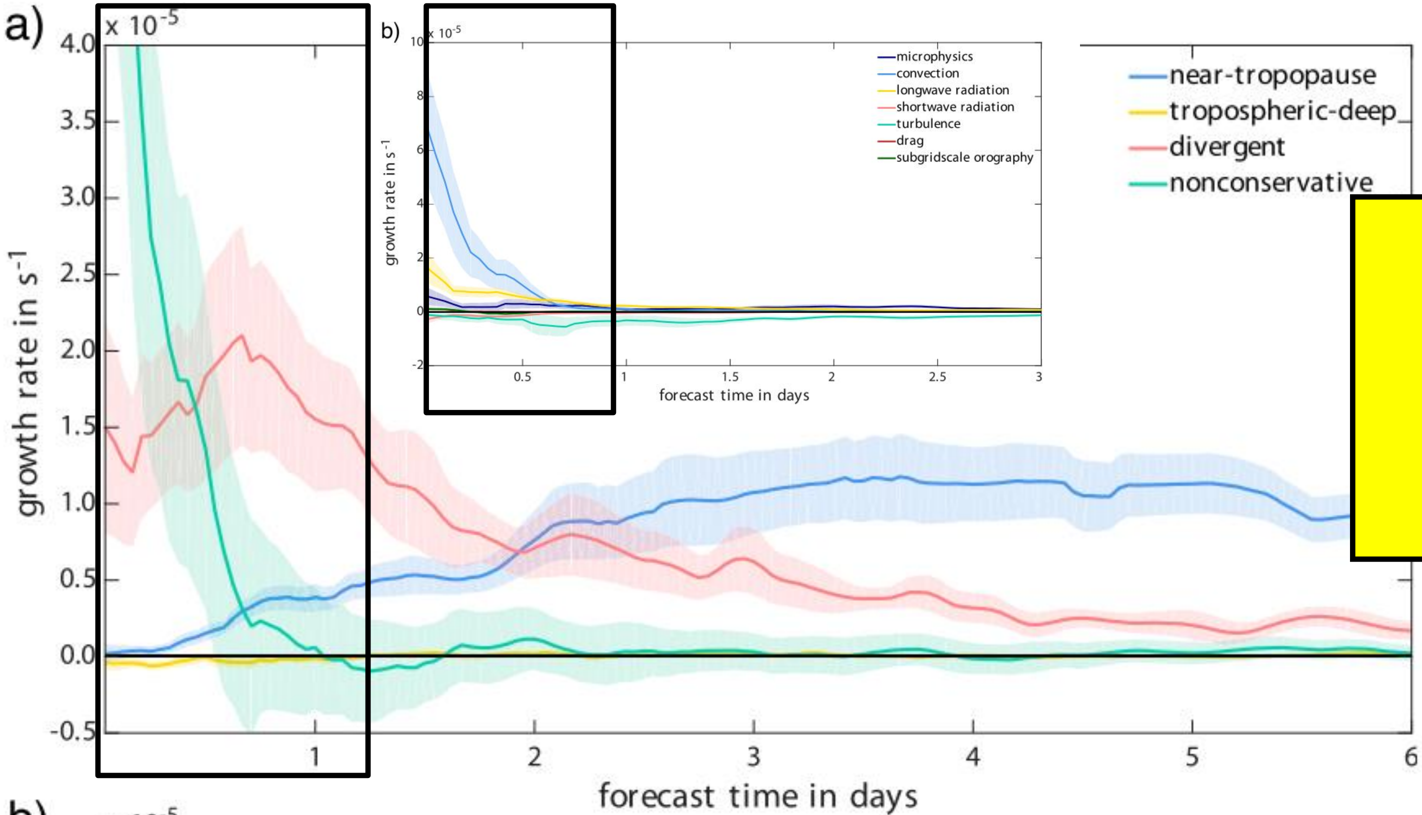
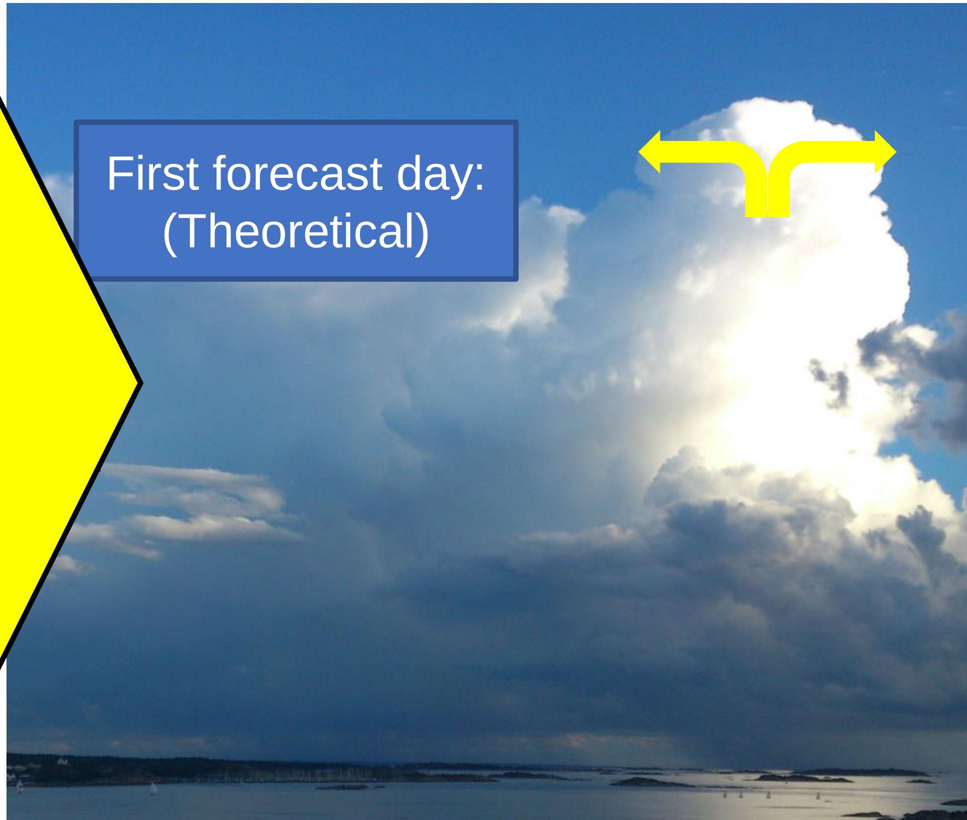
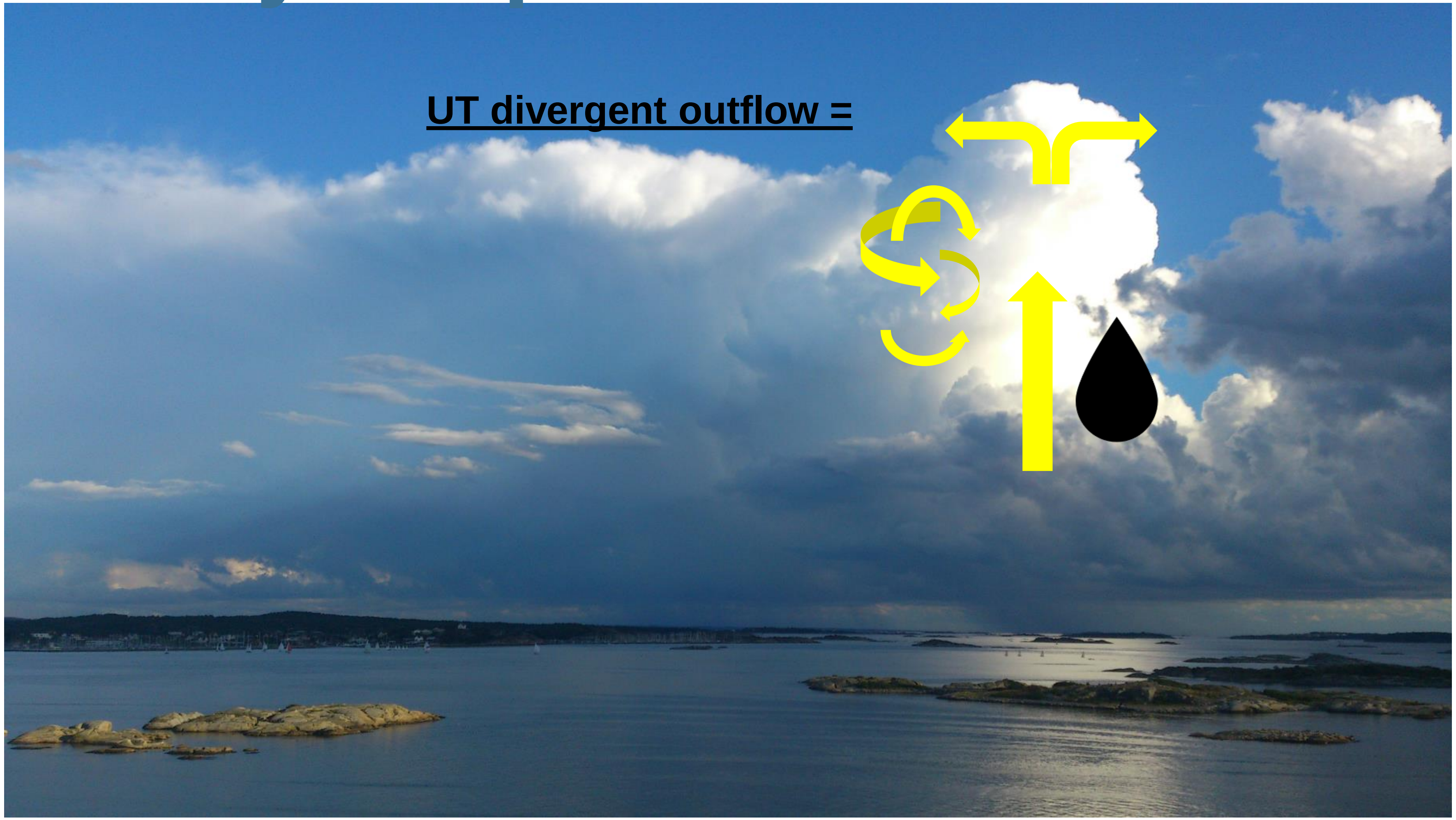


Attribution?



Quantitative assessment UT divergent flow by deep moist convection



- Large eddy simulations (CM1 v19), explicit and parameterized convection (ICON 2.6)

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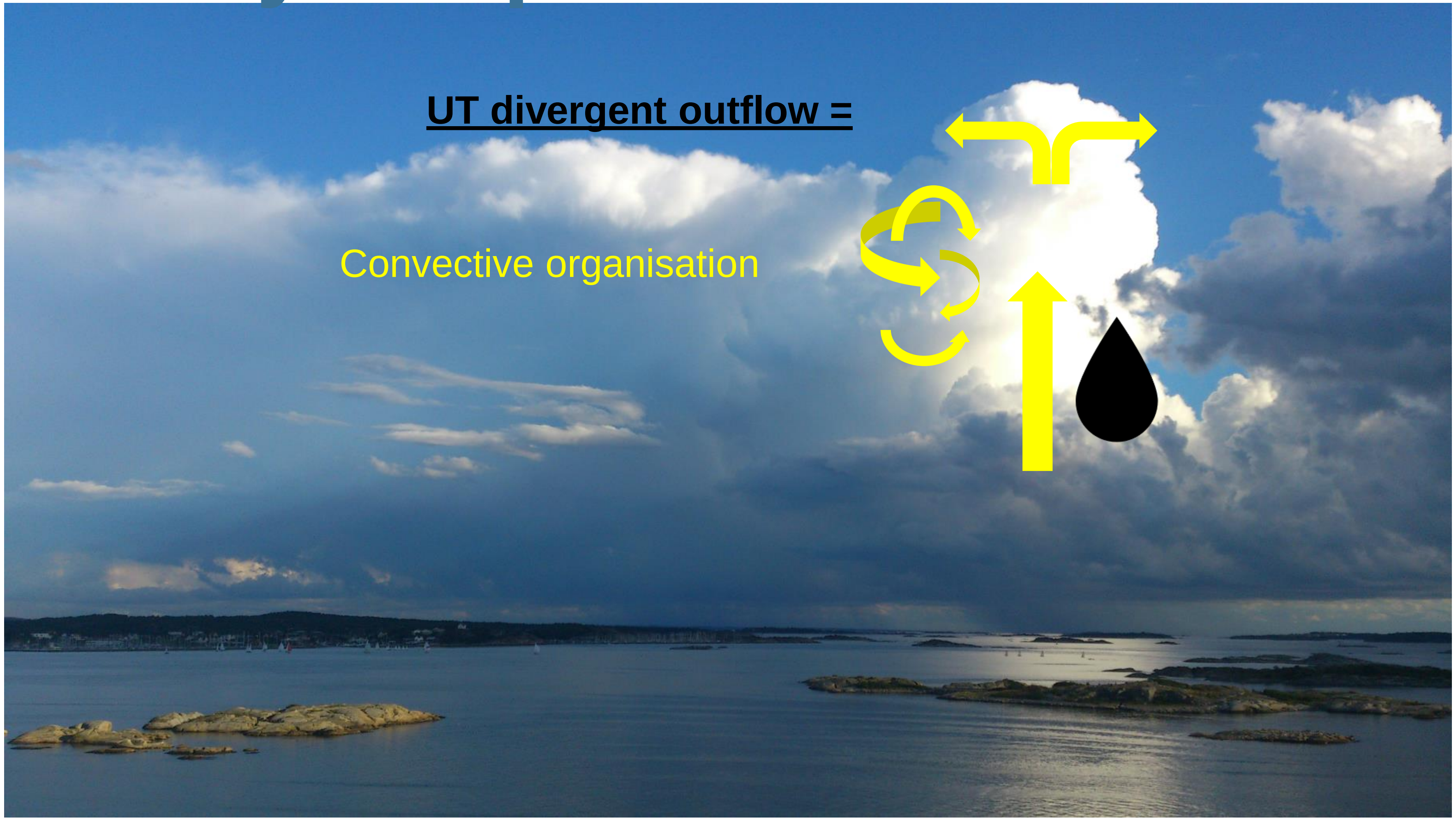

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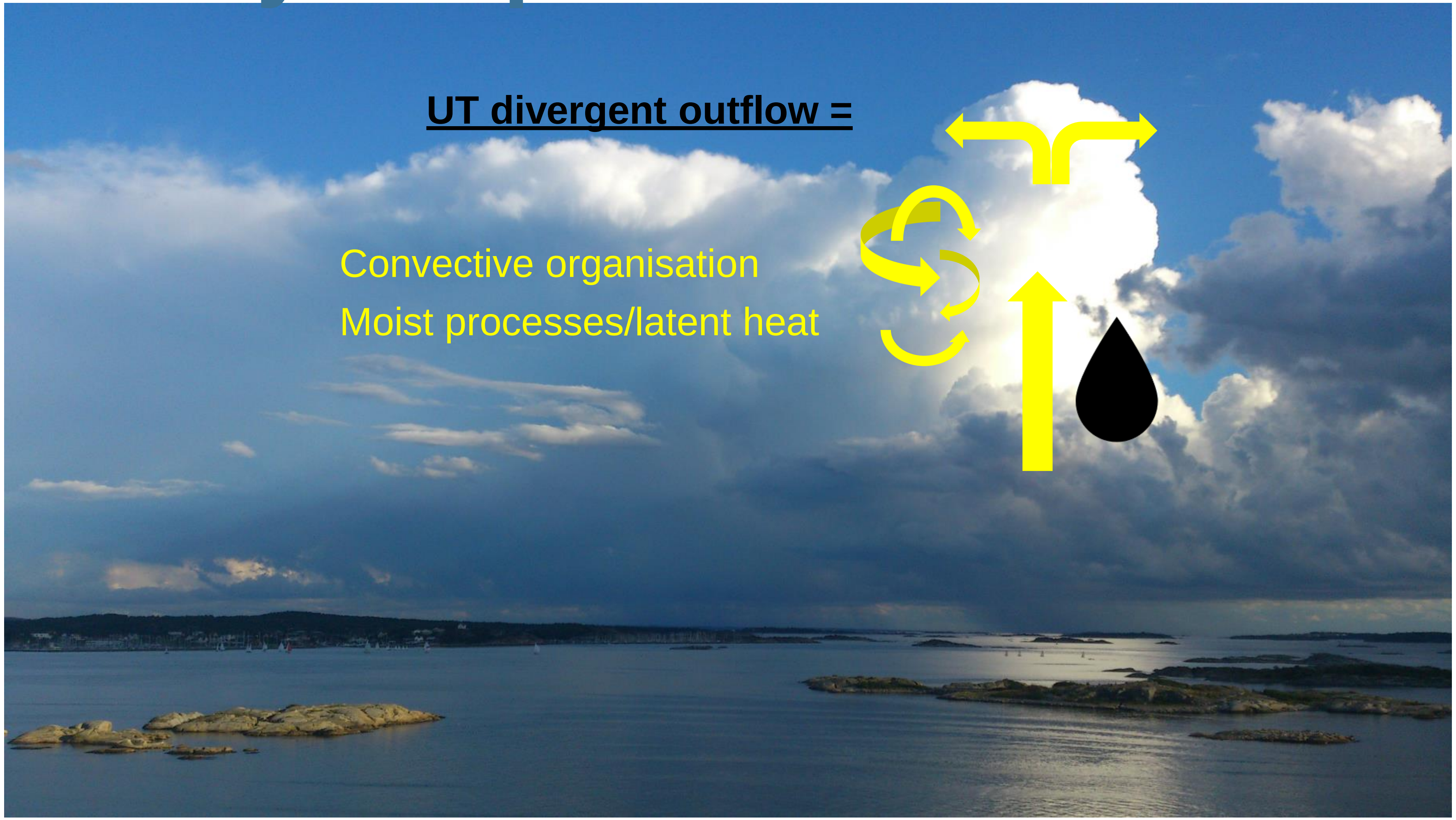

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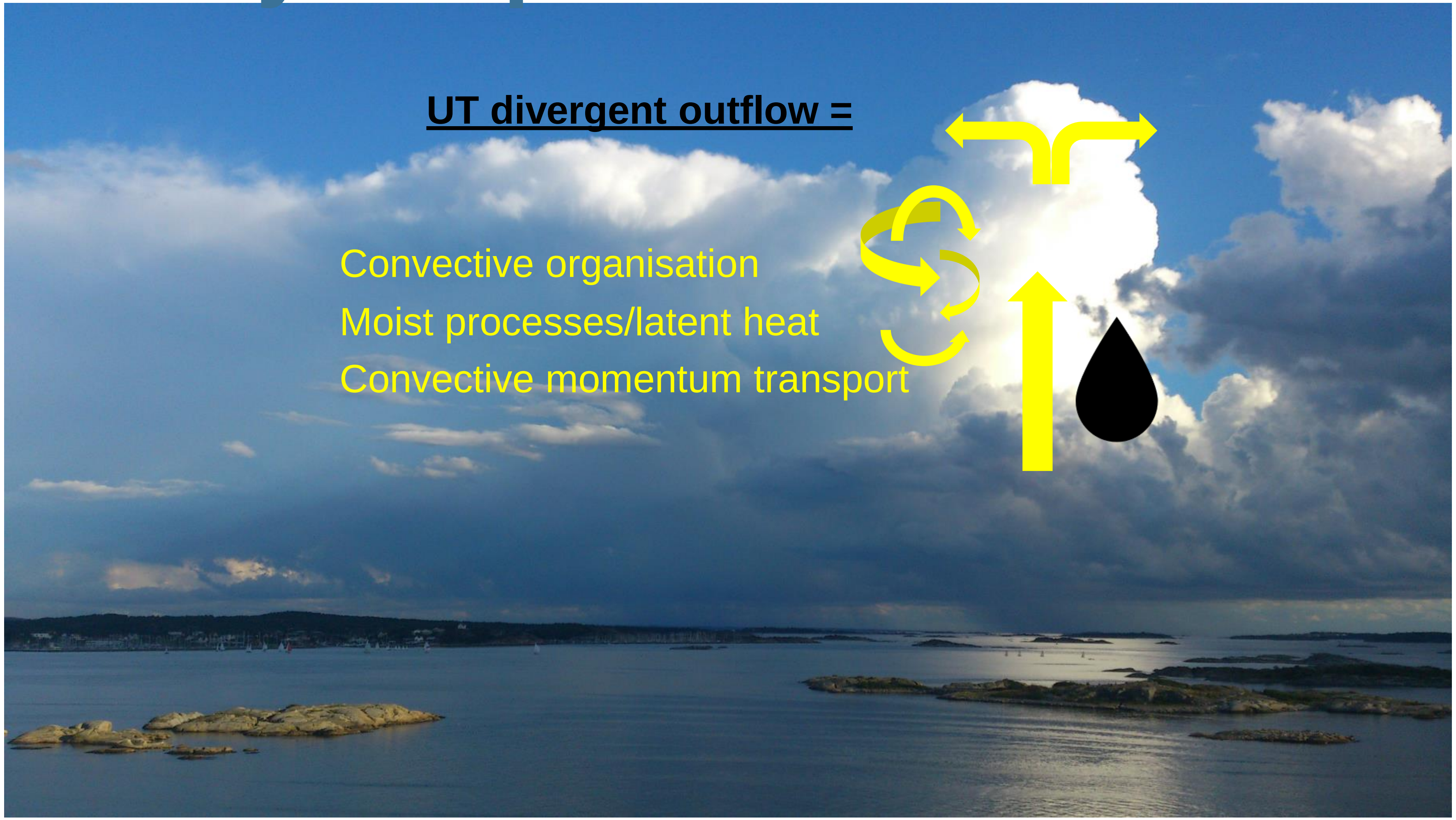

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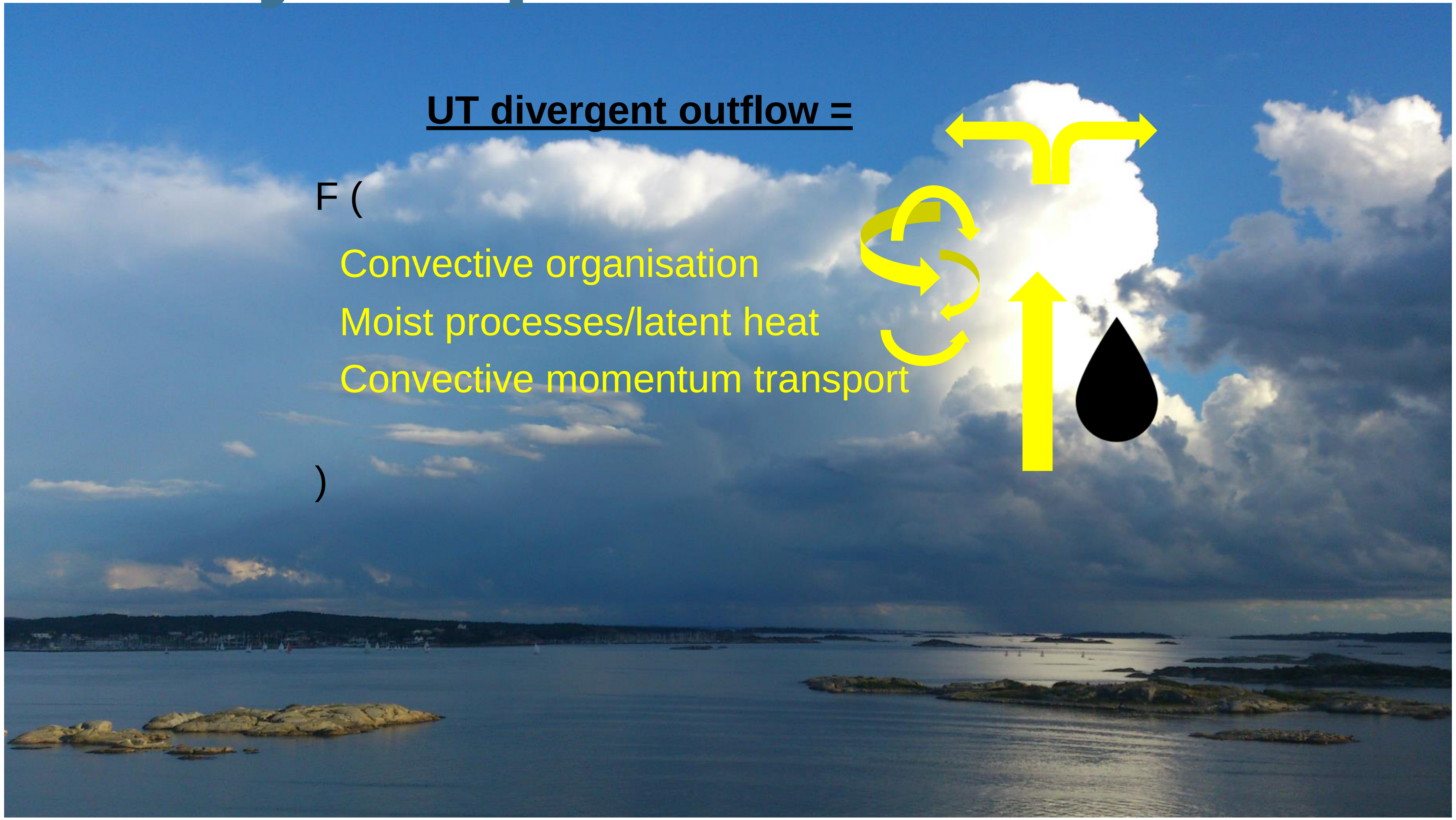

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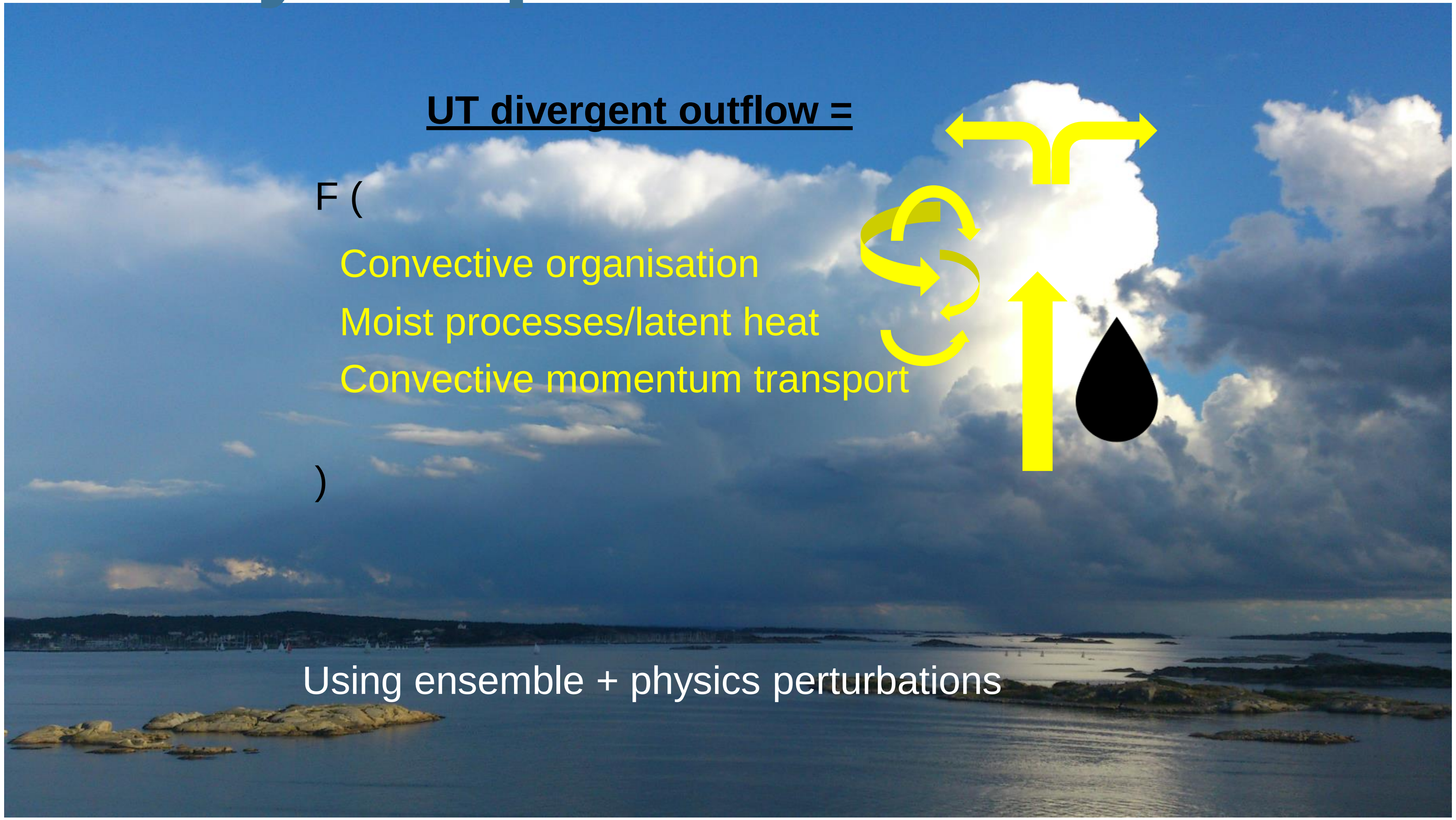


- Large eddy simulations (CM1 v19), explicit and parameterized convection (ICON 2.6)

Methods: simulation strategy

1. Idealized Large eddy simulations

Mode of organization: regular multicell convection, supercell, (infinite length) squall line

- Latent heating (constant of release) as proxy
- Convective momentum transport (completely off, ±50%, conserved)
- Ensemble
- Resolution

2. Parameterized convection (ICON global 26 km + 13 km EU nest)

3. Study explicit convection (ICON LAM, 2 km Southern Germany)

Physical understanding

Mostly practical NWP implications

Methods: simulation strategy

1. Large eddy simulations

Mode of organization: ordinary multicell convection, supercell, squall line

- Ensemble
- Latent heating
- Convective momentum transport
- Resolution

Physical understanding

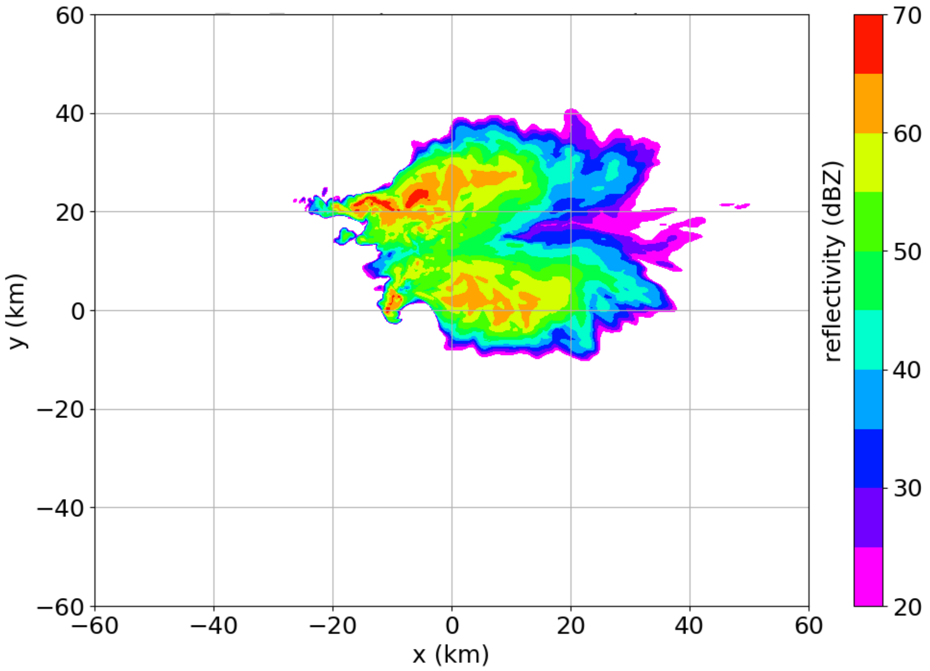
Quantitative assessment of box averaged UT divergence versus precipitation.

- Box with convectively affected circulation would typically grow in time

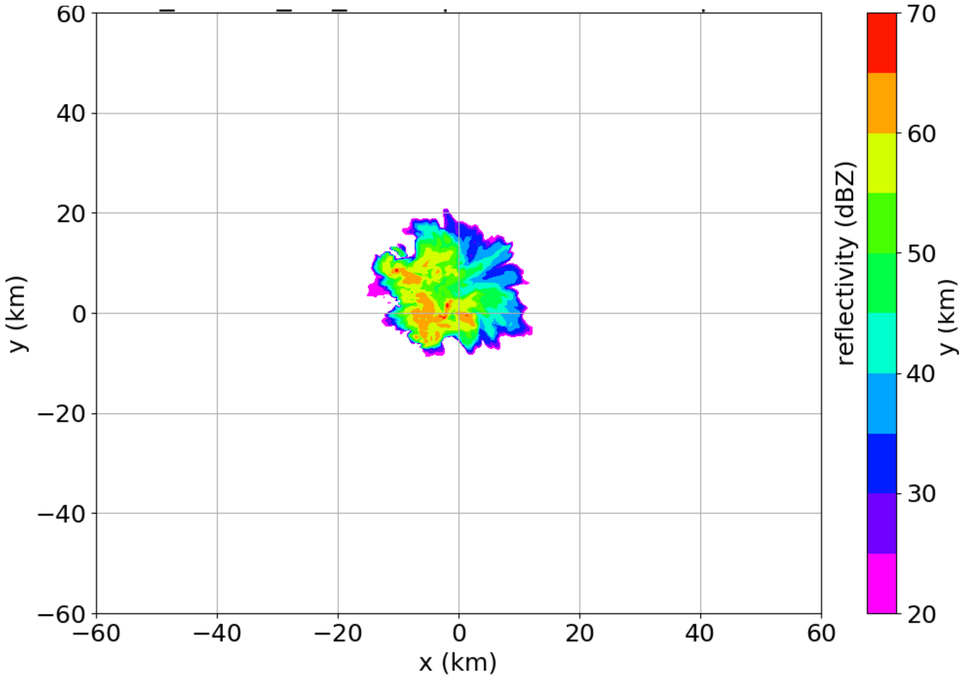
Ensemble + perturbed physics LES: dx, dy = 200 m, dz = 100 m, L = 120x120 km, H = 20 km (5 km sponge layer), T = 2 hours

Simulations: Convective structures

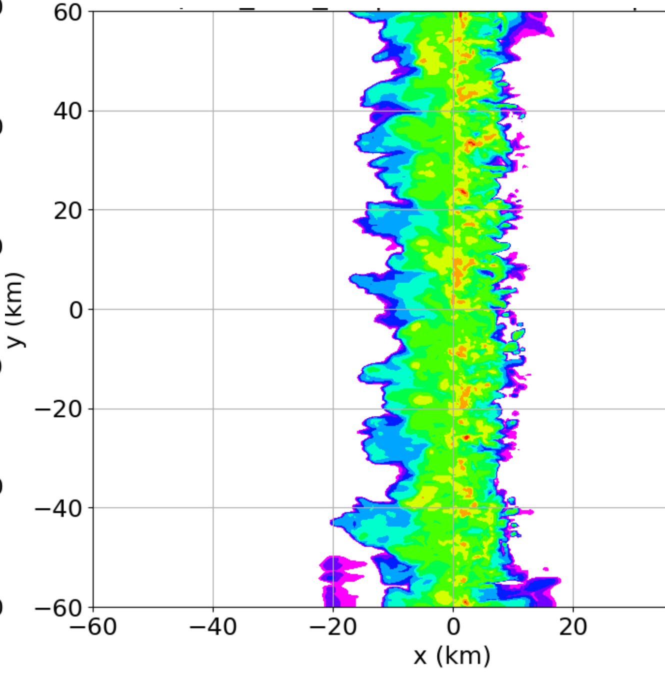
Supercell



Isolated multicell



Squall line

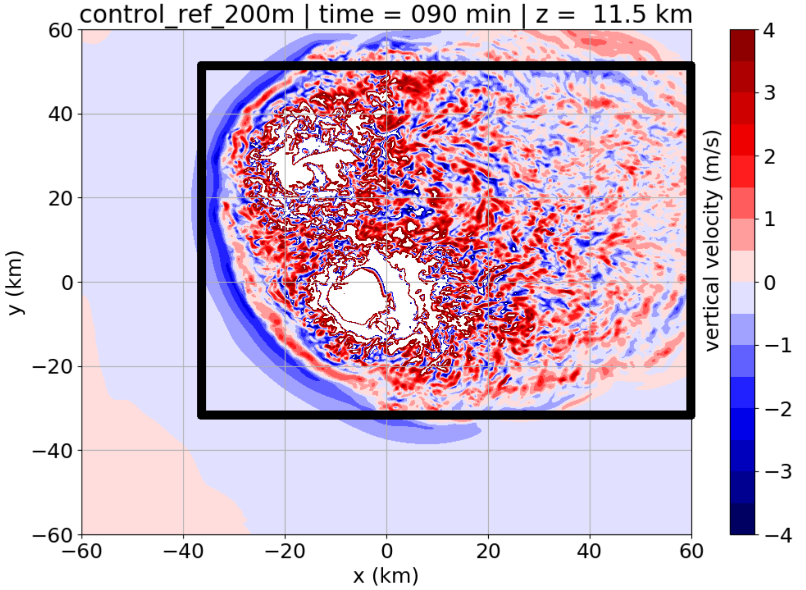


Simulations: integration domains

States at integration **end** times of initial box analysis, w (m/s)

Supercell

$t_{end} = 90$ min



Isolated multicell

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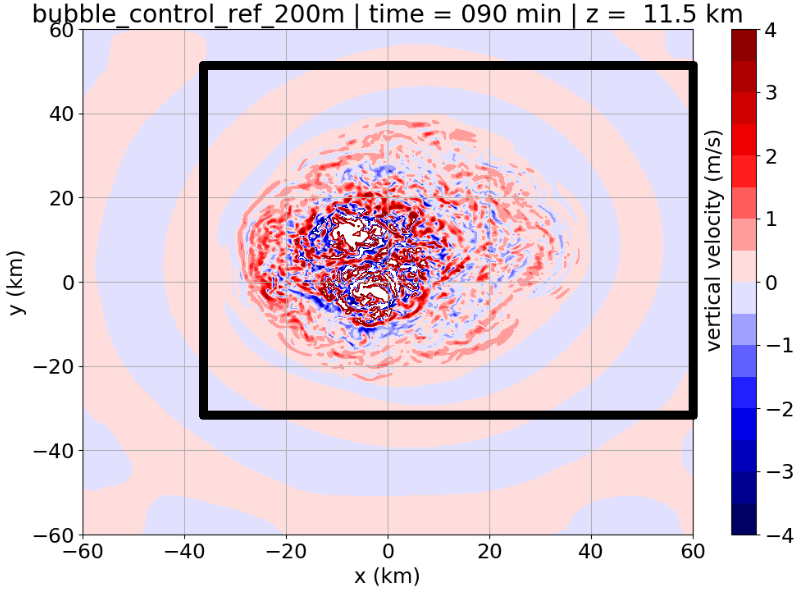
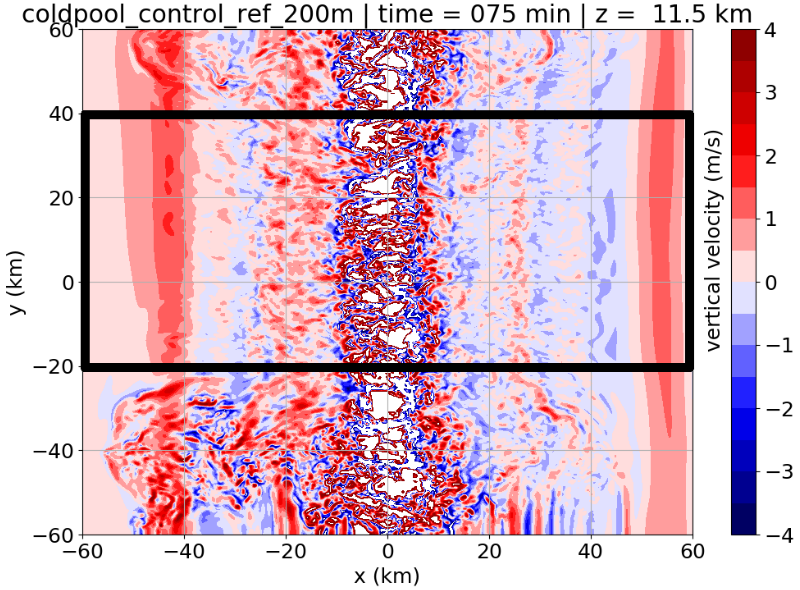


Squall line

$t_{end} = 75$ min



Tropopause level

Results: Mean divergence & condensation profiles

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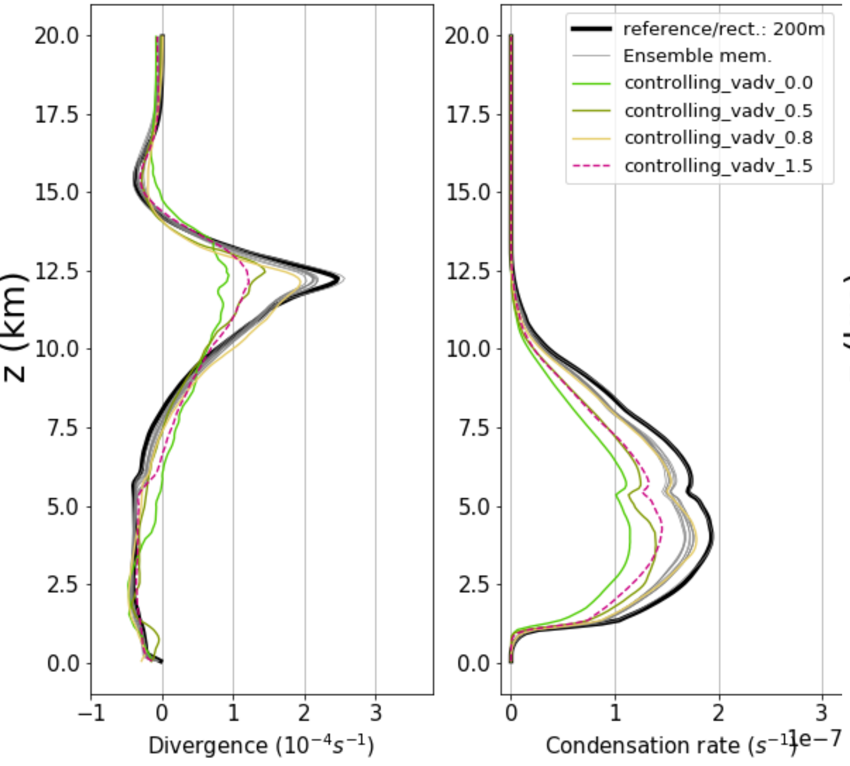
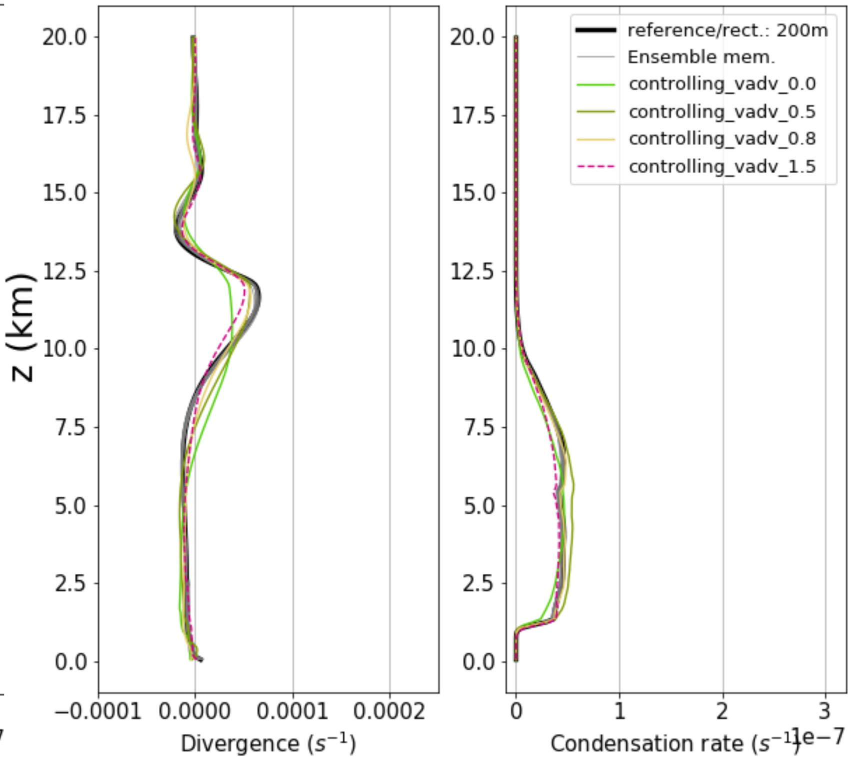
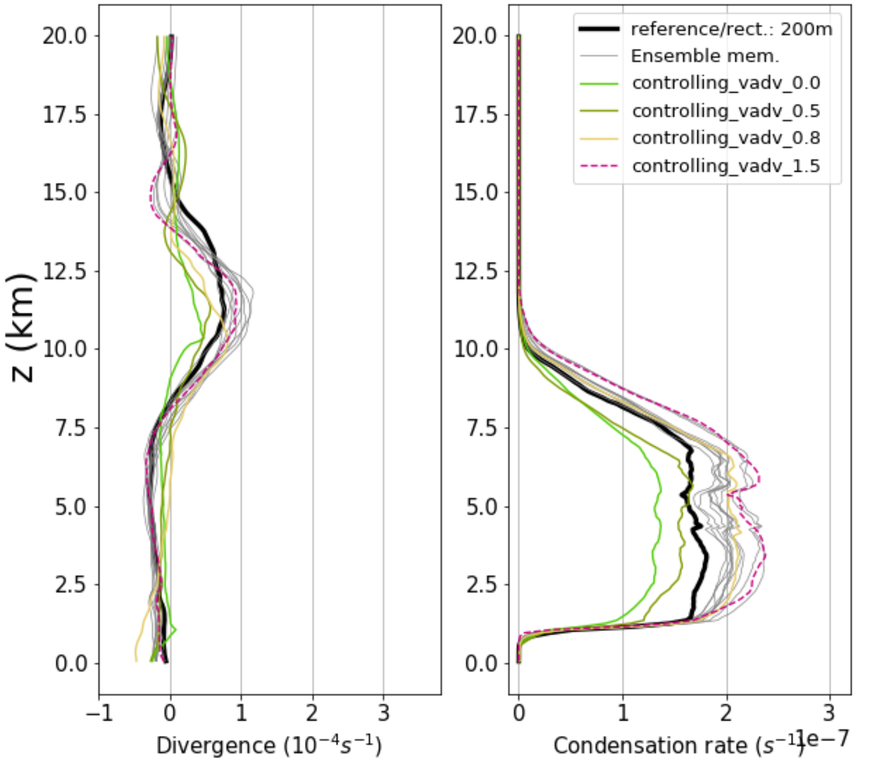
Supercell



Isolated multicell

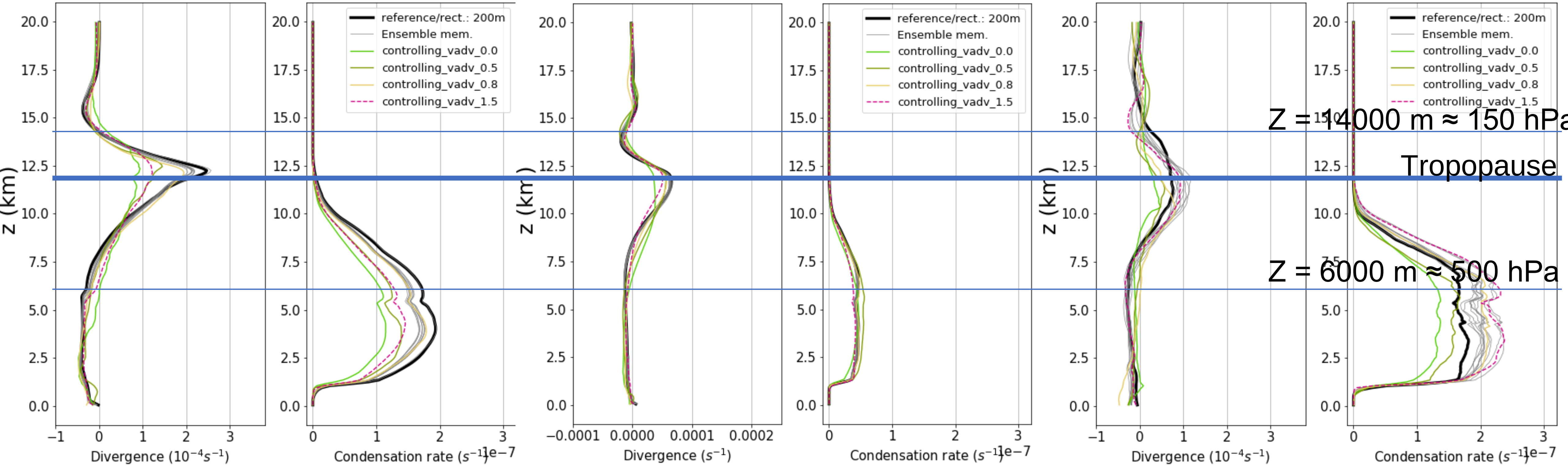


Squall line

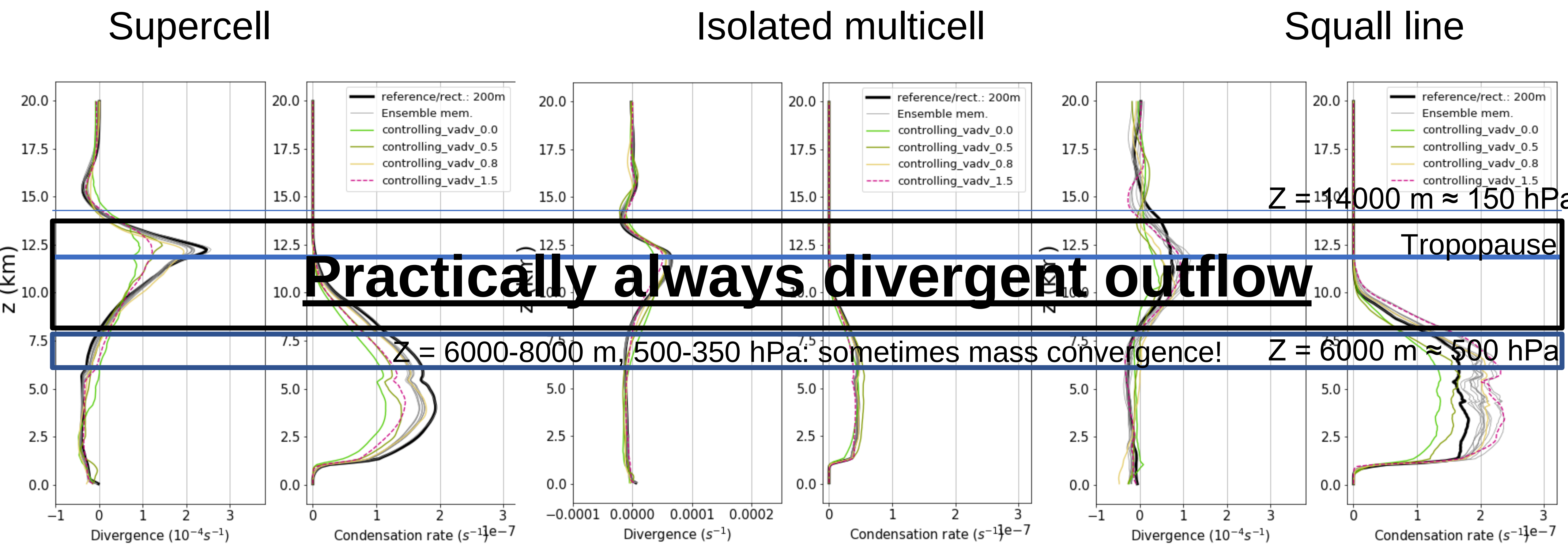


Results: Mean divergence & condensation profiles

Supercell Isolated multicell Squall line



Results: Mean divergence & condensation profiles



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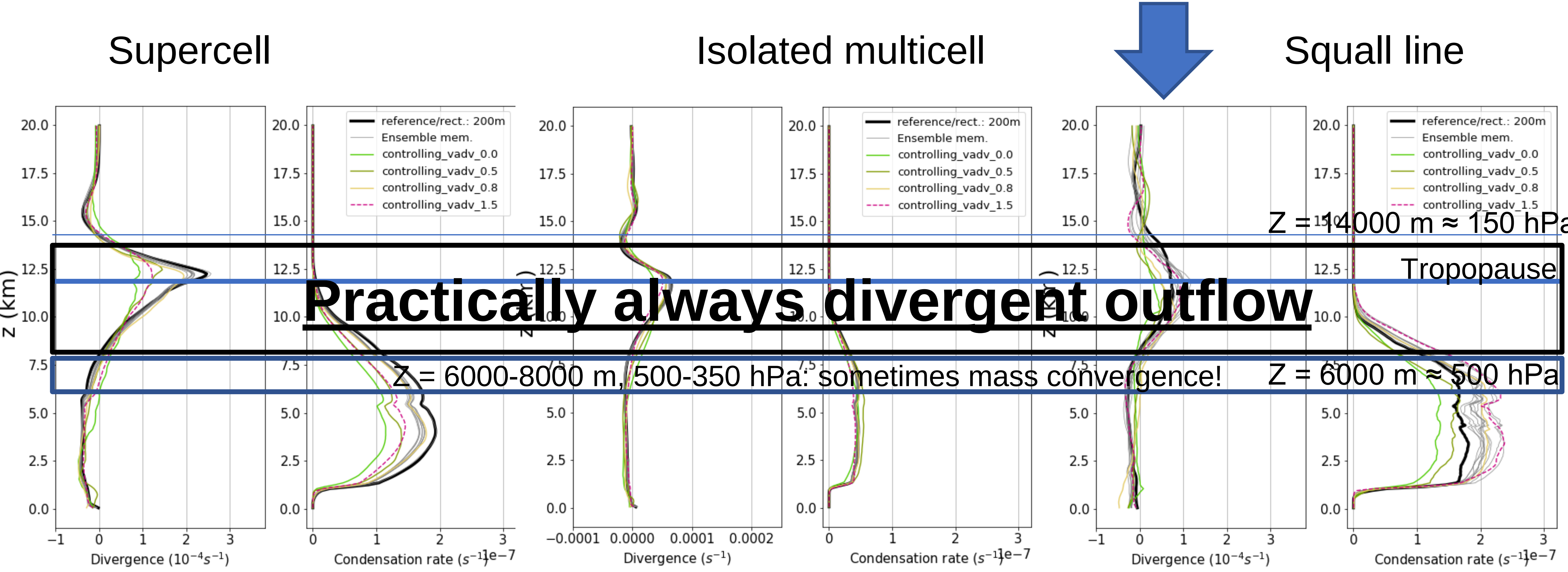
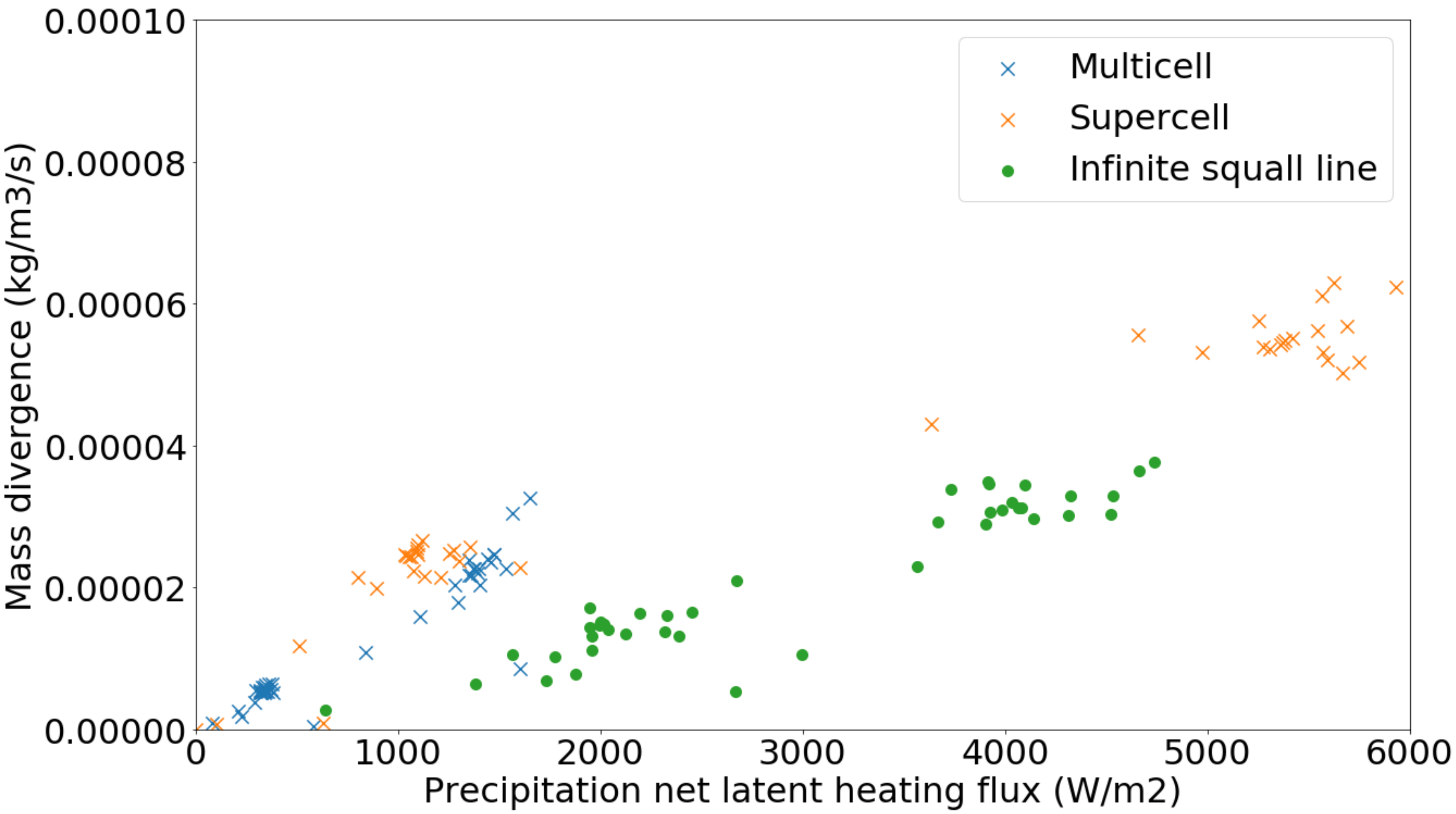


Divergence vs. latent heating

Time and box averaged divergence

- UT divergence increases with forcing by net latent heating
- **Weaker** divergence squall line
- CMT effect not detectable



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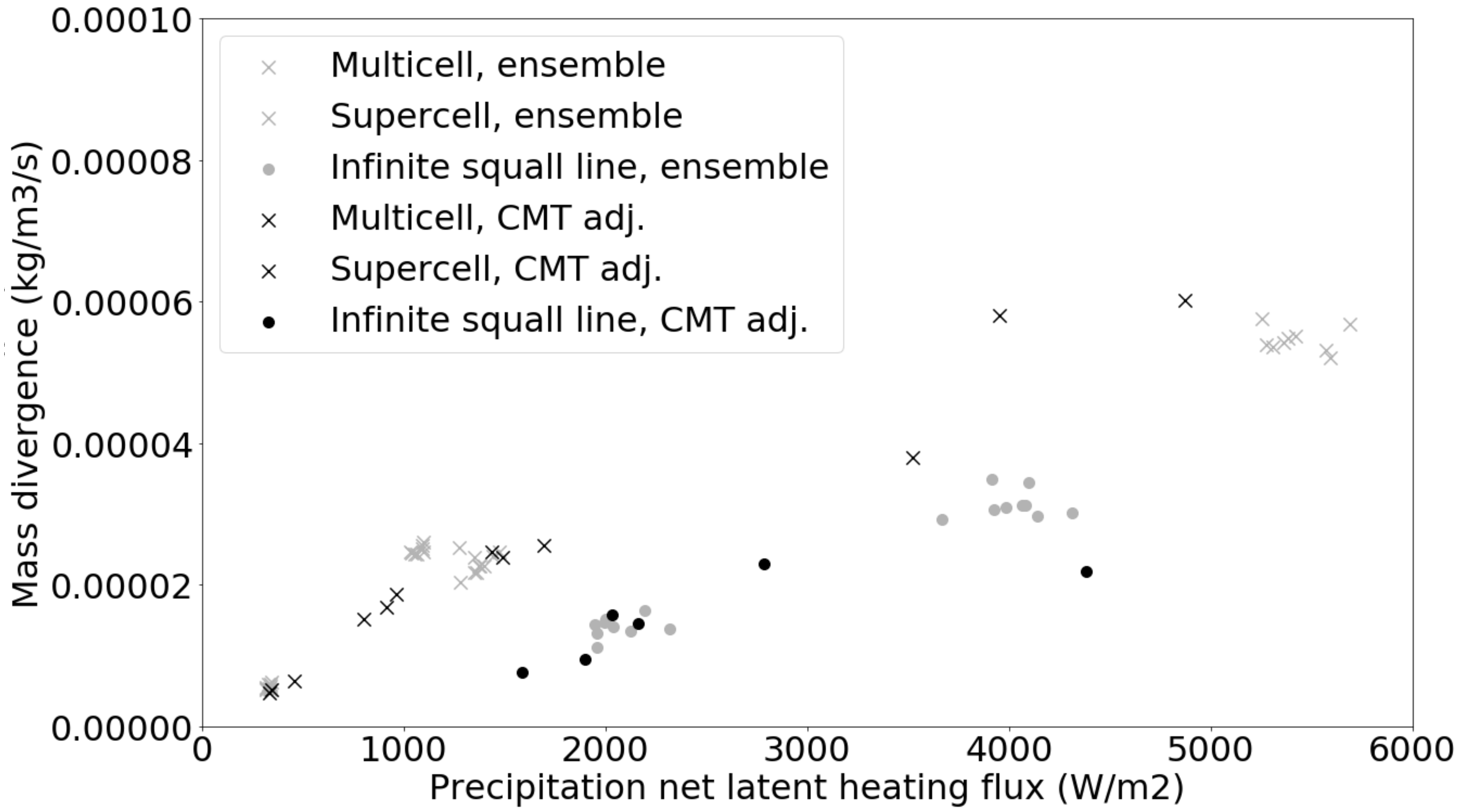
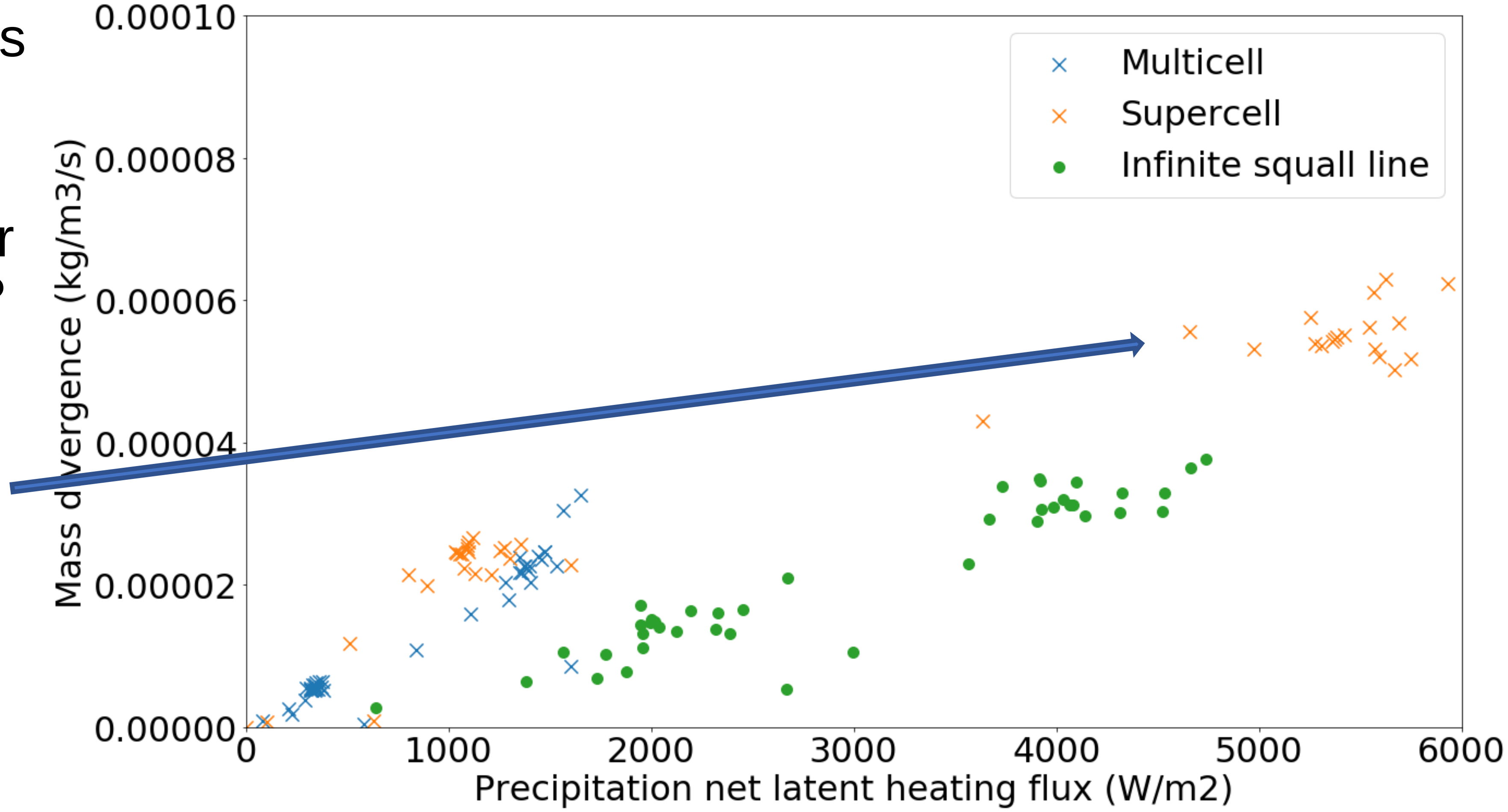


Divergence vs. latent heating

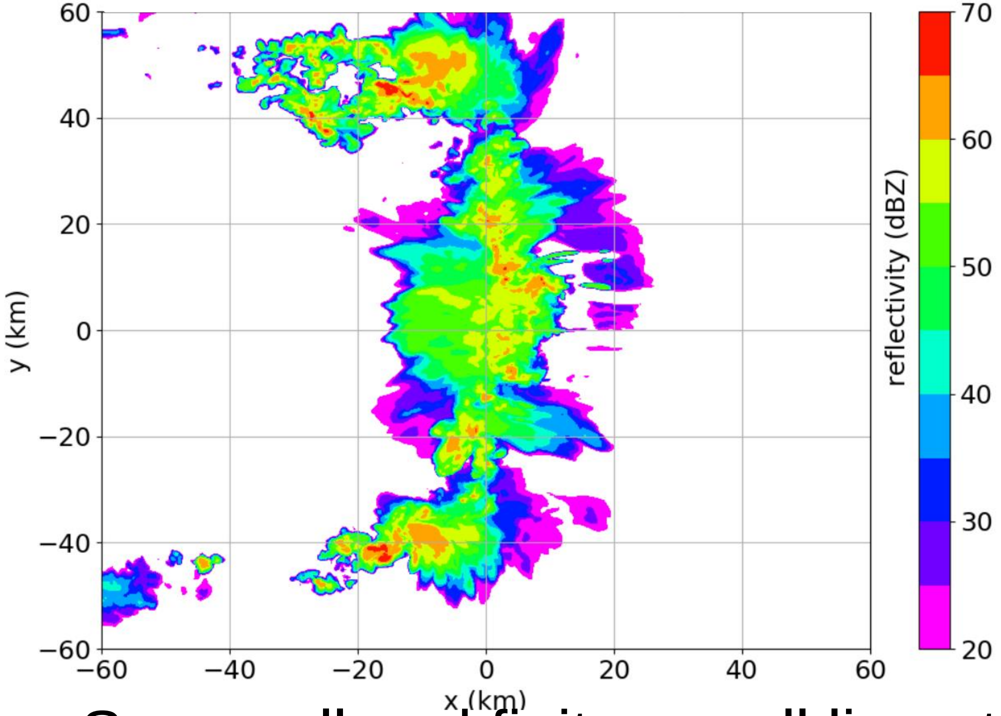
- Relation with net latent heating varies with organisation, why?
- Underdetection? Or aggregation effect?

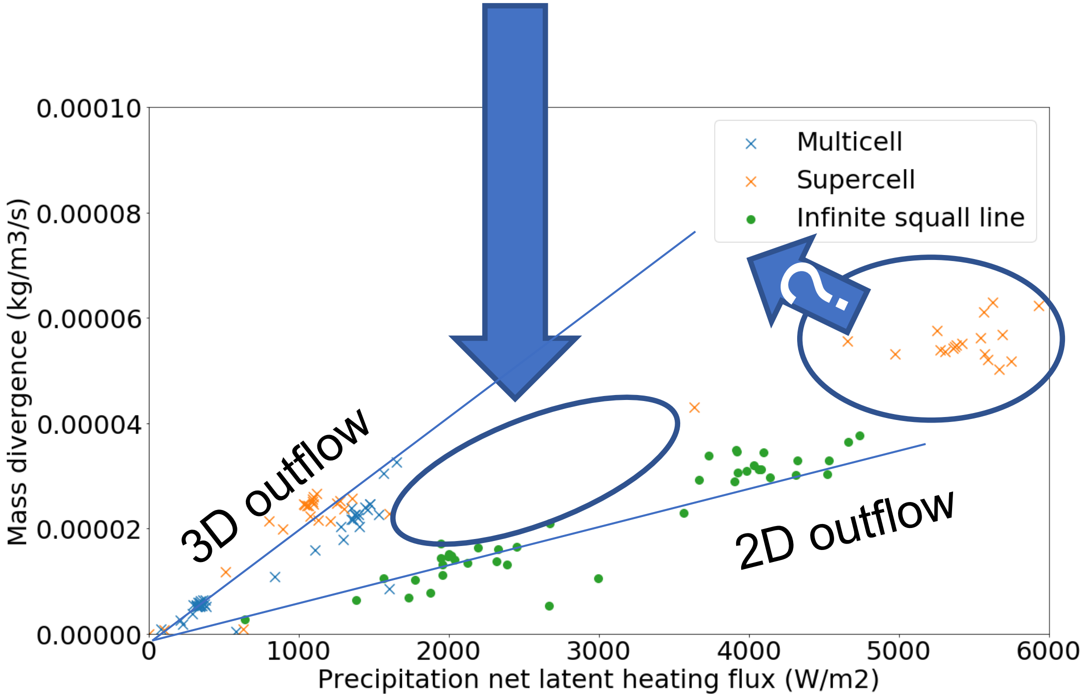


Geometry experiments

- Finite length squall line triggered

➔ Hypothesis: intermediate between "limits" of 2D and 3D outflow/divergence, intermediate magnitude

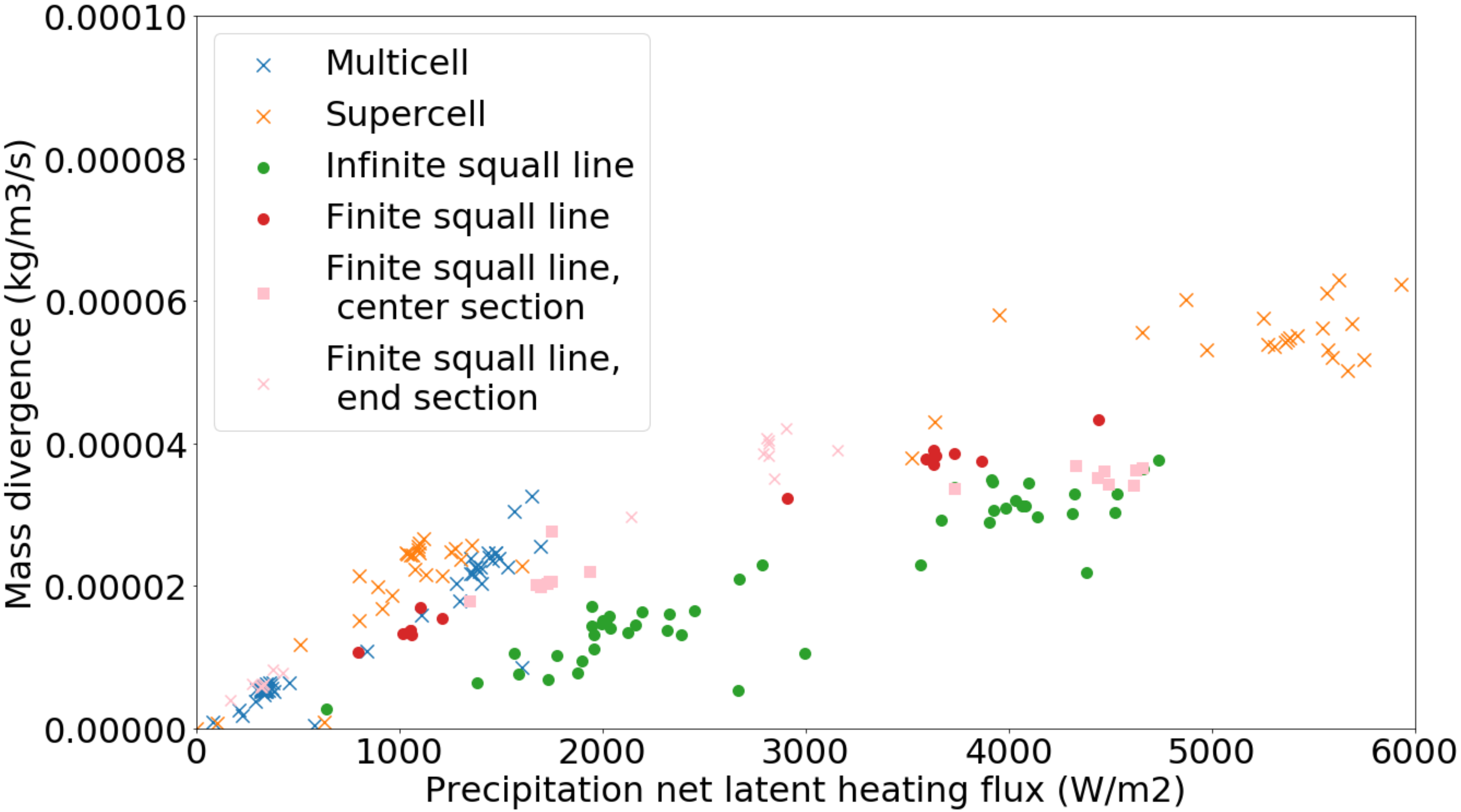




- Supercell and finite squall line at larger domain

Geometry experiments

- Finite squall line and its subsections: consistent with outflow dimensionality
- Convective aggregation



Paper in preparation

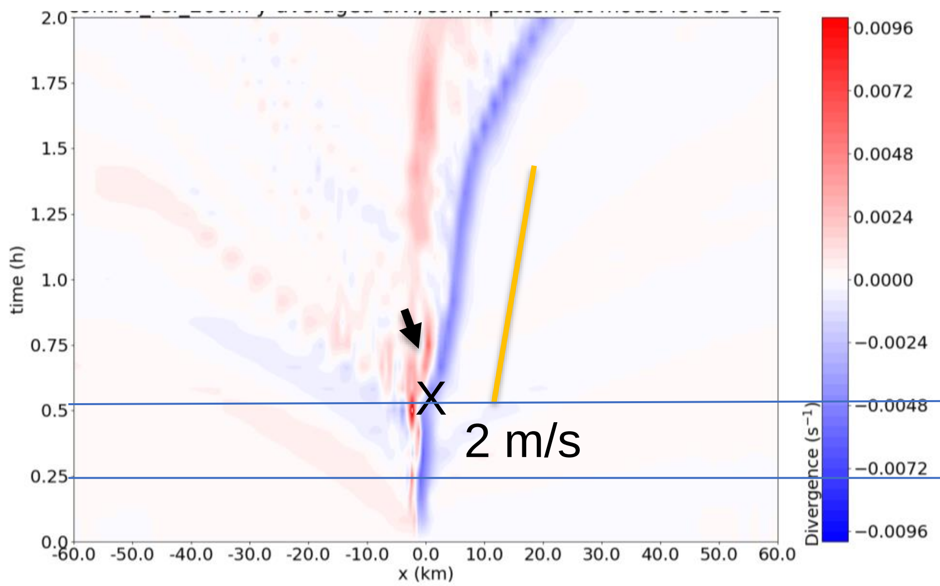
On the squall line variability

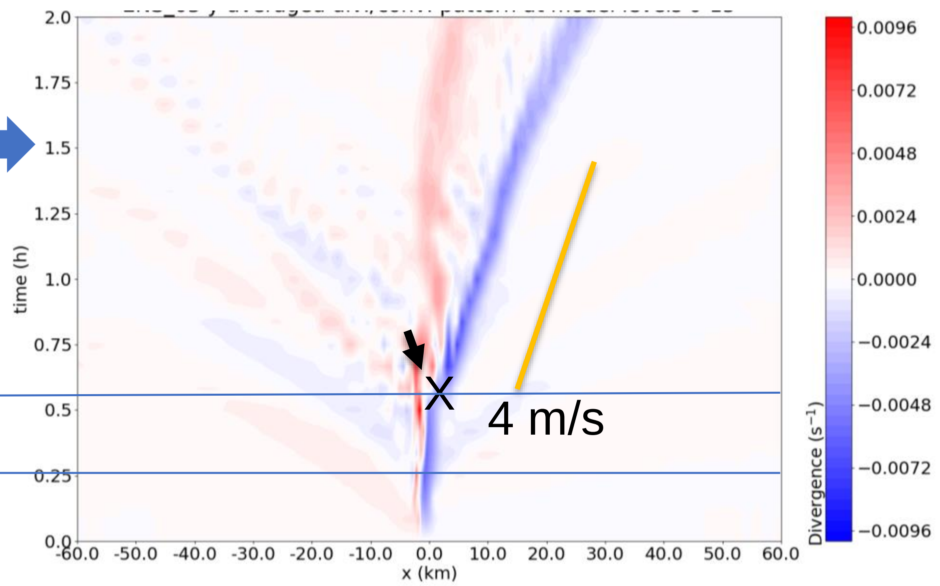
- Time evolution of low level convergence (along-line avg.)
- Differential cold pool velocity

$V_{cold\ pool}$ = 2.5 m/s

$V_{cold\ pool}$ = 4.3 m/s

Init condition difference: < 2% (47 m) in shear layer depth!





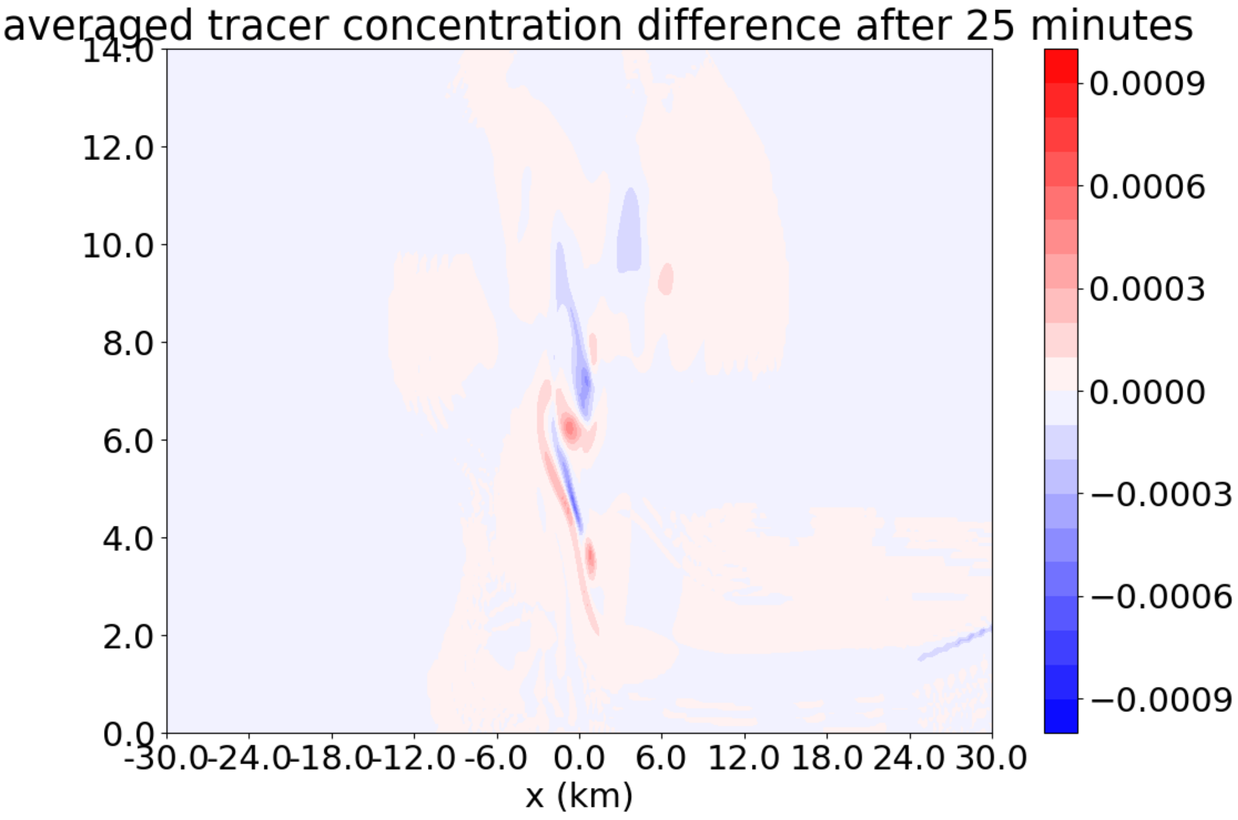
Init 2

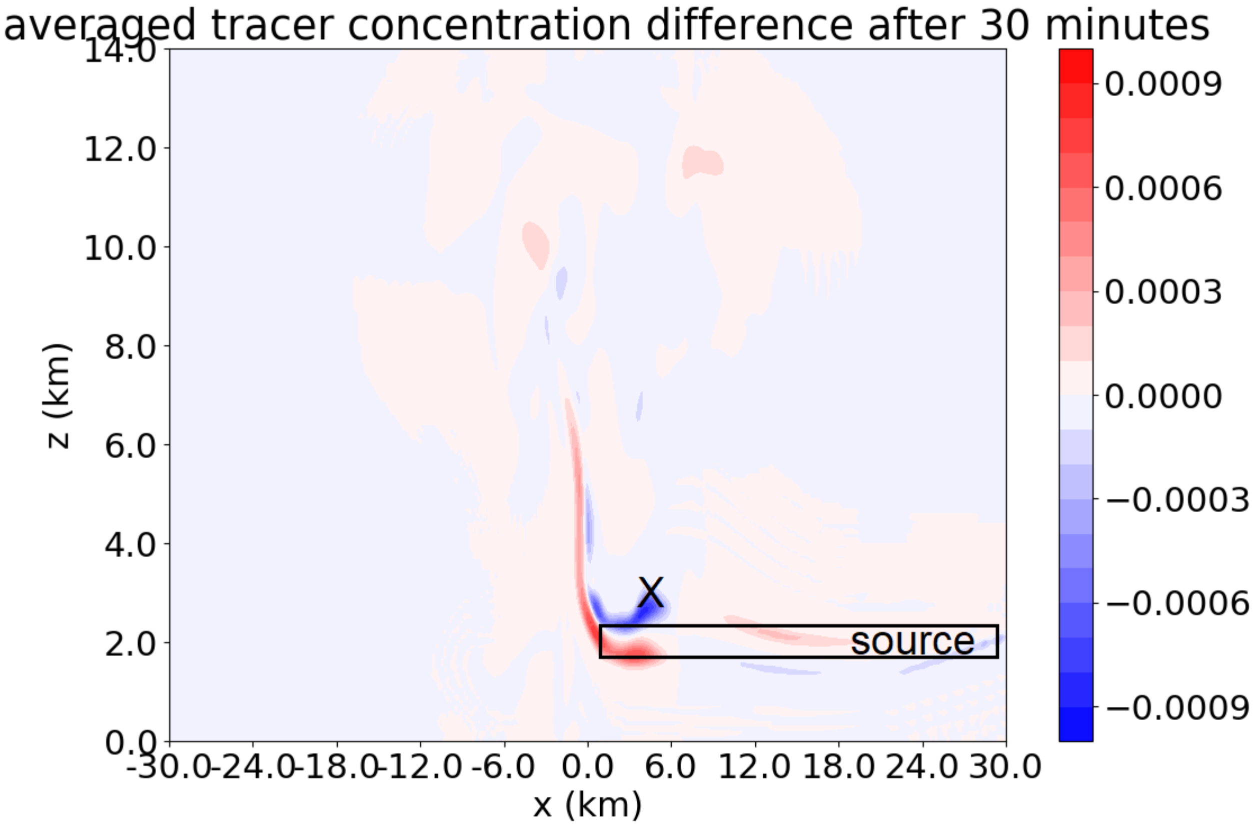
Init 1

Sensitive squall line dependence

- Gravity wave signal
- Secondary phase of convective initiation
- 30 to 45 mins: differential tracer transport

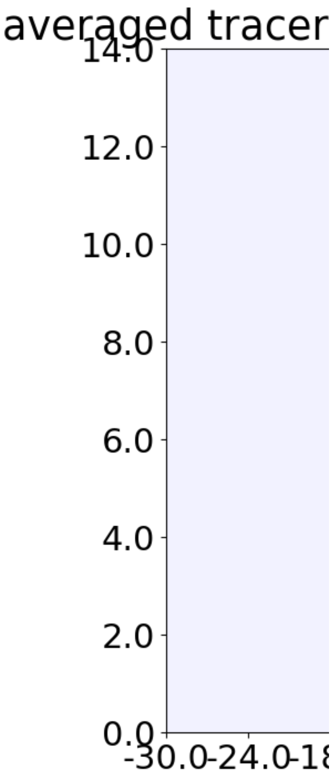
Y-averaged tracer X-section



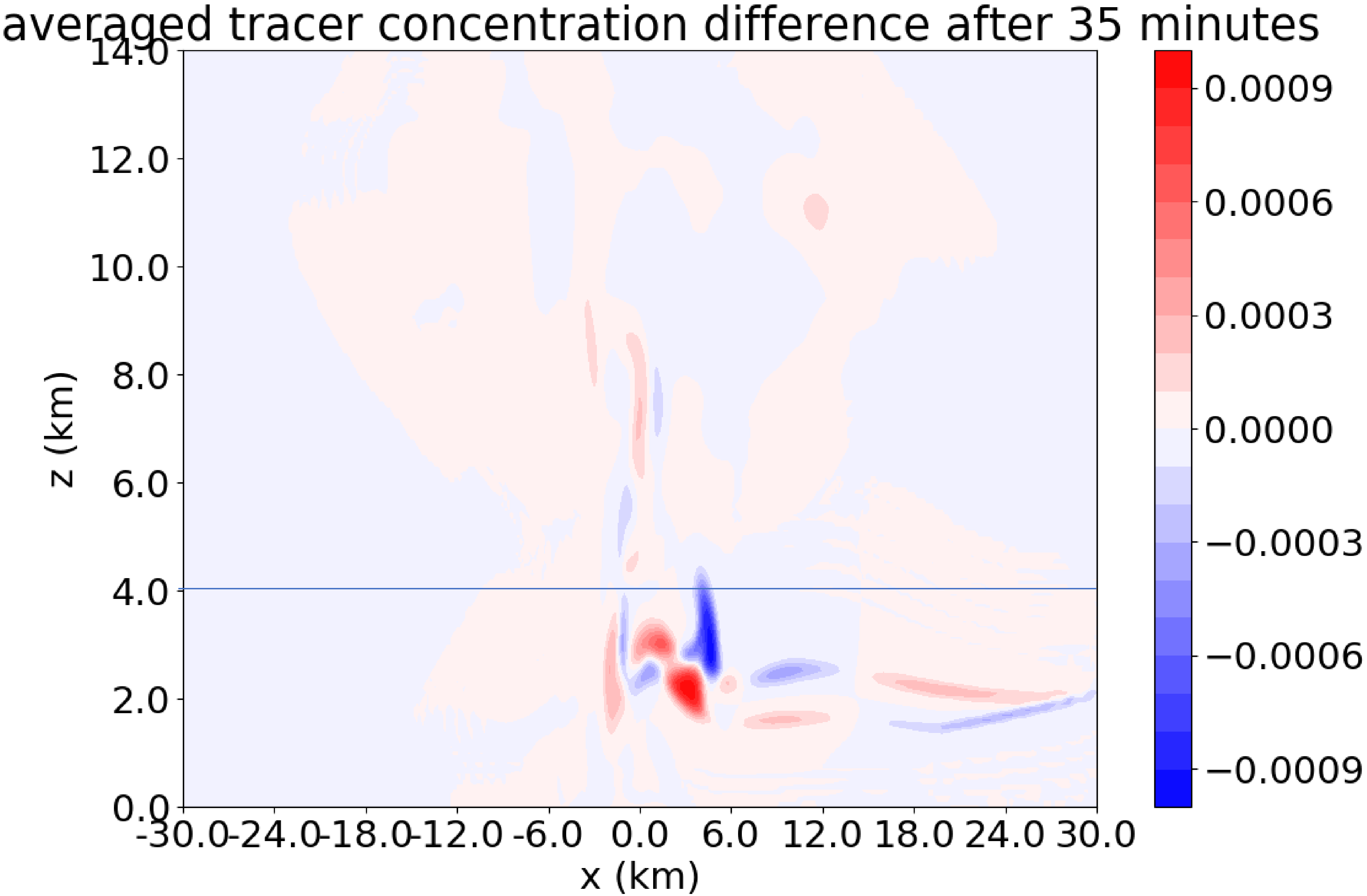


Se

- Gr
- Se
- 30



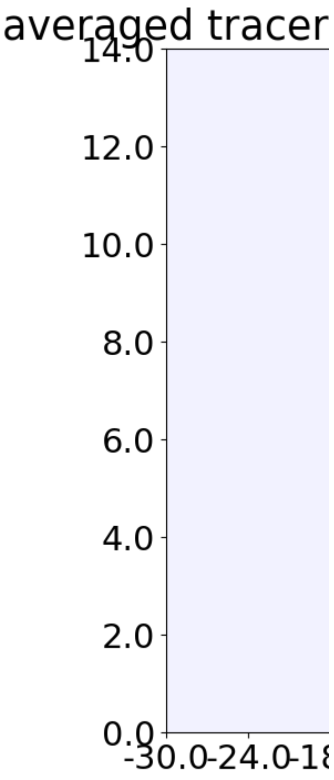
averaged tracer
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
-30.0-24.0-18



averaged tracer concentration difference after 35 minutes
z (km)
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
-30.0 -24.0 -18.0 -12.0 -6.0 0.0 6.0 12.0 18.0 24.0 30.0
x (km)
0.0009
0.0006
0.0003
0.0000
−0.0003
−0.0006
−0.0009

Se

- Gr
- Se
- 30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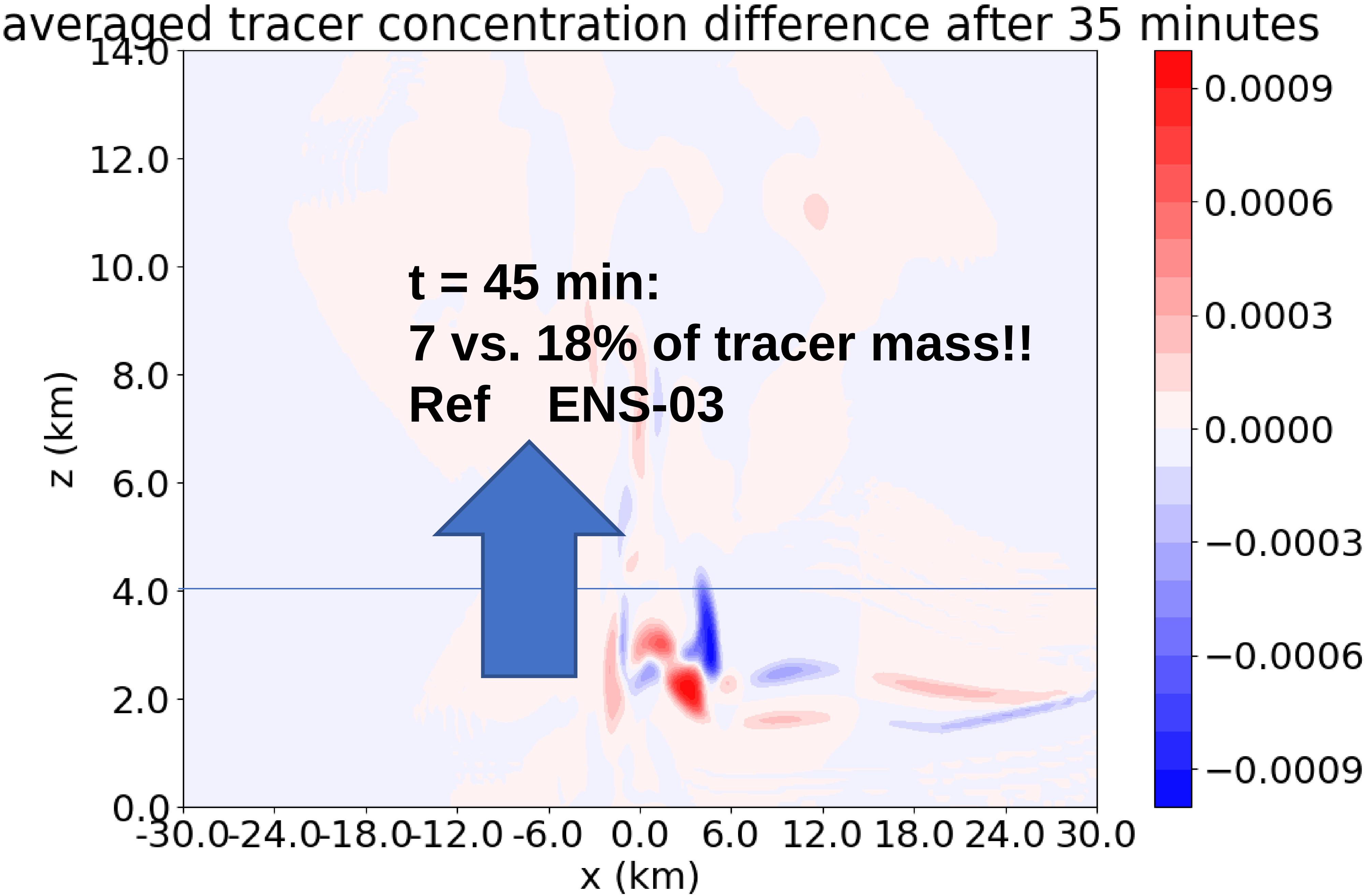
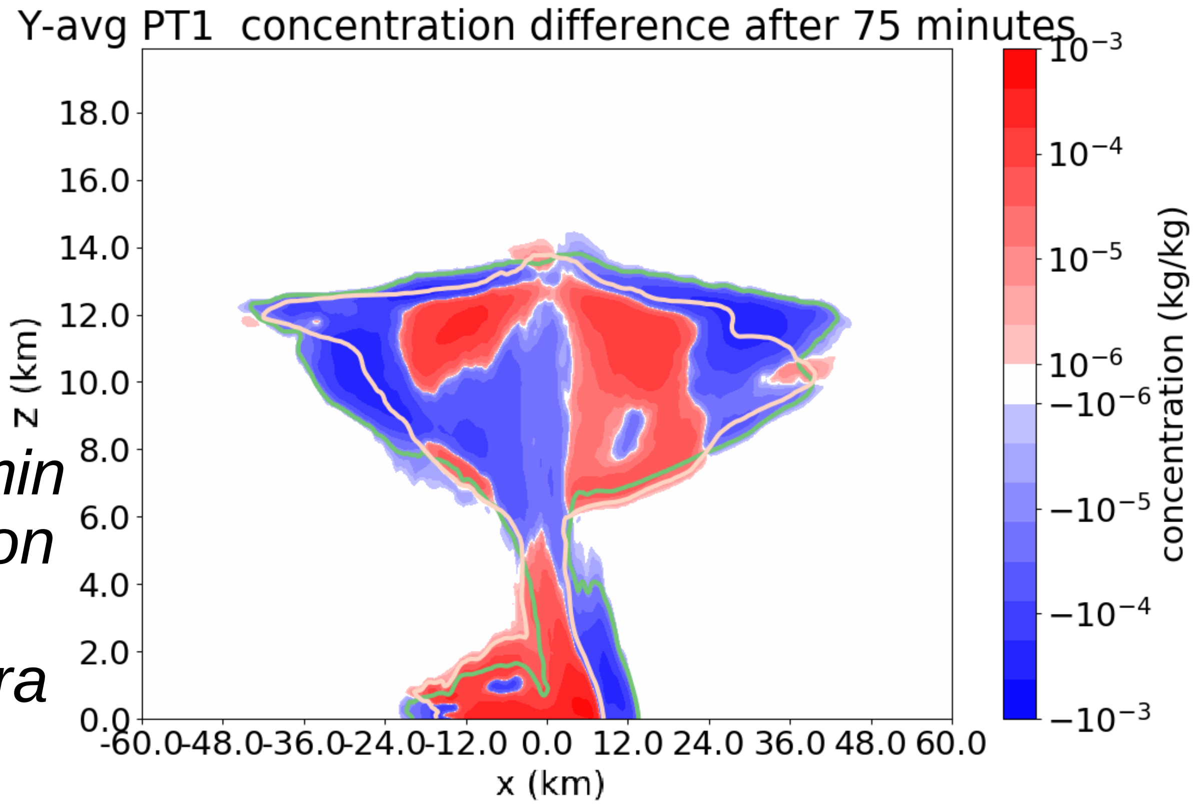

averaged tracer concentration difference after 35 minutes
t = 45 min:
7 vs. 18% of tracer mass!!
Ref ENS-03
z (km)
x (km)
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
-30.0 -24.0 -18.0 -12.0 -6.0 0.0 6.0 12.0 18.0 24.0 30.0
0.0009
0.0006
0.0003
0.0000
−0.0003
−0.0006
−0.0009

Sensitive squall line dependence

- Gravity wave signal
- Secondary phase of convective initiation
- 30 to 45 mins: differential tracer transport

- Affect cold pool acceleration
- Circulation effect remains visible

(Second paper in preparation)



Only 24% "extra" divergence during 75 min interval is explained by higher precipitation intensity as a result of more intense convection in ENS-03, whereas 38% extra divergence is detected

Summary & conclusions

- We can utilize UT divergence and its uncertainty to gain insight in the (diabatic) feedback from convective processes to large scale flow

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UT divergent outflow depends on

- **Linearly on (net) latent heating** (given dimensionality/aggregation)
- **Convective organization** (dimensionality outflow + aggregation)

But is not ***directly*** related to convective momentum transport

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- **Convective organization** (dimensionality outflow + aggregation)

But is not ***directly*** related to convective momentum transport

Squall lines reveal large **intrinsic sensitivity** and thus spread, as showcased by secondary phase of initiation

Detected UT divergence can vary by up to 38%, while precip latent heating only explains a 24% of this variability

Thank you for your attention! Questions?

UT divergent outflow depends

- **Linearly on (net) latent heating/precip**

(given dimensionality/aggregation)

- **Convective organization**

Squall lines reveal large **intrinsic sensitivity** as showcased by secondary phase of initiation