MUMIP – How dissimilar are deterministic physics suites truly and can we unravel the mystery of stochastic physics?

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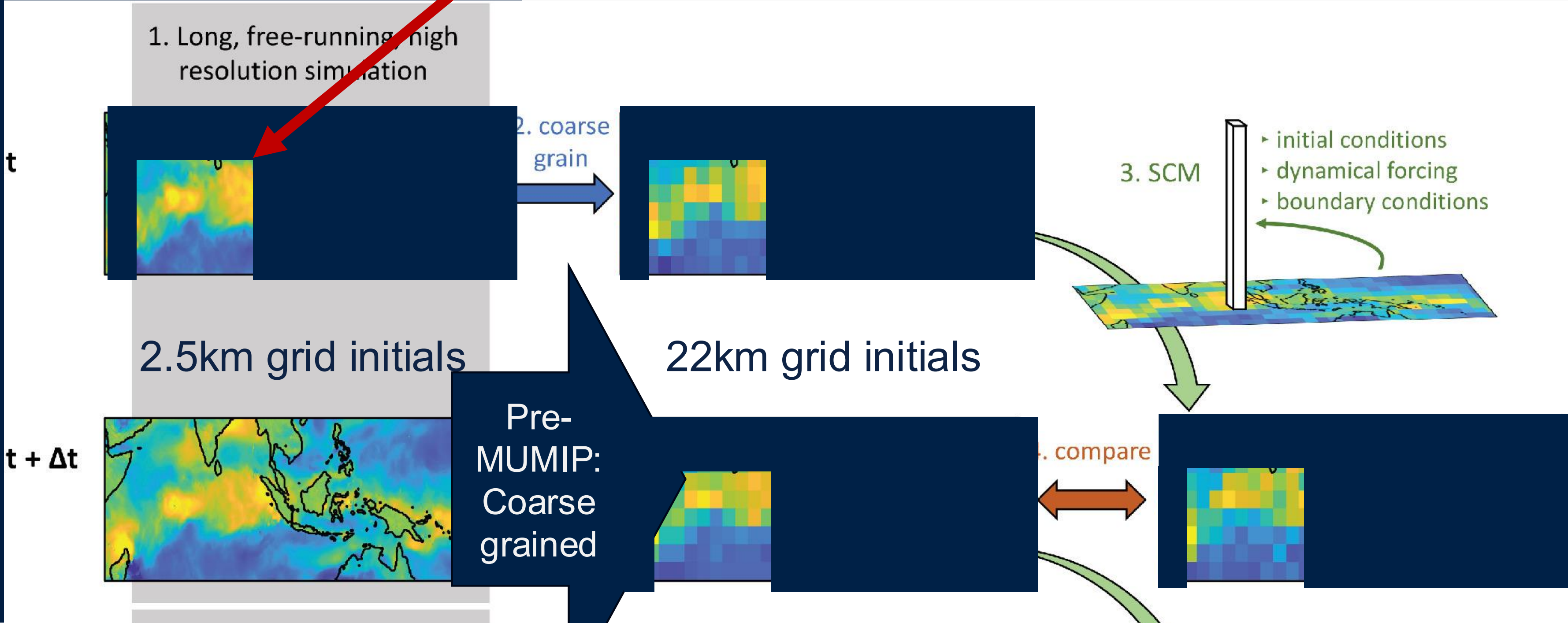
Domain, workflow

Subdomain of Indian Ocean (Christensen, 2020)

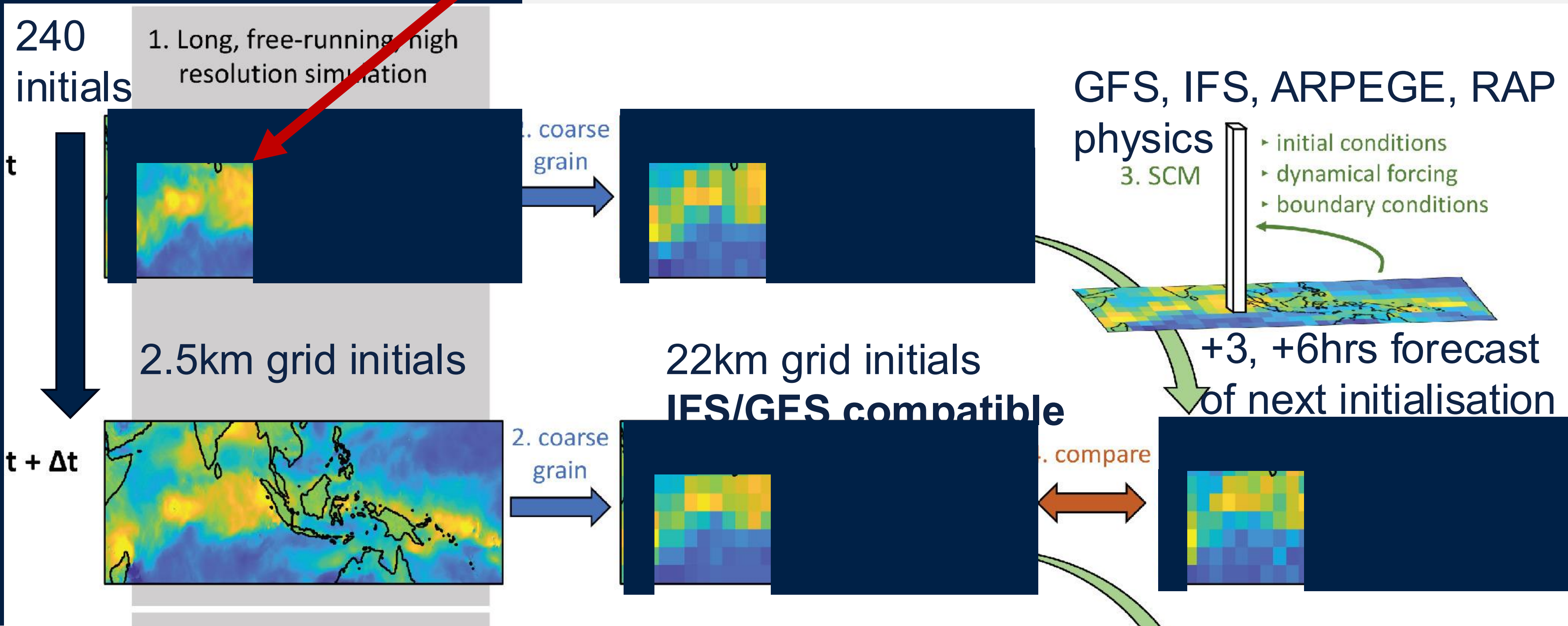
DYAMOND: “Free running” month (first 10 days ignored)



Domain, workflow

Subdomain of Indian Ocean (Christensen, 2020)

DYAMOND: “Free running” month **fixes the full dynamics**



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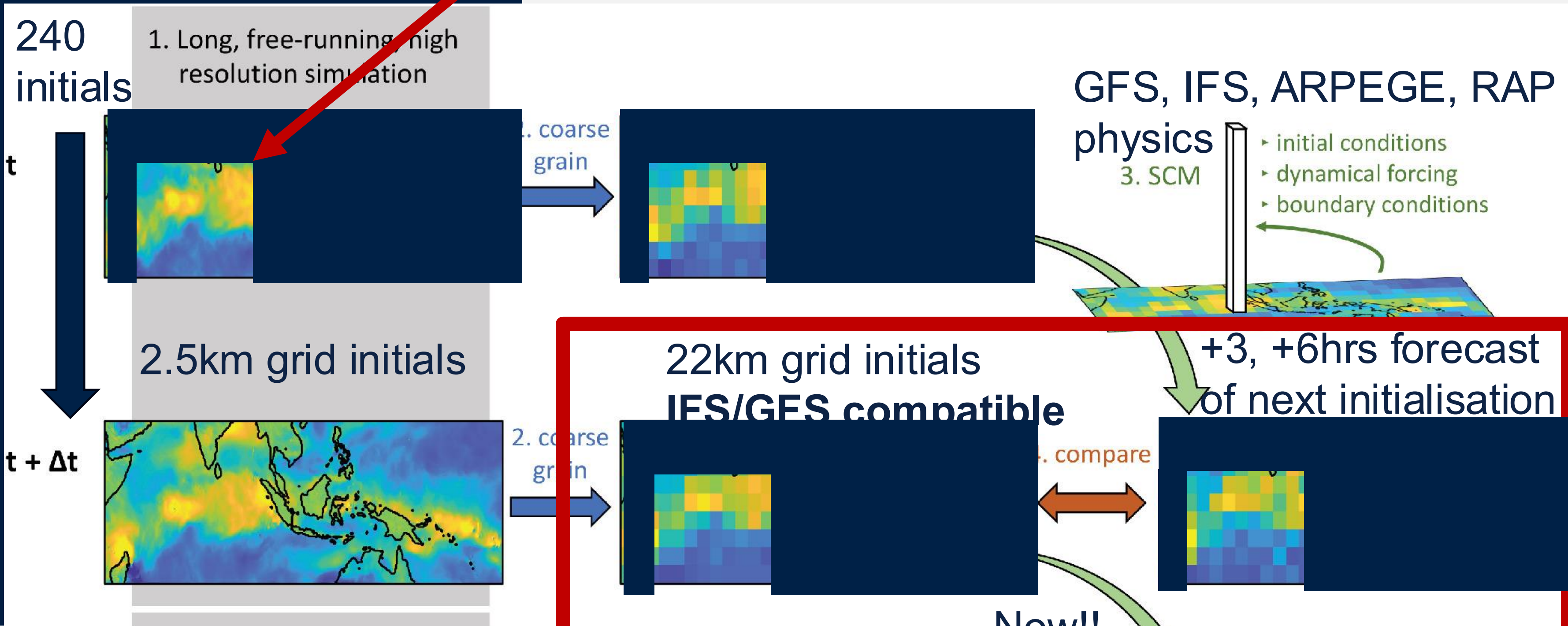

Four single-column models with physics package

An exercise for single column model forced with 10.780.000 **initial conditions** and **dynamical forcings** from convection-permitting ICON, creating spatially consistent interaction between columns.

Grid spacing: 0.2 degrees/22km

Time span: 1 month of DYAMOND dataset

Post-processing ICON data following Christensen 2020

Goal:

Intercomparison of standard physics packages of GFS, RAP, IFS, ARPEGE

Model Uncertainty Model Intercomparison Project MUMIP

Examples of MUMIP motivation

1. *Constrain stochastic perturbations (e.g. of parameters or tendencies – see Christensen, 2020)*

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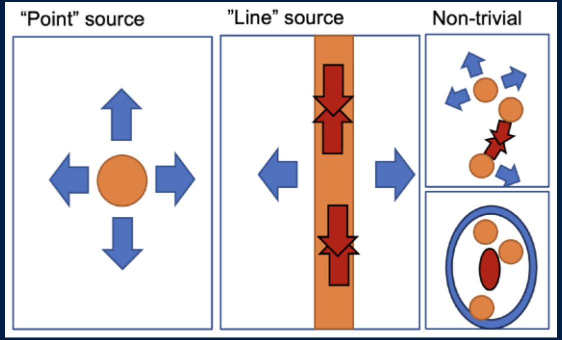
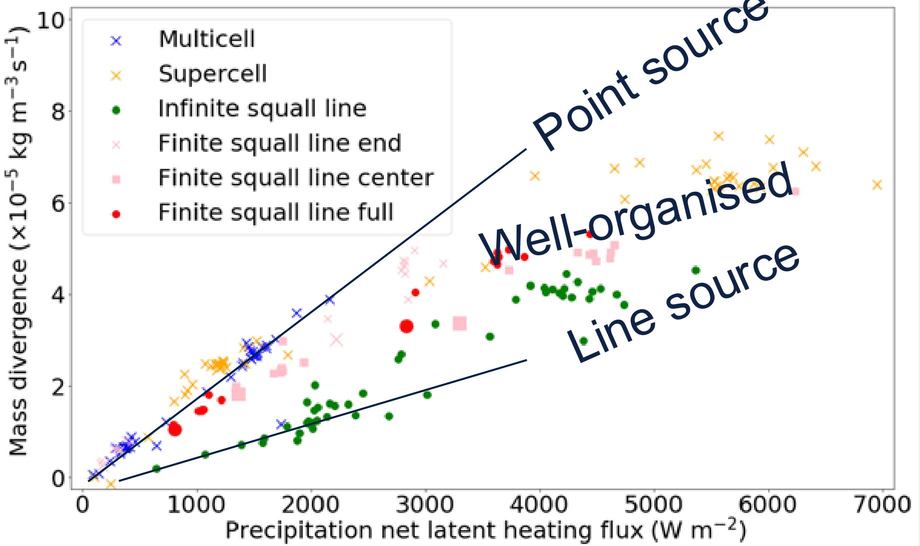
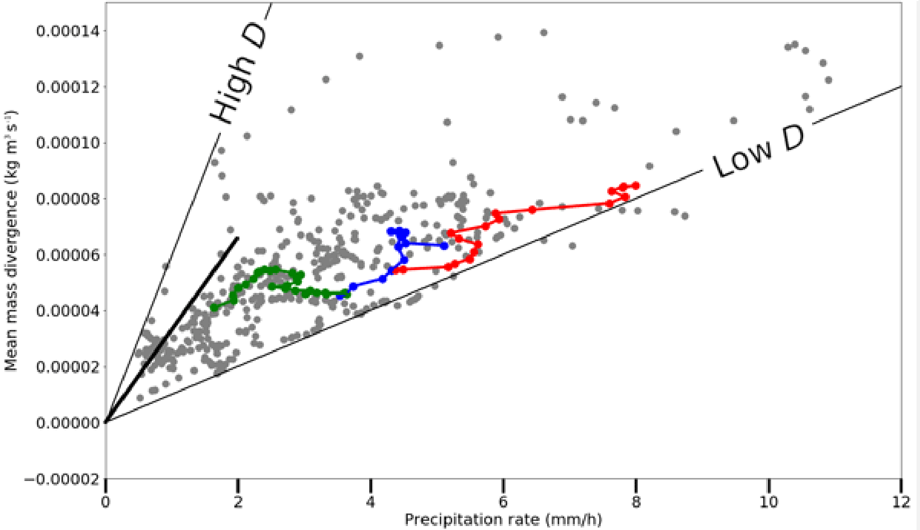
2. **Understand model uncertainty from a physical point of view**
3. *Understand and predict sub-grid variability*

…..

Earlier work







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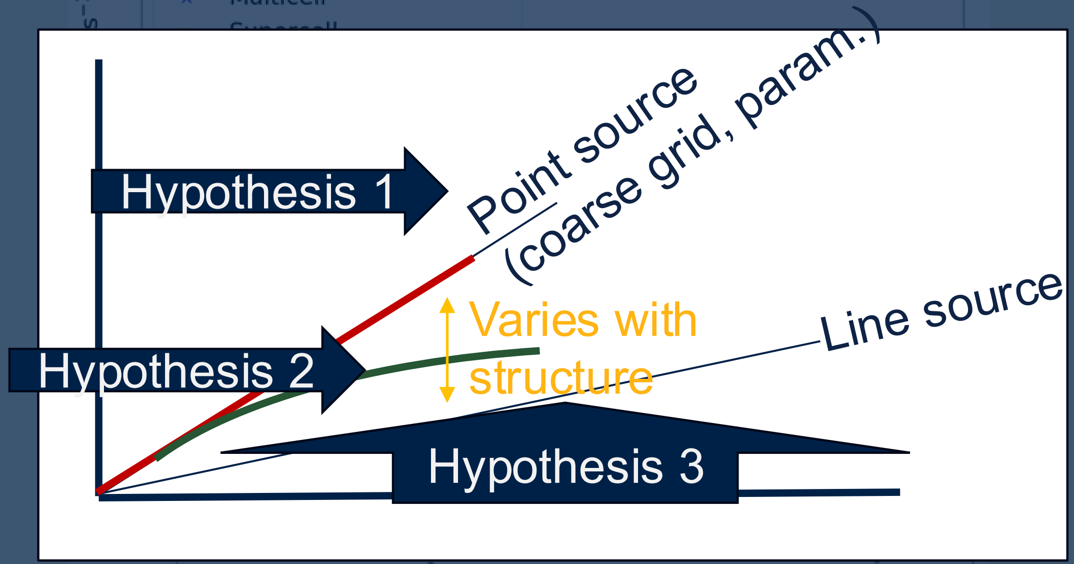
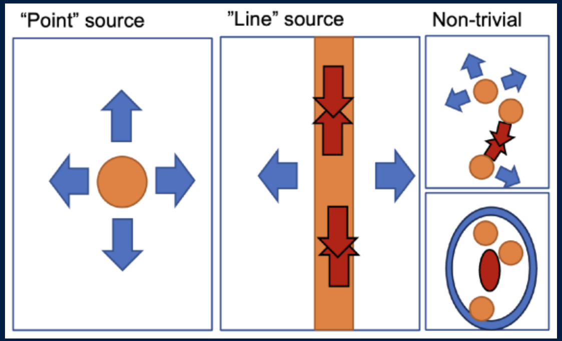


The variation with convective structure is hypothetically caused by interactions between gravity waves



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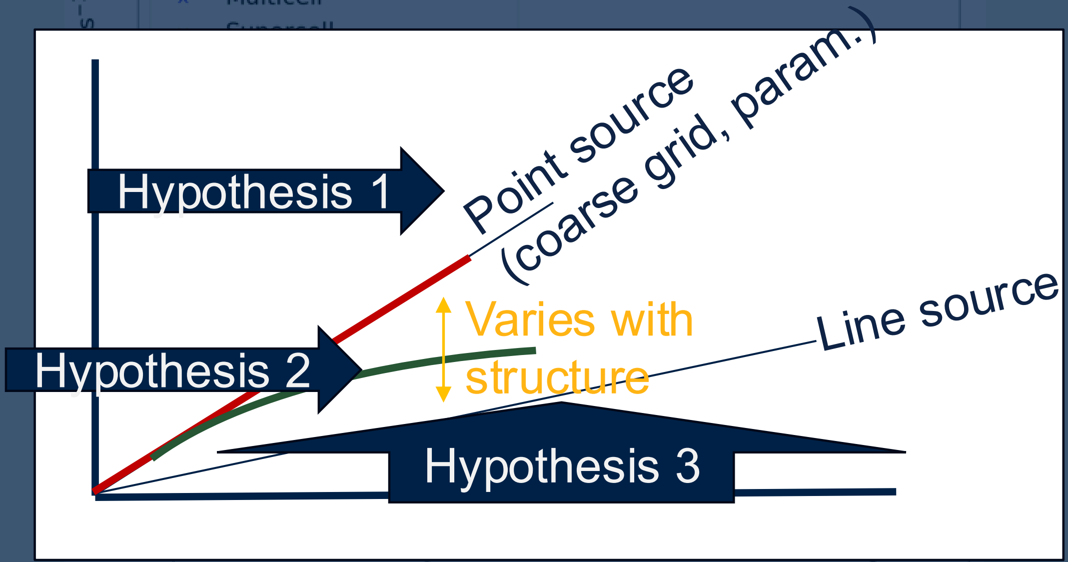
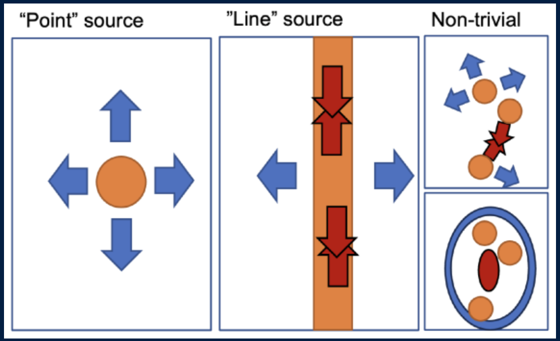
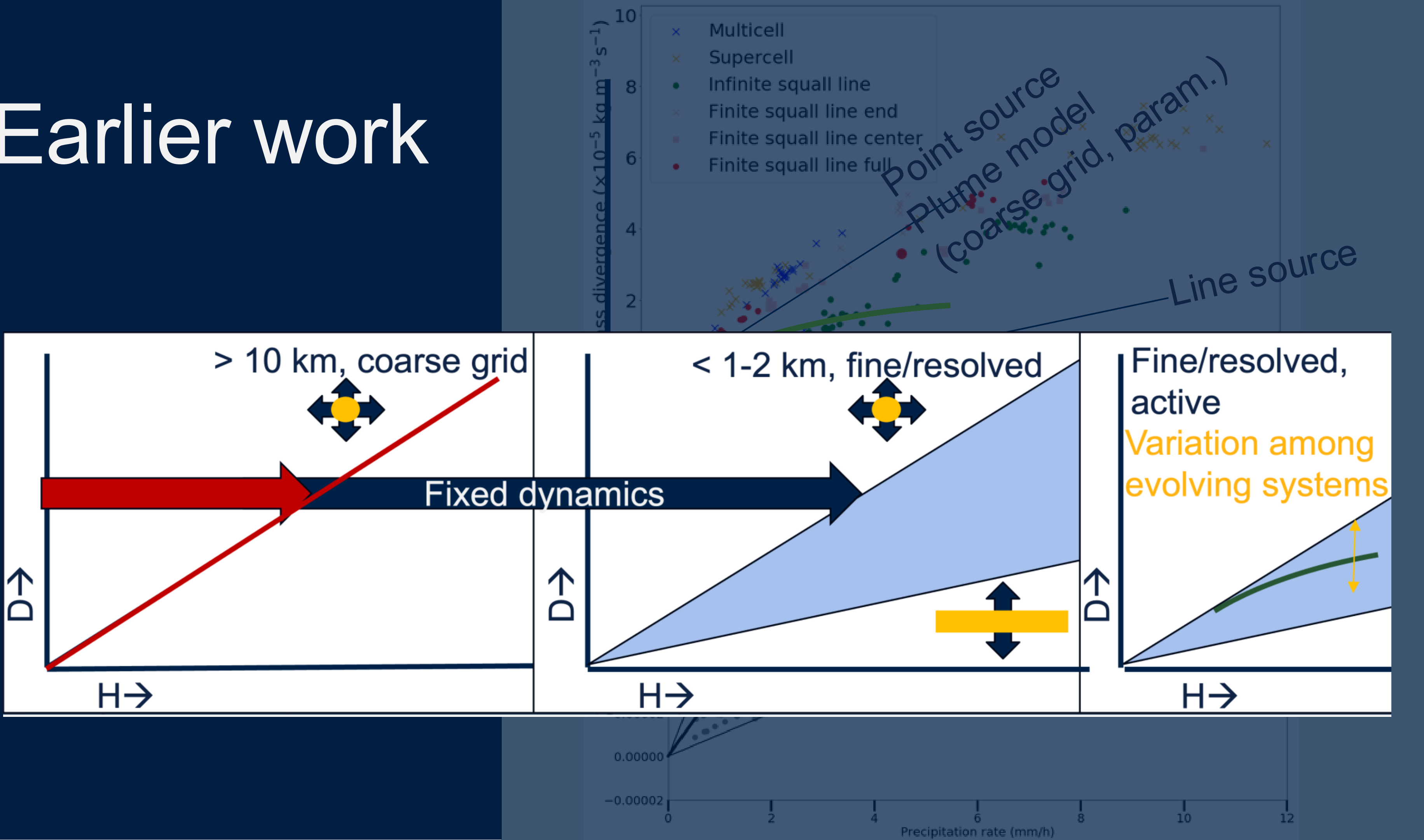




The variation with convective structure is hypothetically caused by interactions between gravity waves

Resolved variation at < 3 km!!

Earlier work



Earlier work

Divergent outflows vary because of:

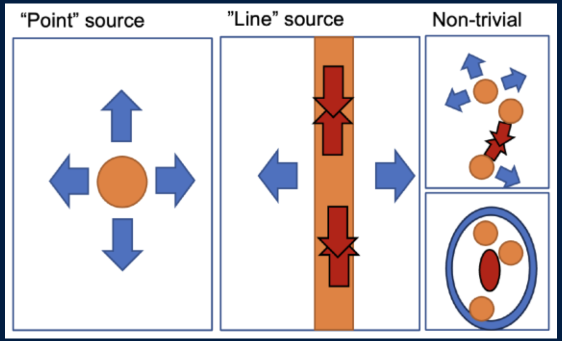
- Being generated as a gravity-wave- bores → Convective structure

- Coarse grids presumably resolve coarsest/aliased gravity waves, of one flavour only!

This imposes linear dependence between latent heating and mass divergence

Hypothesis: No variation about linear dependence

at coarse grids



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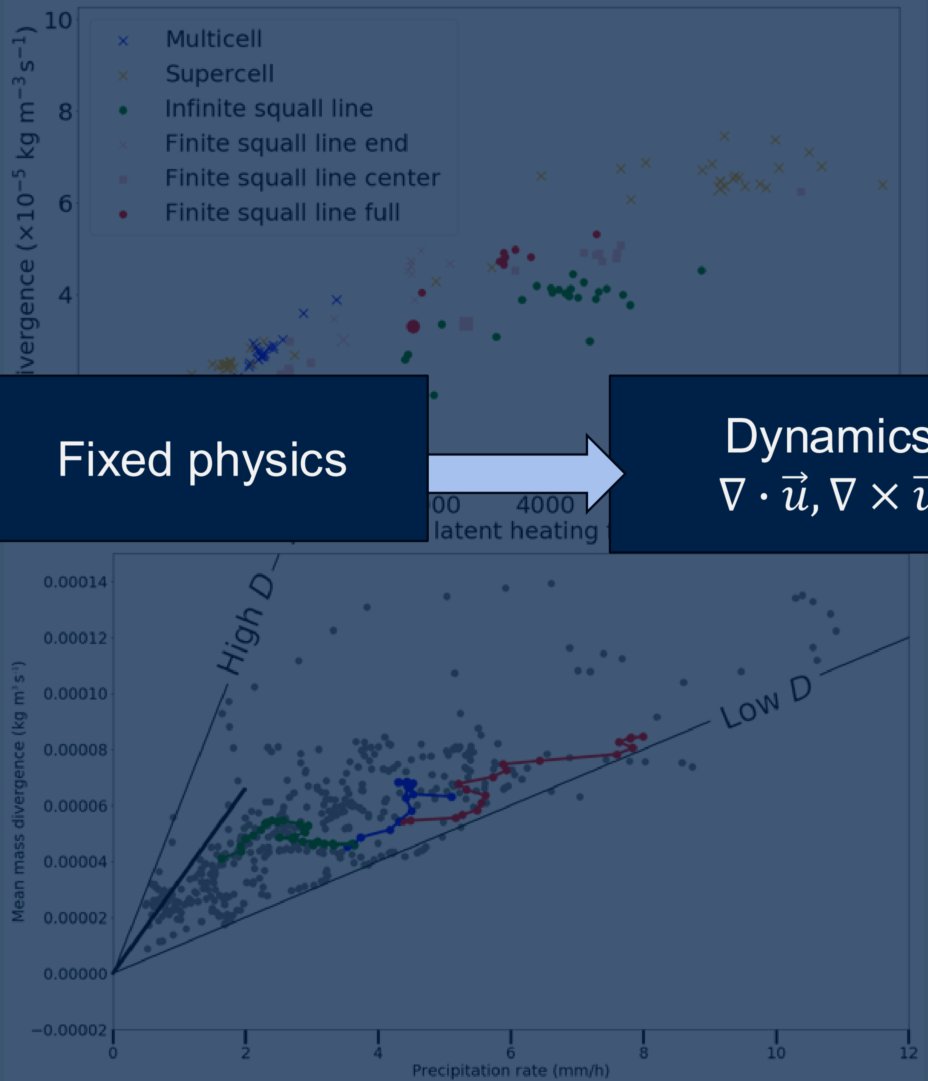
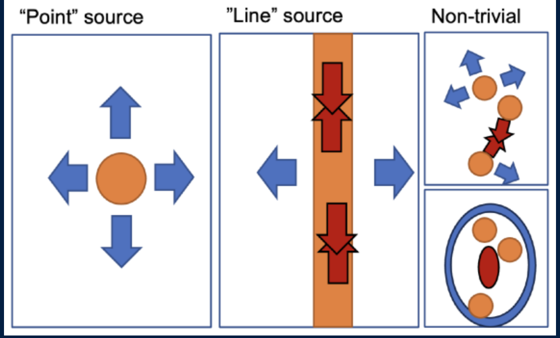
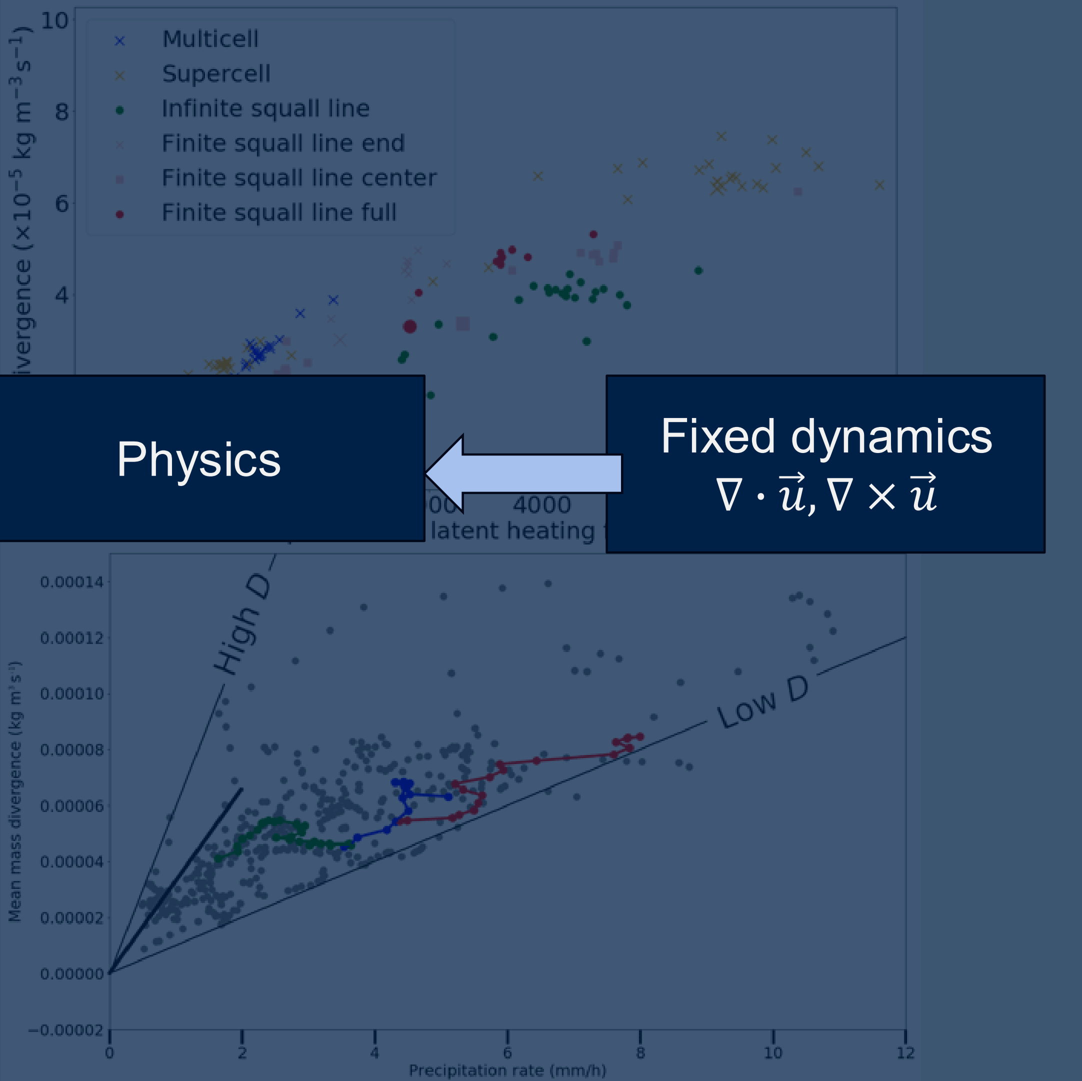


Fixed physics → Dynamics $\nabla \cdot \vec{u}, \nabla \times \vec{u}$

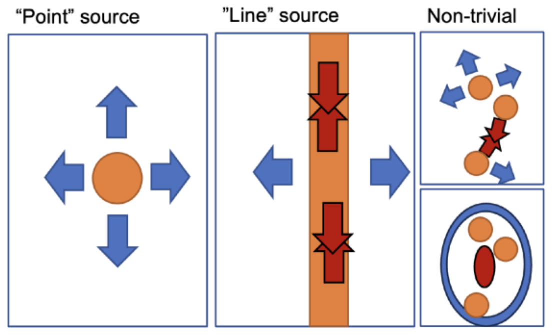


MUMIP

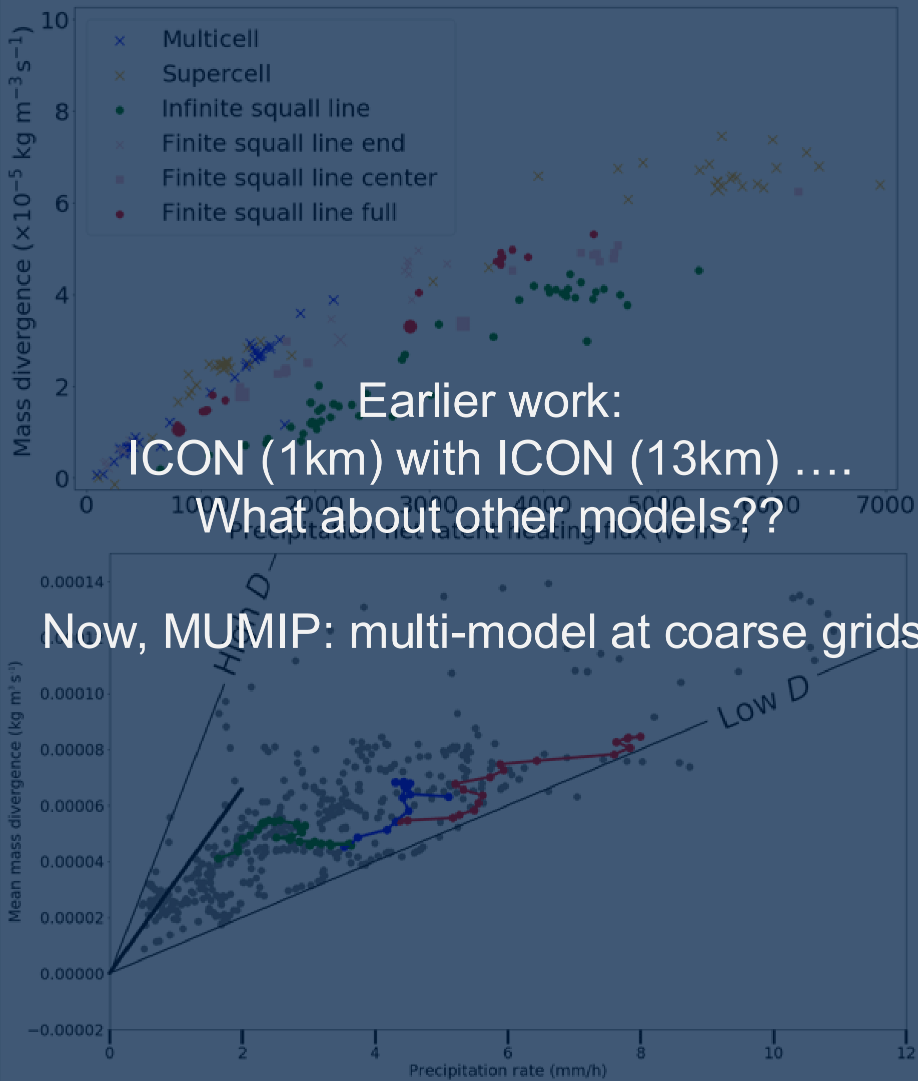


Physics

Fixed dynamics
$\nabla \cdot \vec{u}, \nabla \times \vec{u}$



MUMIP



Earlier work:

ICON (1km) with ICON (13km) ….

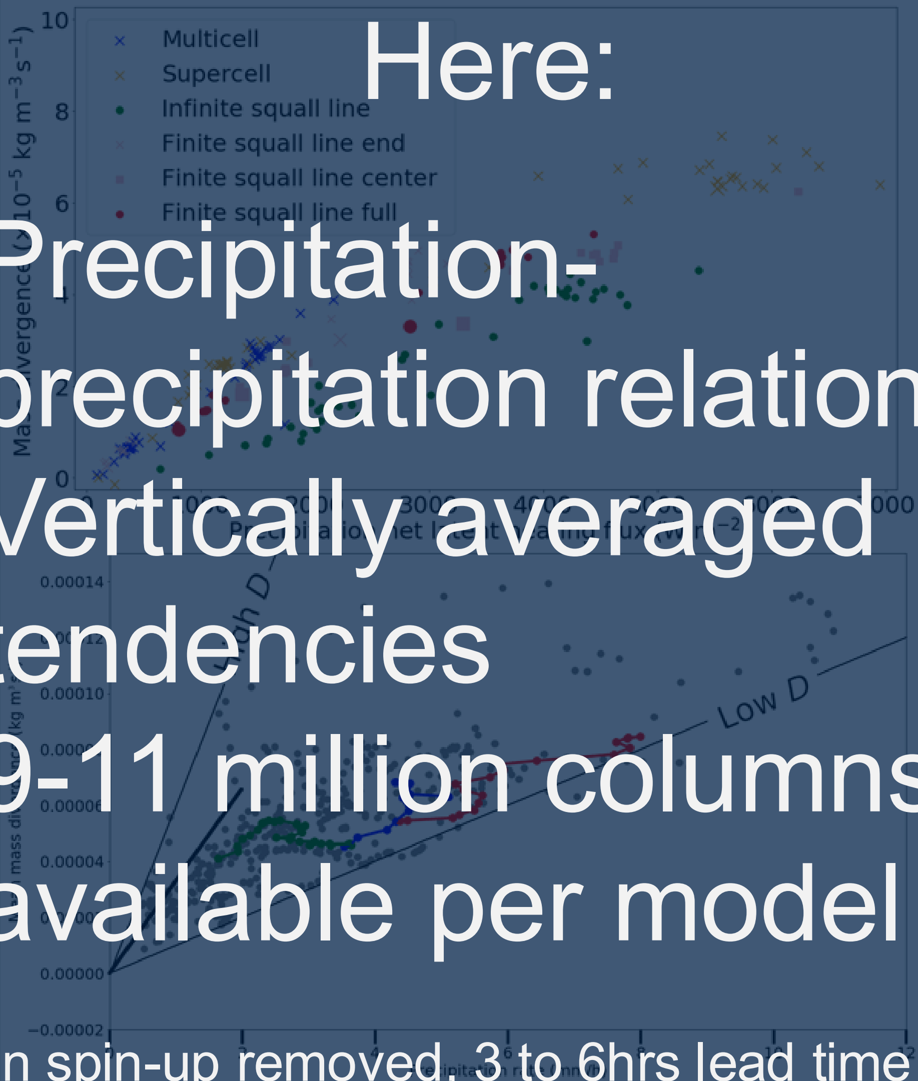
What about other models??

Now, MUMIP: multi-model at coarse grids!

MUMIP

Here:

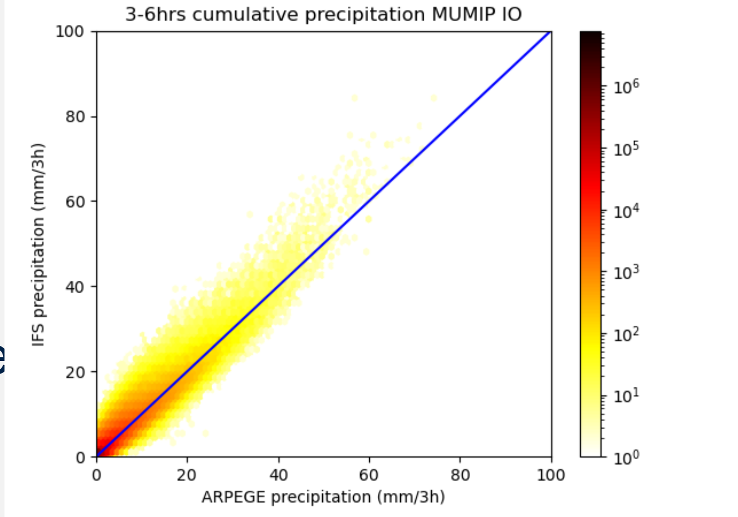
- Precipitation-precipitation relations
- Vertically averaged tendencies
- 9-11 million columns available per model



Main spin-up removed, 3 to 6hrs lead time only!

Precipitation correlations

IFS-ARPEGE MUMIP intermodel correlations are $0.95 - 0.98$



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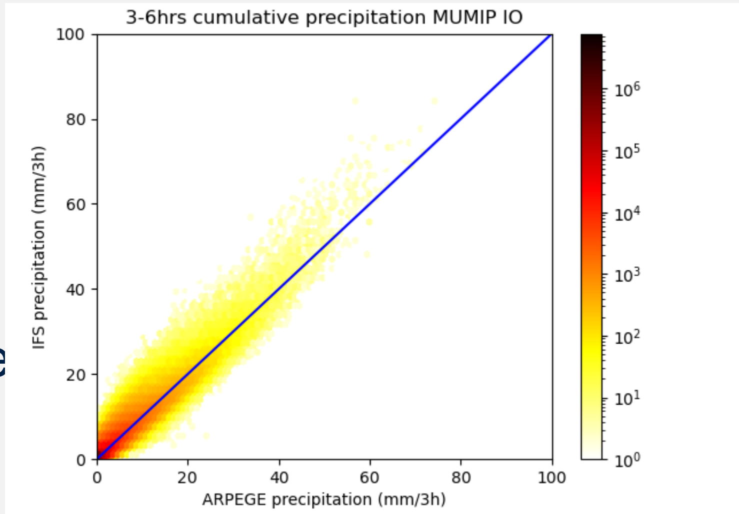

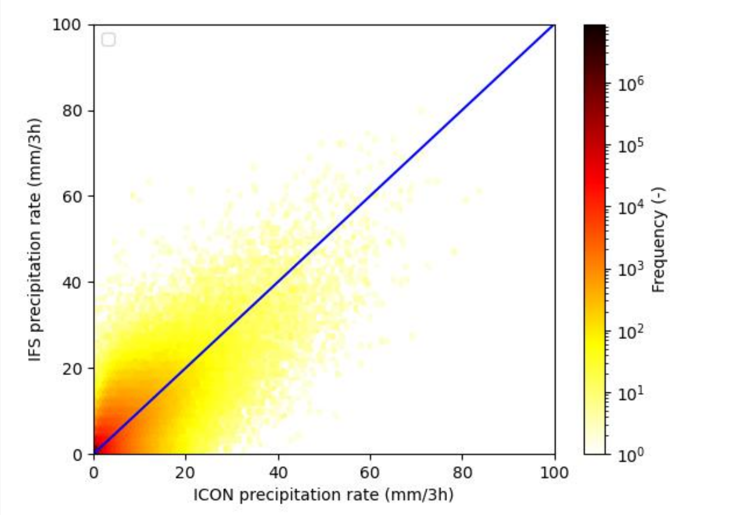

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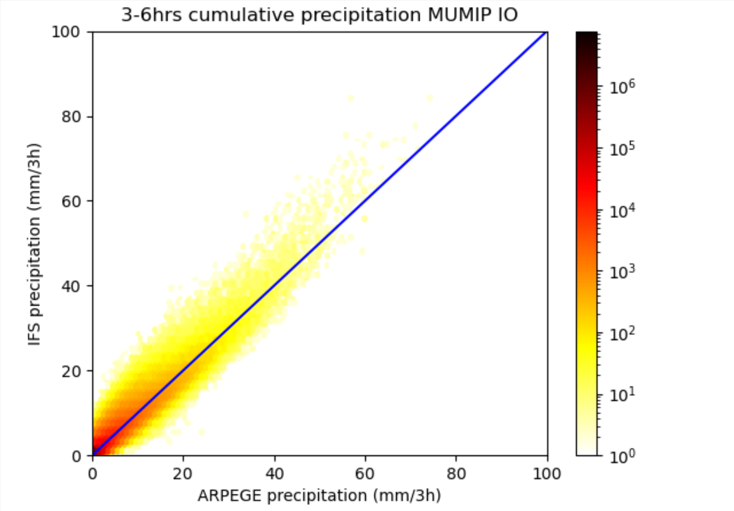
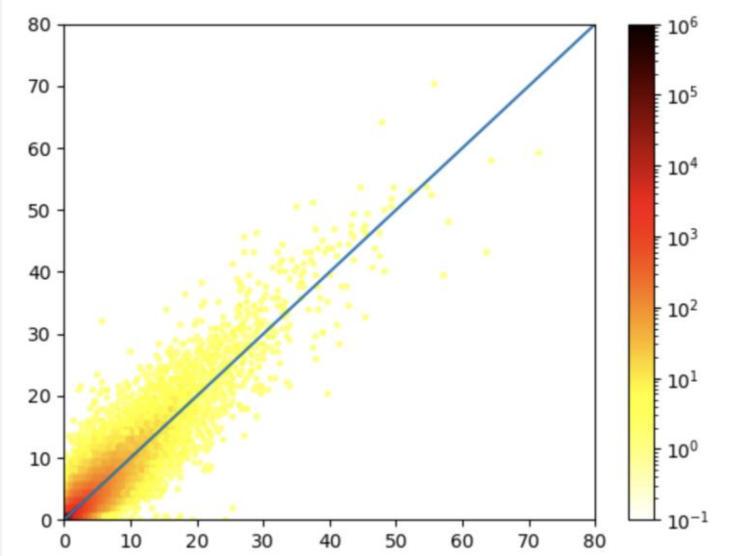


Coarse-grained 1.0 degrees

Advection & column assumption



Precipitation correlations

Native column data

1.0 degrees averages

Each contain a substantial source of missing variability at Mesoscale Convective System scales!

Precipitation correlations

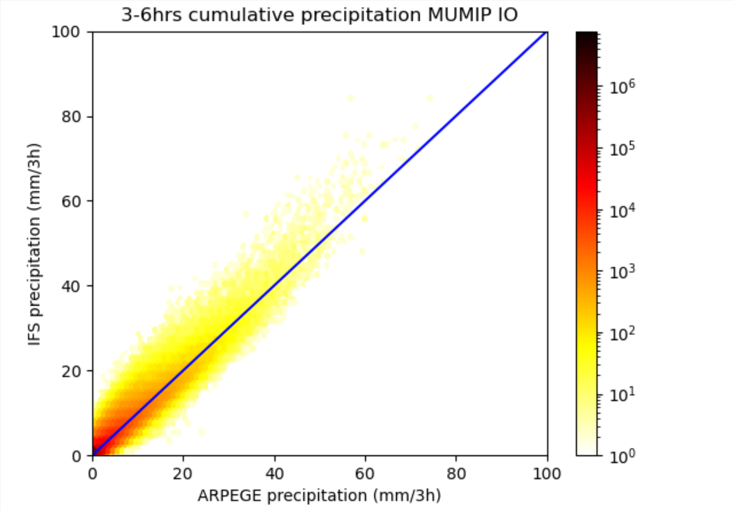
IFS-ARPEGE

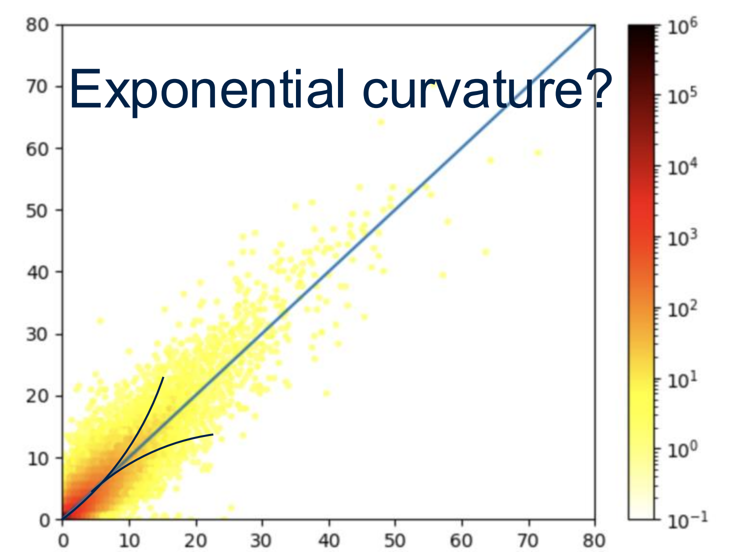
MUMIP

intermodel

correlations are

$0.95 - 0.98$





Precipitation correlations

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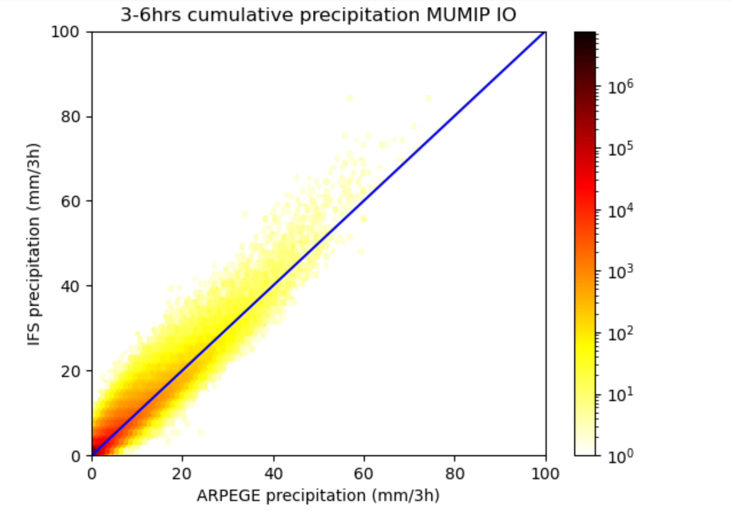
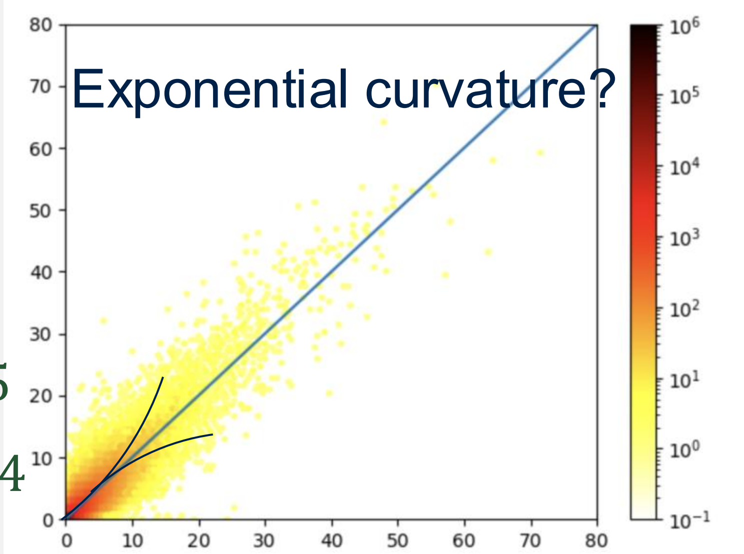


IFS: 1.06 ± 0.004

ARPEGE, RAP: $1.05 \pm 0.004; 0.005$

GFS: 1.02 ± 0.004



Discussion

- Exact curvature depends on "drizzle problem" (0.00… mm/h)
- Conditional exponent for high precipitation rate
  IFS/ARPEGE/RAP ≈ fit

IFS: 1.06 ± 0.004

ARPEGE, RAP: $1.05 \pm 0.004; 0.005$

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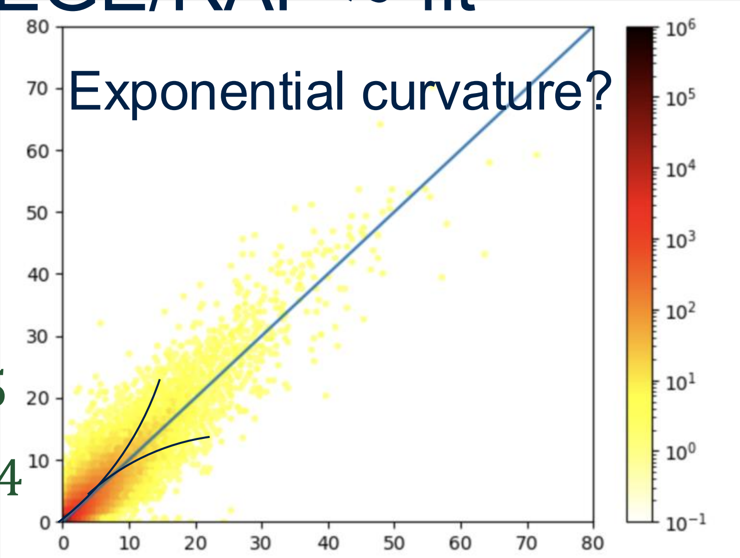


First: 2-layer tendencies & precipitation

"Free troposphere" (FT)
500-16.500m altitude

"Mixed layer" (ML)
0-500m altitude

Tendency model:

2x: T, q_v

2x: Vertically averaged physics, dynamics

2x: layers

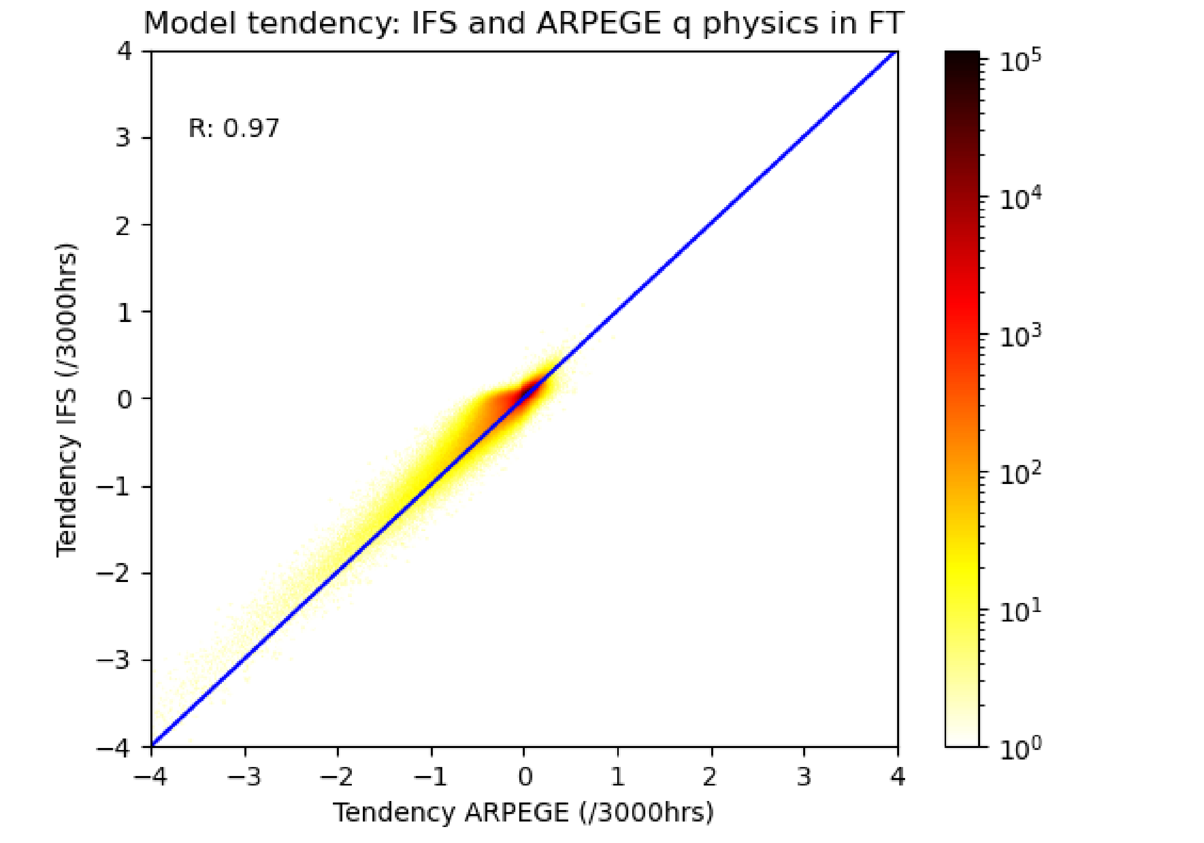
8 tendencies per model

Following: IFS, ARPEGE, ICON (ICON = pseudo-physics tendencies)

Mean free-tropospheric humidity tendency

Essentially: Tendency = - Precipitation (r = -0.97)

At coarse grids



Correlation table

Key points:

- Free-tropospheric humidity flux correlations ≈ precipitation correlations

- Temperature tendency from physics seems hardly under-dispersed

- Mixed layer (boundary layer & turbulence scheme?) seem to have reasonable uncertainty

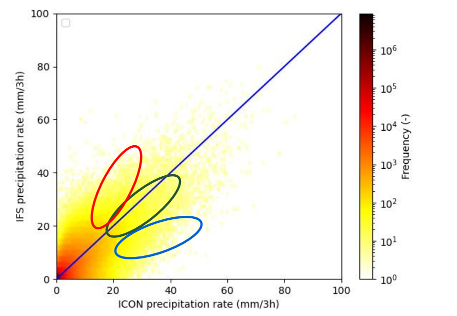
Quantity, layer	ARPEGE/IFS	IFS/ICON	ARPEGE/ICON
Temp., FT	**0.97**	0.94 (0.94)	0.93 (0.93)
Hum., FT	**0.97**	0.80 (0.81)	0.81 (0.82)
Temp., ML	0.58	0.50 (0.51)	0.42 (0.47)
Hum., ML	0.45	0.42 (0.41)	0.22 (0.24)
Cum. precipitation	0.95	0.81	0.79

Does the ICON-IFS bias depend on

- Convective structure (e.g. linear system’s environments vs. single cell environments), hence shear?
- “Convective” memory? (Not included)

Does the ICON-IFS bias depend on

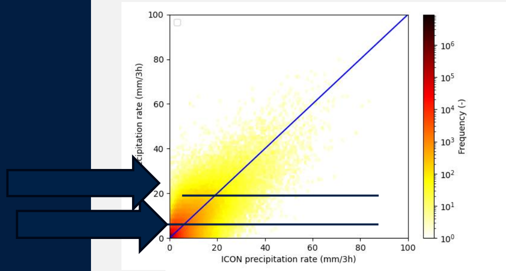
Convective structure/environment?

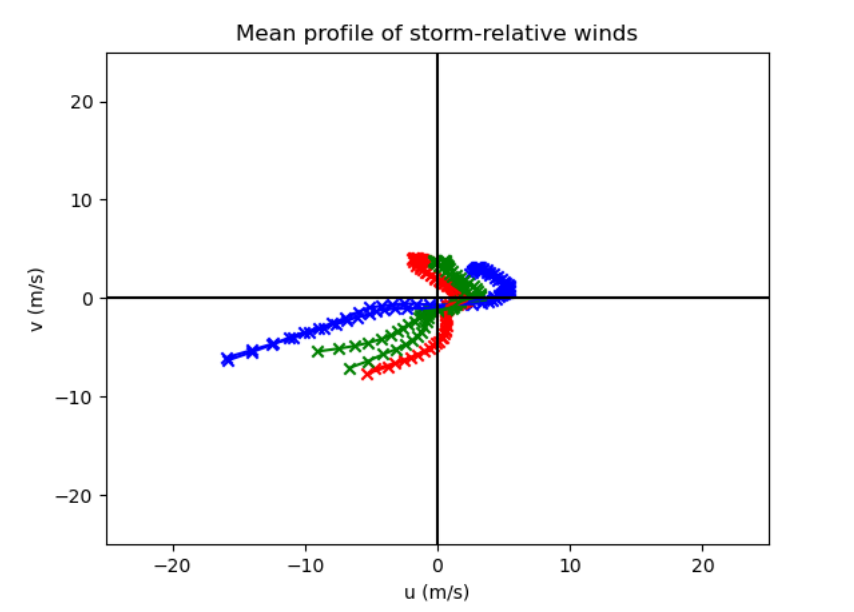


➡ Bins joint PDF!

Conditional shear profiles

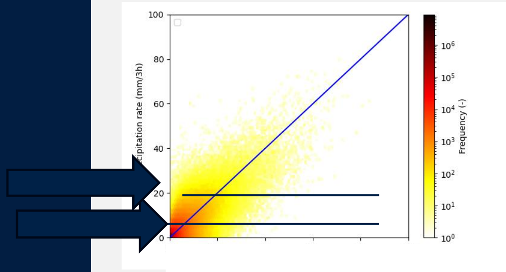
Wind shear profiles

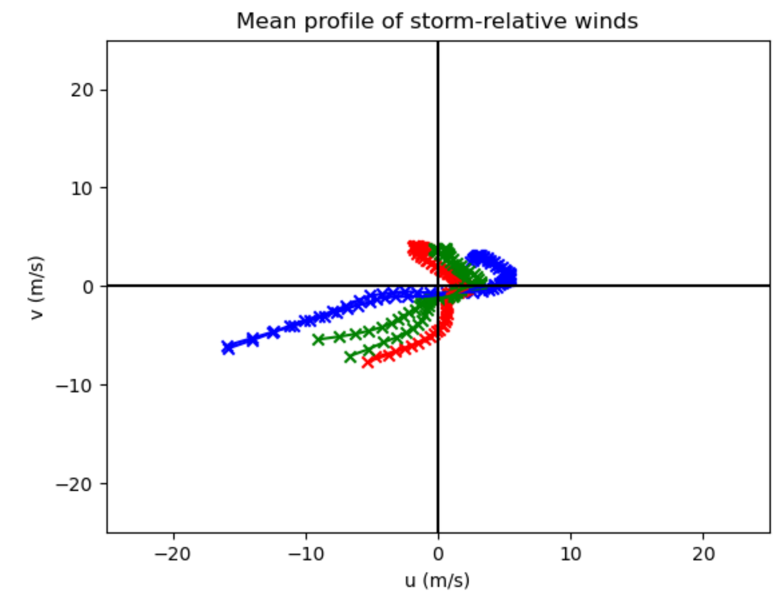




Conditional shear profiles

Wind shear profiles





Green & red profiles appear more suitable for lateral inflow (i.e., cells closer to each other, hence closer towards 2D flow limit)

Implications

- Hypothesis 1 confirmed: strong linear correlation coarse grid models, little difference between their model physics!!
- Hypothesis 2 confirmed: (slightly) exponential relation between benchmark precip & coarse model precip
- Hypothesis 3 seems ok, but needs further investigation

Implications

- Free-tropospheric humidity physics tendency most overconfident at coarse grids, when compared to other the other physics tendencies (mixed-layer physics & temperature)
- Nearly perfect anti-correlation with precipitation (column assumption, i.e., IFS example)

Implications

- When imposing identical dynamics, IFS under- or overestimate of precipitation *w.r.t. benchmark* relates to convective environment
- The results are consistent with hypotheses posed in earlier work; stochastic physics can "emulate" convective organisation

Implications

- Tapering to free-troposphere, multiplicative nature and offset water conservation are strong characteristics for emulation of convection with SPPT
- Lag correlations of physics humidity tendency can improve, but not under “dry” circumstances

Discussions

- Indian Ocean might not have a lot of well-organised quasi-2D squall lines (e.g. unlike continents/midlatitude summer)
- Hypothesis that stochastic schemes could be optimised (e.g., data-driven) towards local clim. of convective organisation
- Further discrimination between different convective structures: future MUMIP experiments?!!

Conclusion

- Hypotheses broadly supported by MUMIP, IO experiment
- Stochastic perturbations with multiplicative nature sensible from "convective organisation" angle
- Free-troposphere $dq_{v,physics}$ great targets of stochastic perturbations
- Stochastic perturbations likely optimisable by region with tailored precip analysis!!

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Thank you

Interested? Contact Hannah Christensen/Edward Groot/MUMIP team

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Spread sequence

LES-study, CM1

< Pre-print/MUMIP/website >

ICON-study

Thank you

Interested? Contact Edward Groot (Large.Edward.simulations (at) gmail.com