High resolution forecasts of summer convection

or

Uncertainty analysis of summer convection over land using an ensemble of high-resolution forecasts within the project HD(CP)^2

Martin Köhler, Daniel Klocke, Tobias Göcke, DWD

Physical processes in present and future large-scale models

ECMWF Seminar 1.-4. September 2015

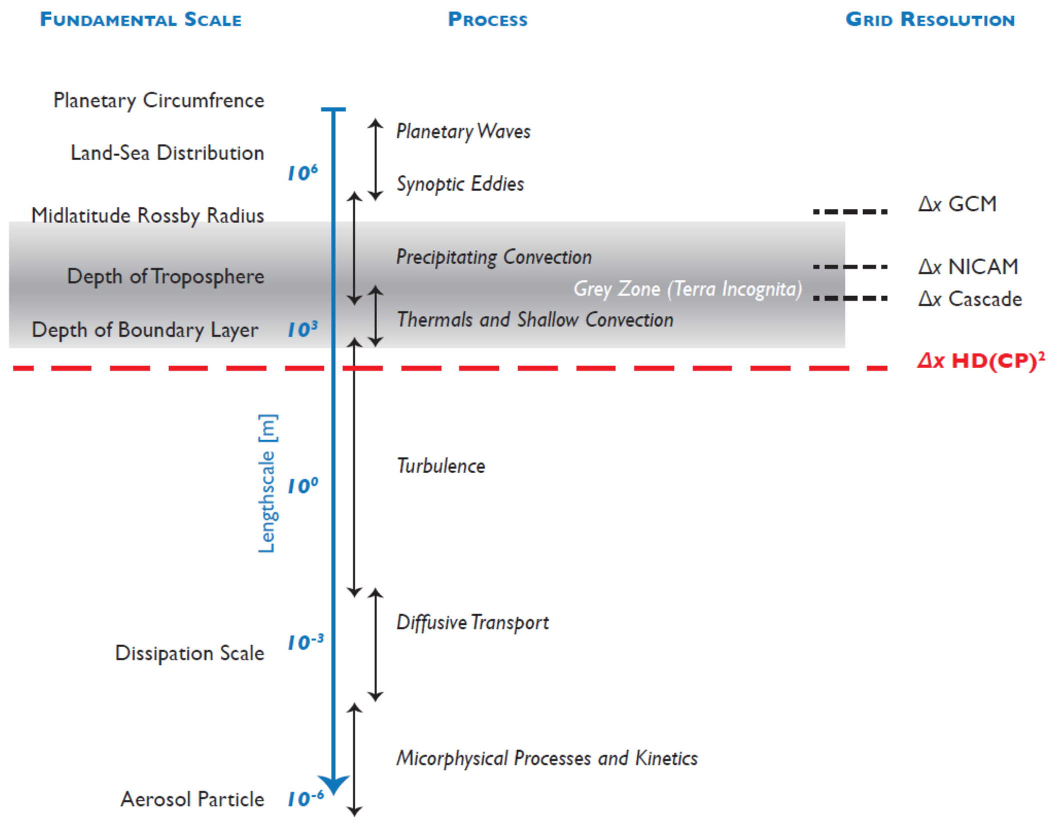
HD(CP)²

hdcp2.eu

High definition modelling

Multiscale

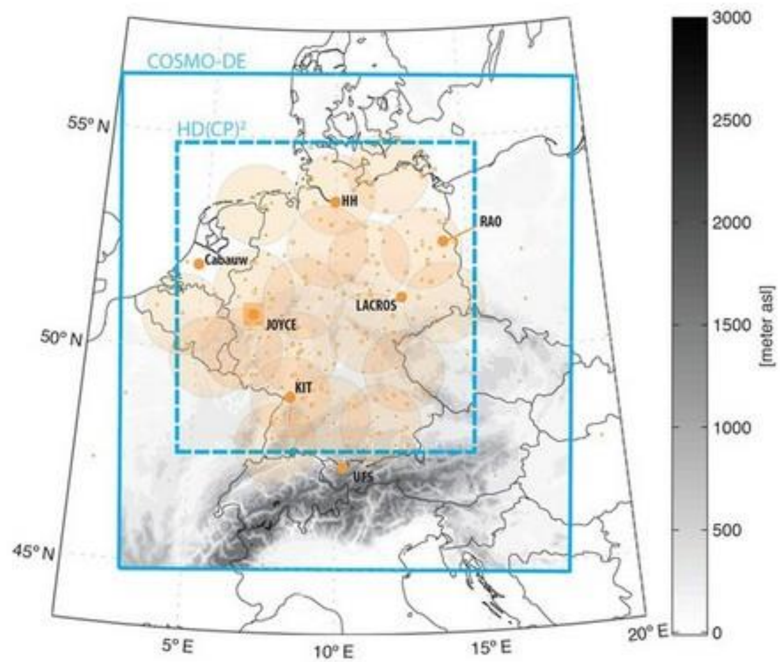
cloud / precipitation problem



HD(CP)2 proposal, steering committee: Stevens, Crewell, Jones, Biercamp, Burkhardt, Seifert,Macke, Simmer 2011

Between the resolution of typical GCMs and **100m** is the „grey“ zone where parameterisation is hard to achieve / understand.

High definition modelling on a limited domain

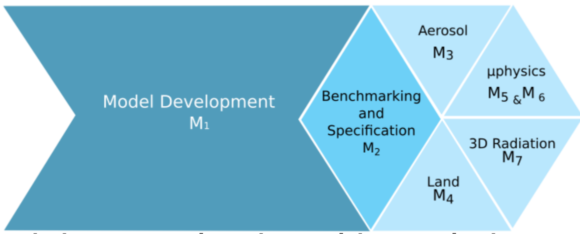


HD(CP)2 proposal, steering committee: Stevens, Crewell, Jones, Biercamp, Burkhardt, Seifert,Macke, Simmer 2011

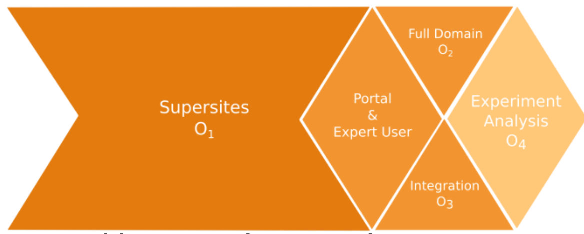
A resolution of **100 meter** implies automatically a regional domain for current computer power. Bonus: Germany has a dense network of observation stations / supersites.

HD(CP)² Strategy

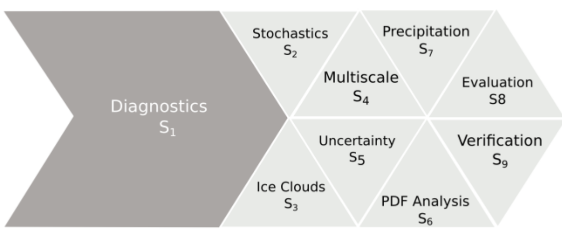
hdcp2.eu



Higher resolved, multi-resolution models



More / better observations



Evaluation technique / parameterisations

Multiscale

cloud / precipitation problem

- 100 people (50 FTE +)
- 19 institutes / universities across Germany
- Funded by BMBF

HD(CP)² Scaling ICON

hdcp2.eu

DWD

JUQUEEN BlueGene/Q HiQ club
458,752 cores (1,835,008 threads)
100m LES over Germany

SuperMUC (Intel Xeon Phi)
65536 cores
100m LES over Germany

ECMWF (CRAY/Intel)
92160 threads
5km global, 20971520 grid cells, 2.5h

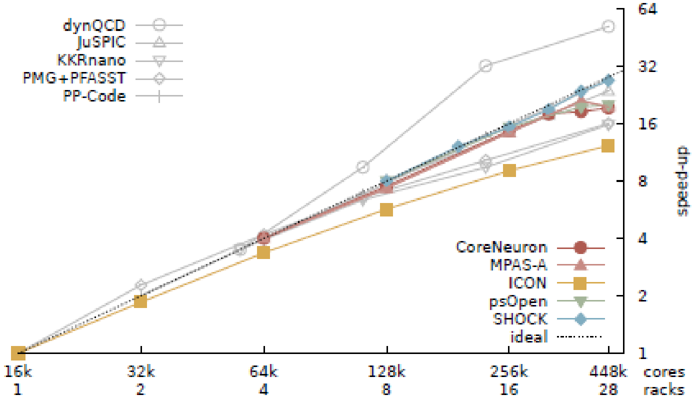
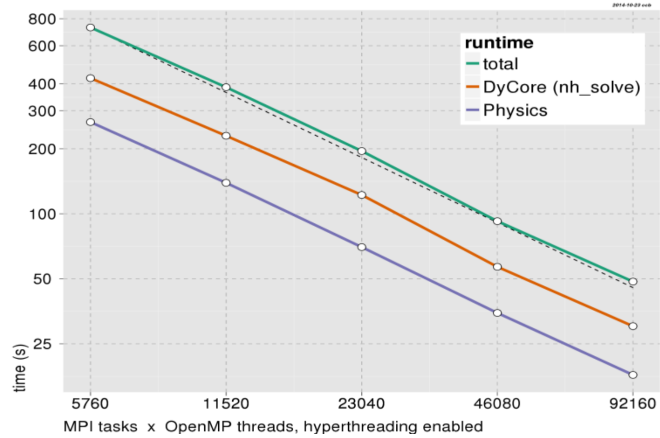


Figure 3: Strong scaling results of the workshop codes with results from existing High-Q Club members included in light grey.

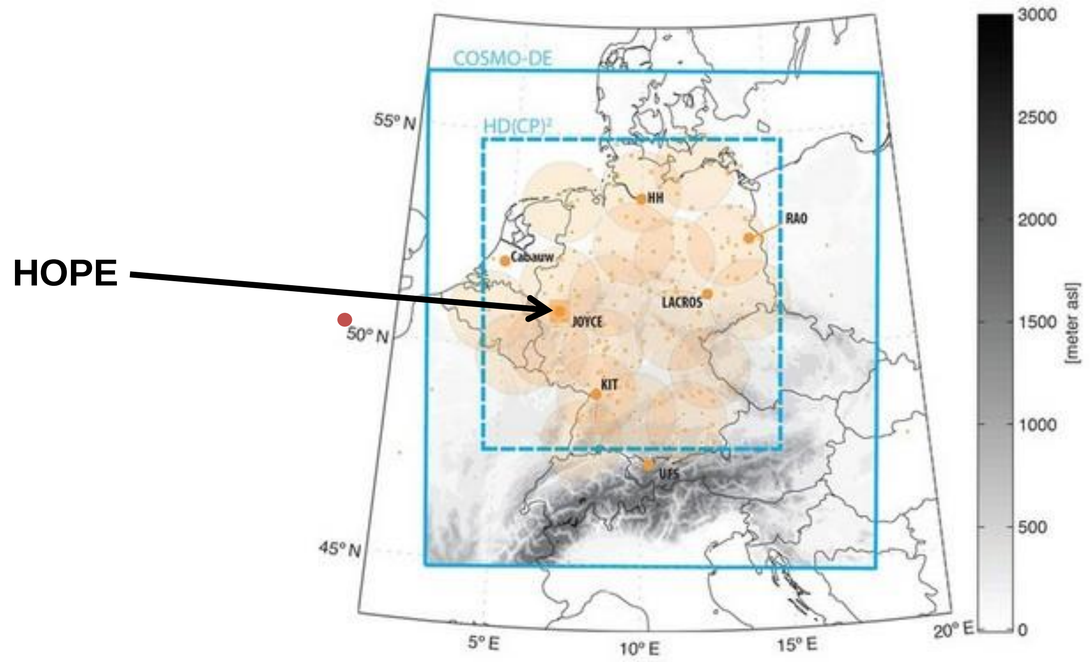


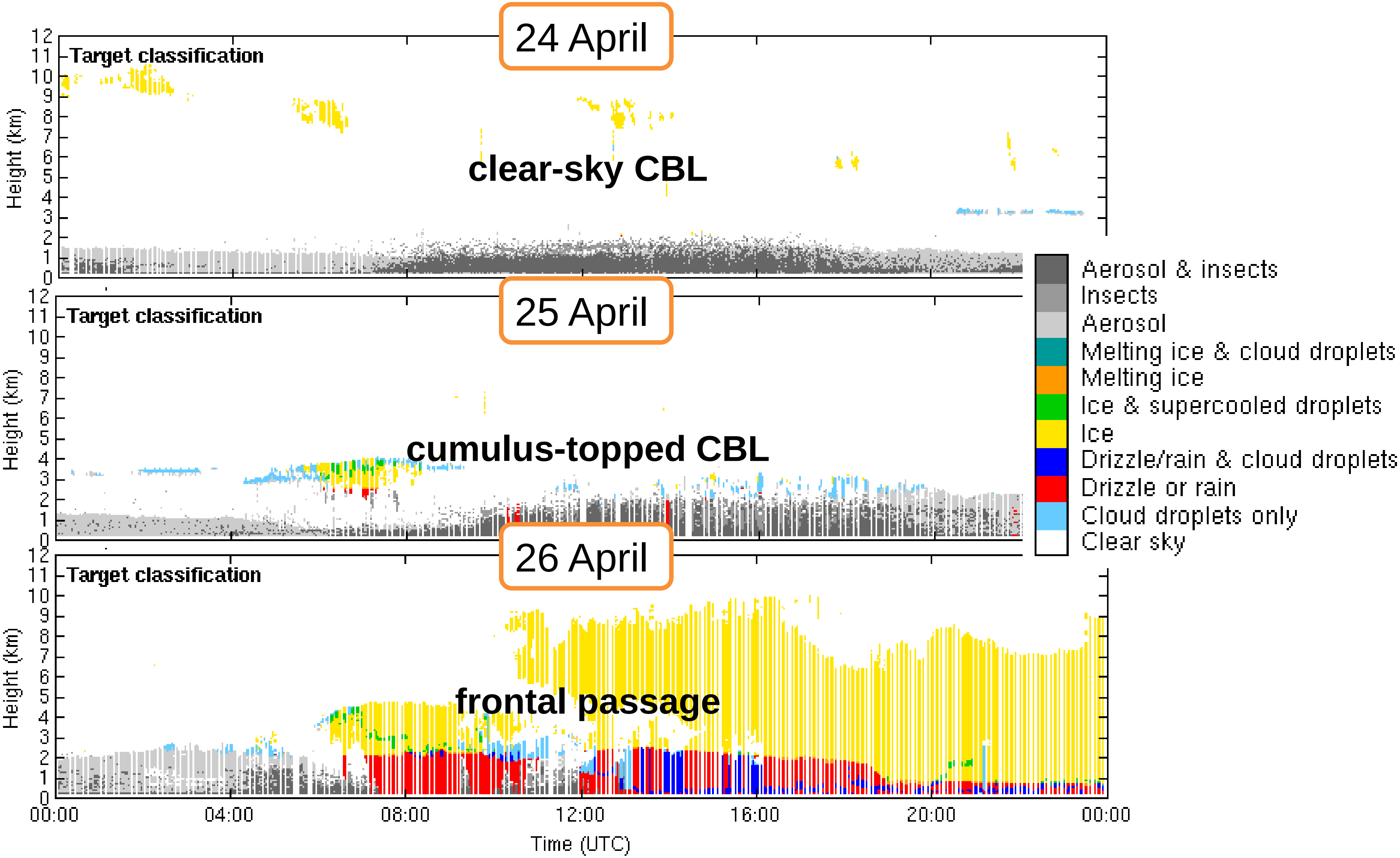
Campaign: HOPE

HD(CP)²
hdcp2.eu

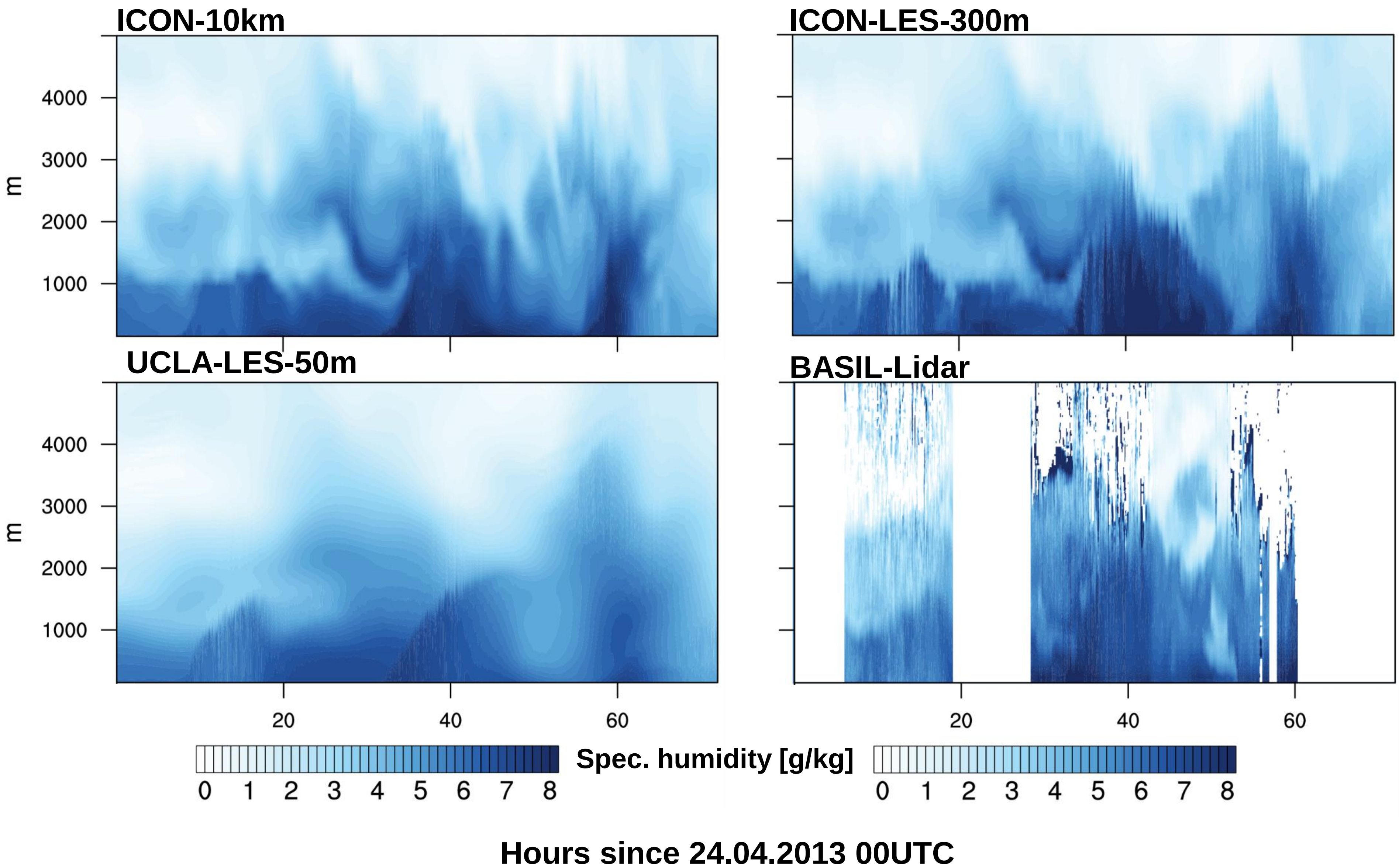
HOPE: HD(CP)² Observational Prototype Experiment (April / May 2013):

Many (German) measurements-centres meet for an intensive measurement campaign

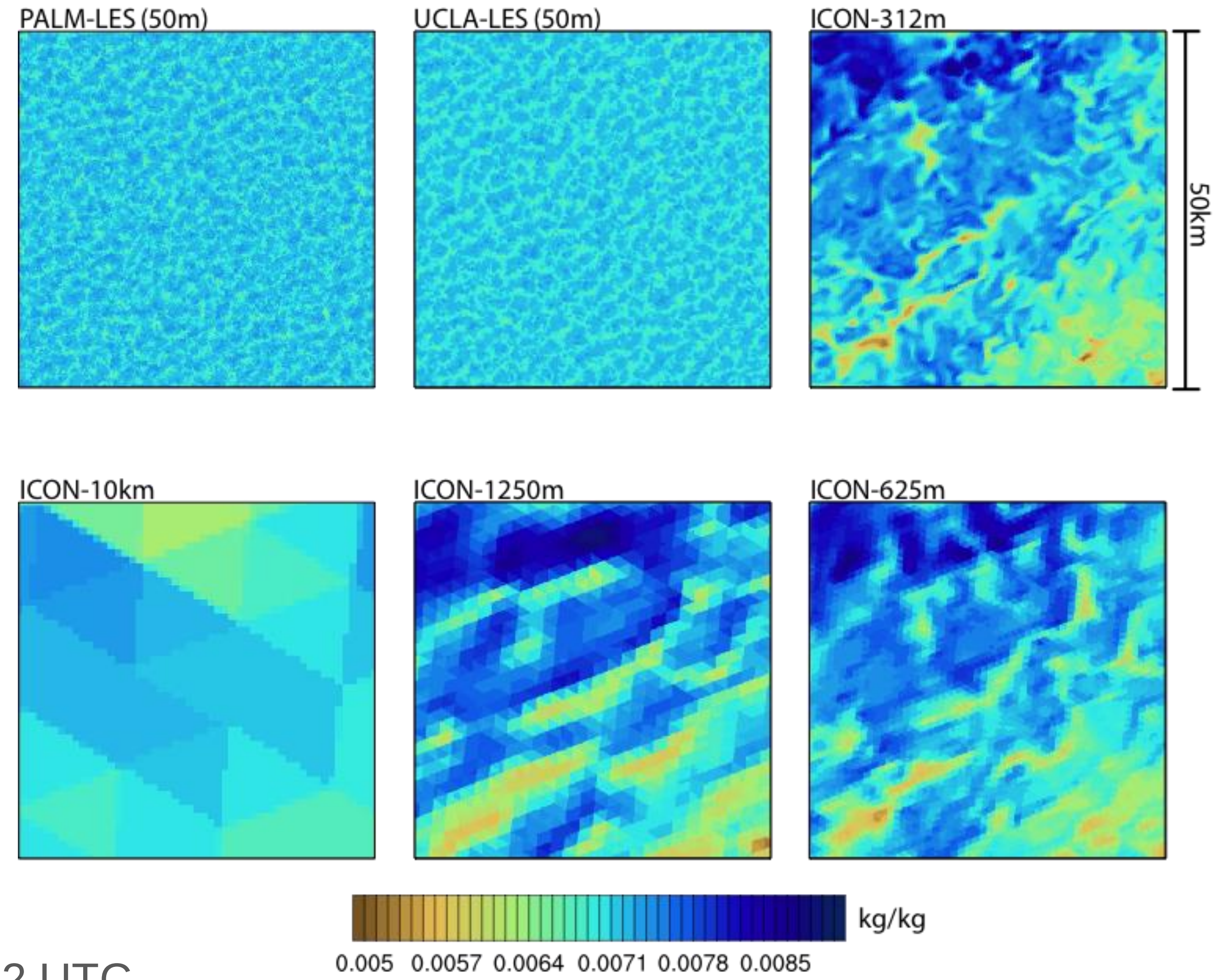




CloudNet product from JOYCE (gop.meteo.uni-koeln.de)

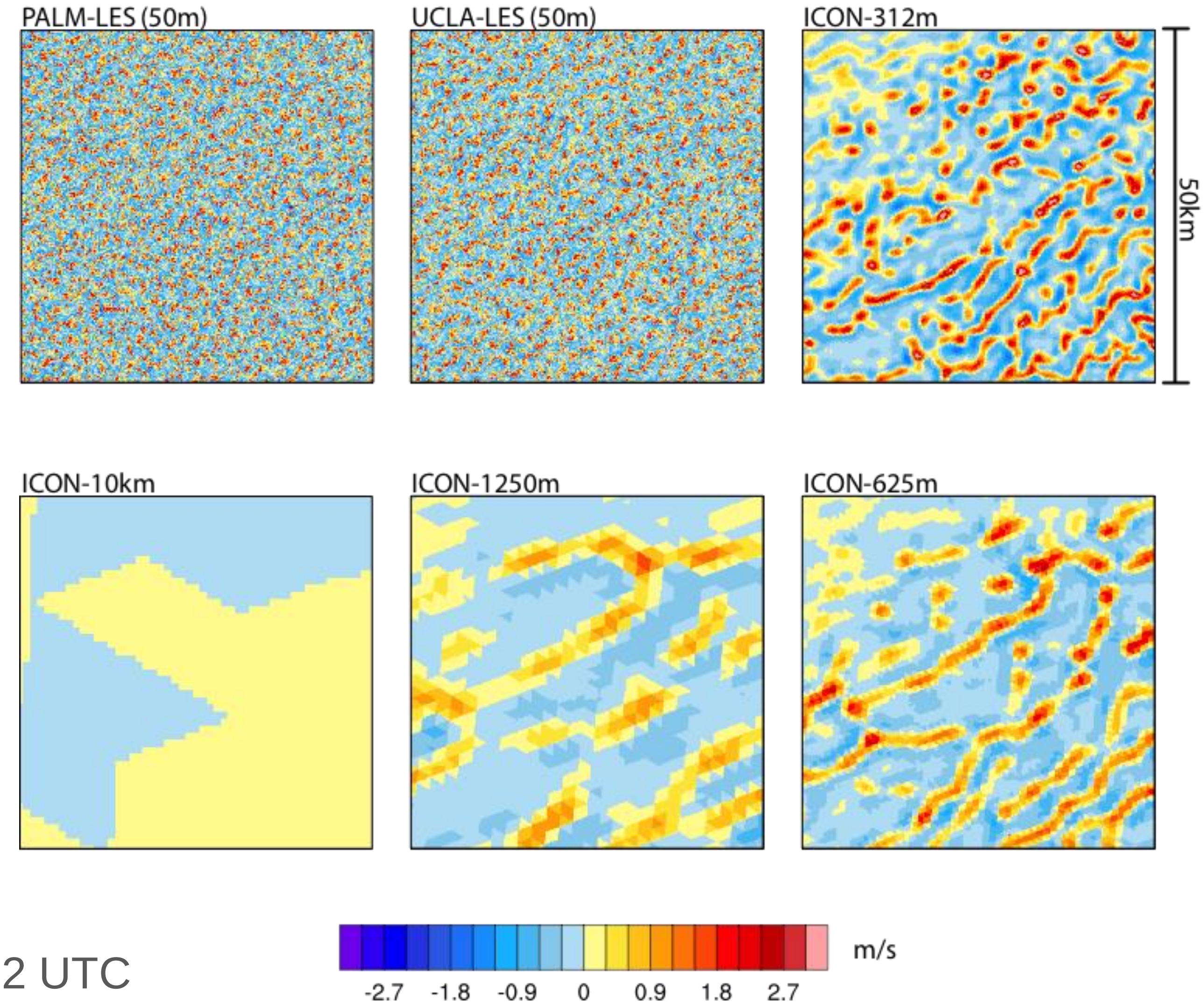

ICON-10km
ICON-LES-300m
UCLA-LES-50m
BASIL-Lidar
m
4000
3000
2000
1000
20
40
60
0 1 2 3 4 5 6 7 8
Spec. humidity [g/kg]
Hours since 24.04.2013 00UTC

Q_V at 700m



25.04.2013 12 UTC

W at 700m



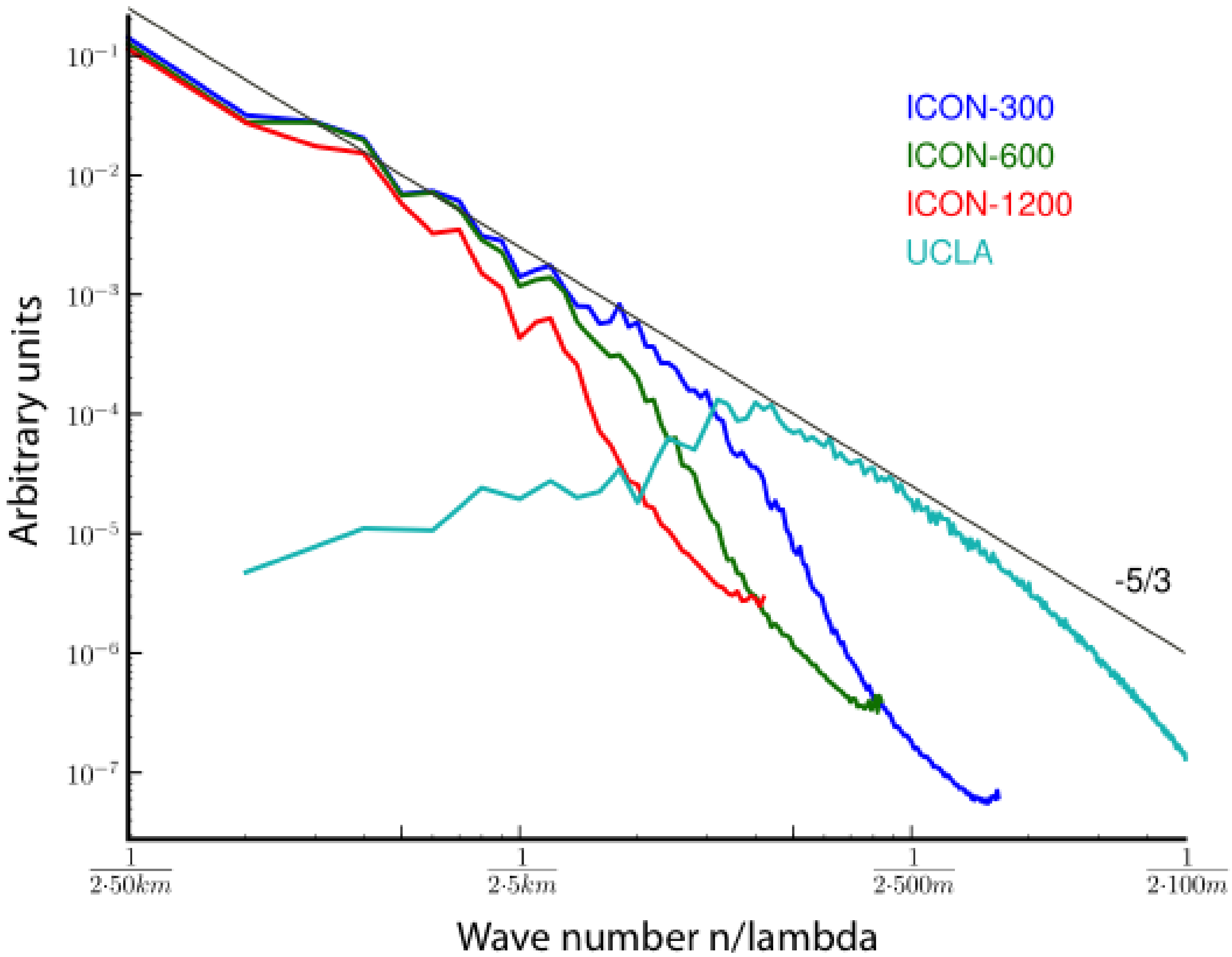
25.04.2013 12 UTC

HD(CP)² hdcp2.eu

TKE spectrum

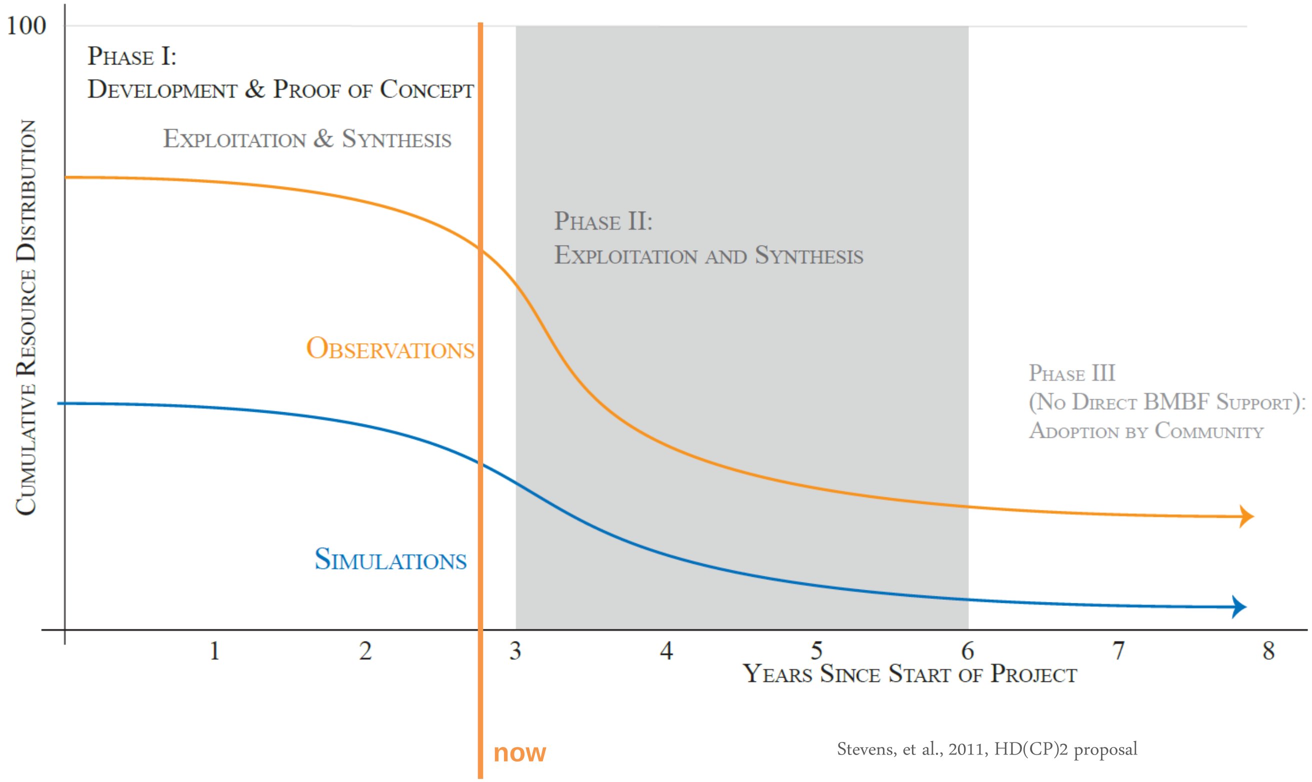
DWD

25.04.2014 12 UTC



HD(CP)² Timeline

hdcp2.eu



Coordinated approach to tackle the cloud/precipitation problem

- Build a model (flexible, 100m resolution) based on ICON
- Organize data for evaluation (create German ARM site)
- Use this model/data framework to generate new ideas

Final workshop 15-19 February 2016: *hdcp2.eu* (abstracts 19. Sept 2015)

Uncertainty in high-resolution convection forecasts

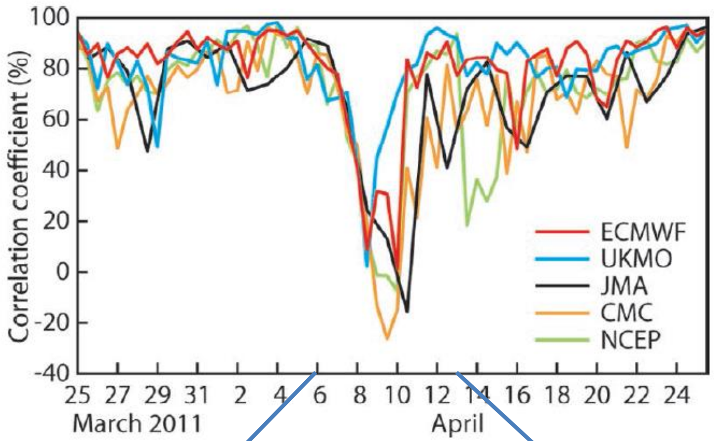
- uncertainty evolution
  - correlation length scale increase with time given small initial uncertainty?
  - growth rate?
  - upward energy cascade from convective scale?

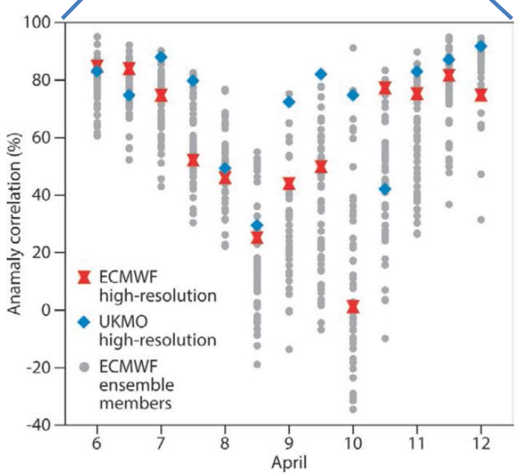
- physics of convective instability?

- benefit to weather forecasting
  - NWP at O(100m) resolution?
  - How to select growing convective modes (initial conition?
  - How best to design stochastic physics?

Rodwell et al 2013: occasional poor forecasts

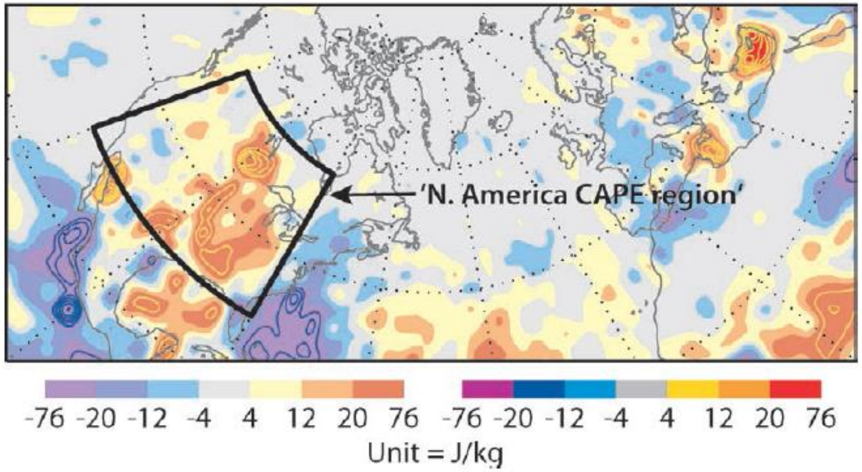
Busts 8-10 Apr 2011





Day 6 forecast skill over Europe

584 Busts in ERA Interim - Composite

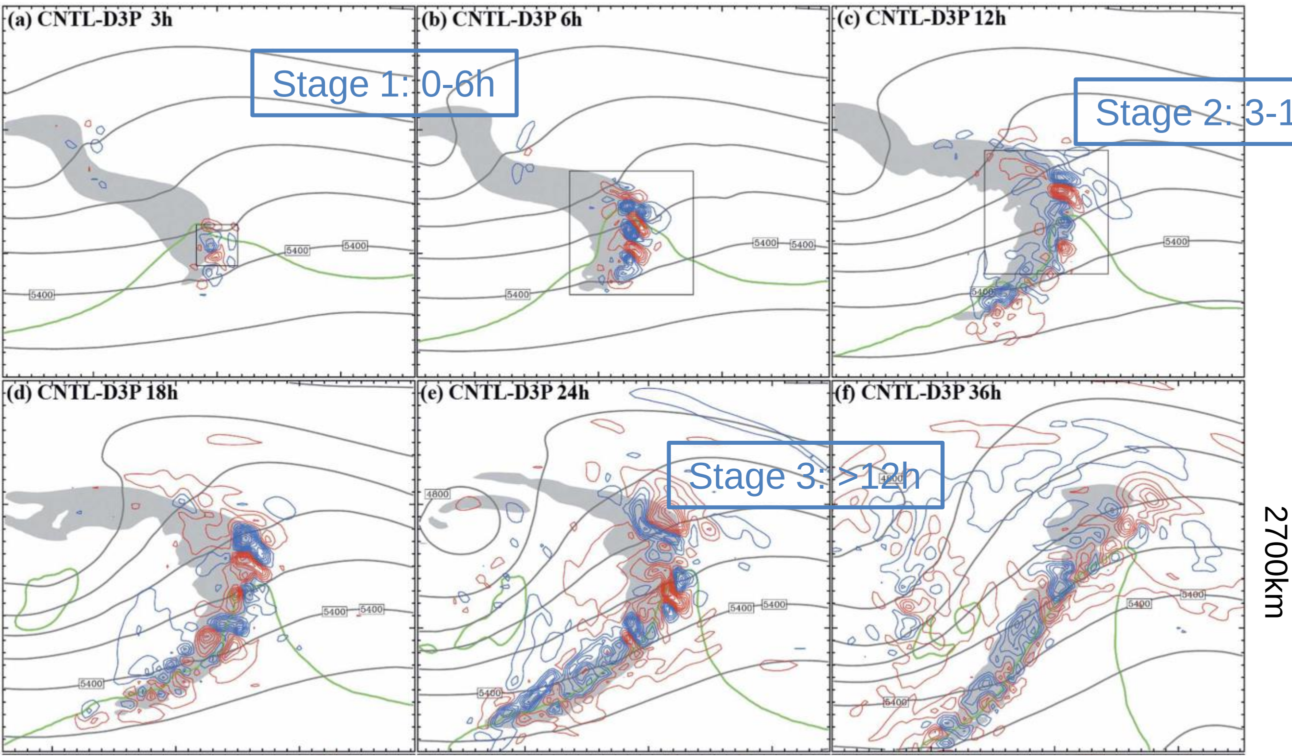


Mean initial (6h) CAPE anomaly for Day 6 busts over Europe
5% level significance: bold color

- Increased initial CAPE over USA correlates with EU busts
- Best and worst ensemble member have same initial perturbation with opposite sign
- MCS slow synoptic evolution
- MCS requires parameterisation

Zhang et al 2007: 3 stages of error growth

Idealized MM5 simulation, nested domain at 10km resolution



3400km

V 500hPa difference (red/blue)
Z 500hPa (black)
Precipitation (grey shaded)
CAPE (green)

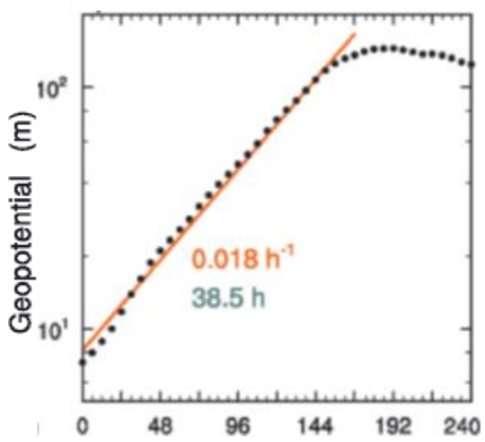
Perturbation: 0.2K

- Stage 1: errors groth fast on small scales due to convective instability and latent heat release, but saturate quickly
- Stage 2: perturbations expand in spatial scale and come into geostrophic balance
- Stage 3: balanced perturbations grow on synoptic scales in presence of baroclinic instability

Hohenegger and Schär 2007a: predictability a synoptic and cloud-resolving scales

RMS difference (pert-control)

ECMWF EPS 50km



COSMO 2.2km

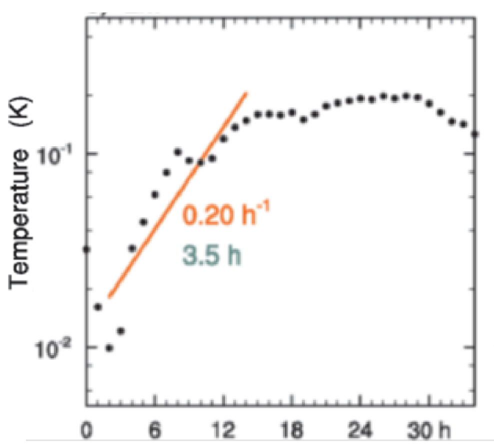


TABLE 1. Typical time scales associated with medium-range synoptic-scale (ECMWF) and short-range cloud-resolving (LM) simulations.

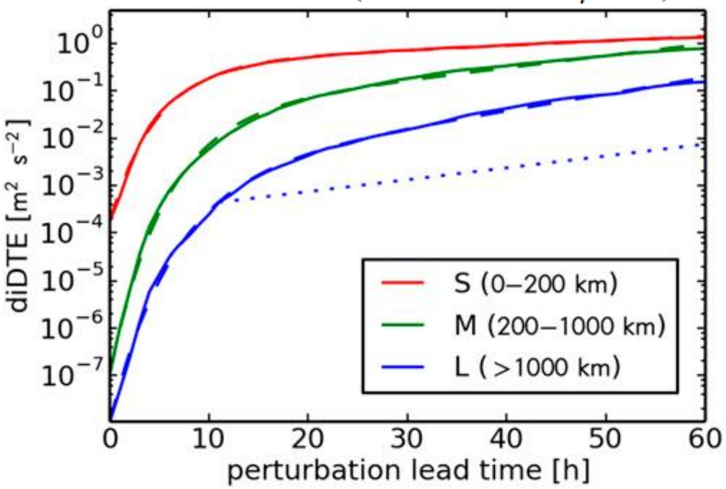
	Lead time T_{lead}	Doubling time T_d	Ratio T_{lead}/T_d	Tangent-linear time T_{lin}	Ratio T_{lead}/T_{lin}	Ratio T_{lin}/T_d
ECMWF	240 h	40 h	6	54 h	4.4	1.35
LM	24 h	4 h	6	1.5 h	16	0.38

- Error growth of convective systems is 10 times larger versus synoptic systems
- Tangent-linear time drops another factor 3 for convective systems (strong non-linearity)

Selz and Craig 2015: quantify error growth at 2.8km

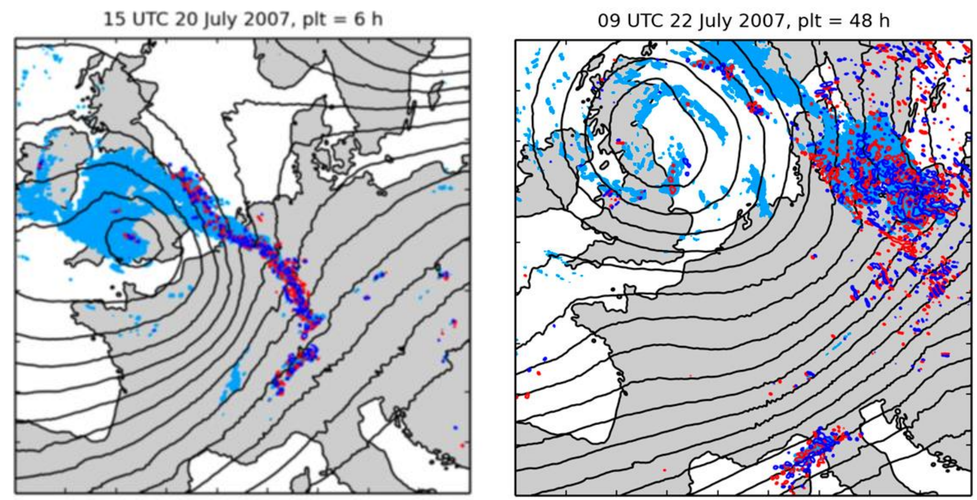
Difference total energy

$$\mathrm{DTE}(\mathbf{x},t) = \frac{1}{2}\left(\Delta u^2 + \Delta v^2 + \frac{c_p}{T_r}\Delta T^2\right)$$



Averaged over Europe and
4 perturbation experiments

Difference vertical wind (dark blue and red)



Geopotential: lines, Precip: light blue

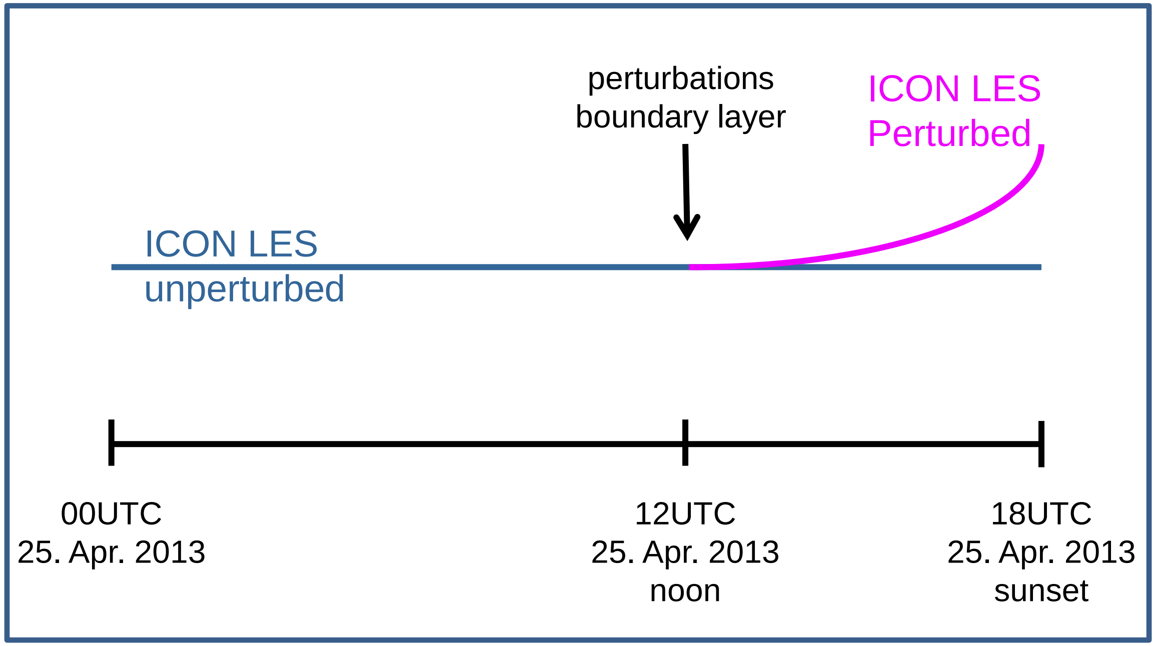
Growth [h]	S	M	L	S wet	S dry
Stage 1	0.61	0.44	0.53	0.34	0.70
Stage 2	4.7	5.5	6.4	3.5	5.1
Stage 3	44	17	12	290	39

Stage 1:
- Latent heat main source of fast growth

Stage 2: Upscale energy cascade to balance
- time-scale for gravity wave to cross Rossy radius of deformation: 7.8h

Stage 3: spread in Z500
- 60h, 2.8km, dT=0.01K: 15 m^2s^{-2}
- 6h ECMWF: 45 m^2s^{-2}

Uncertainty in high-resolution convection forecasts

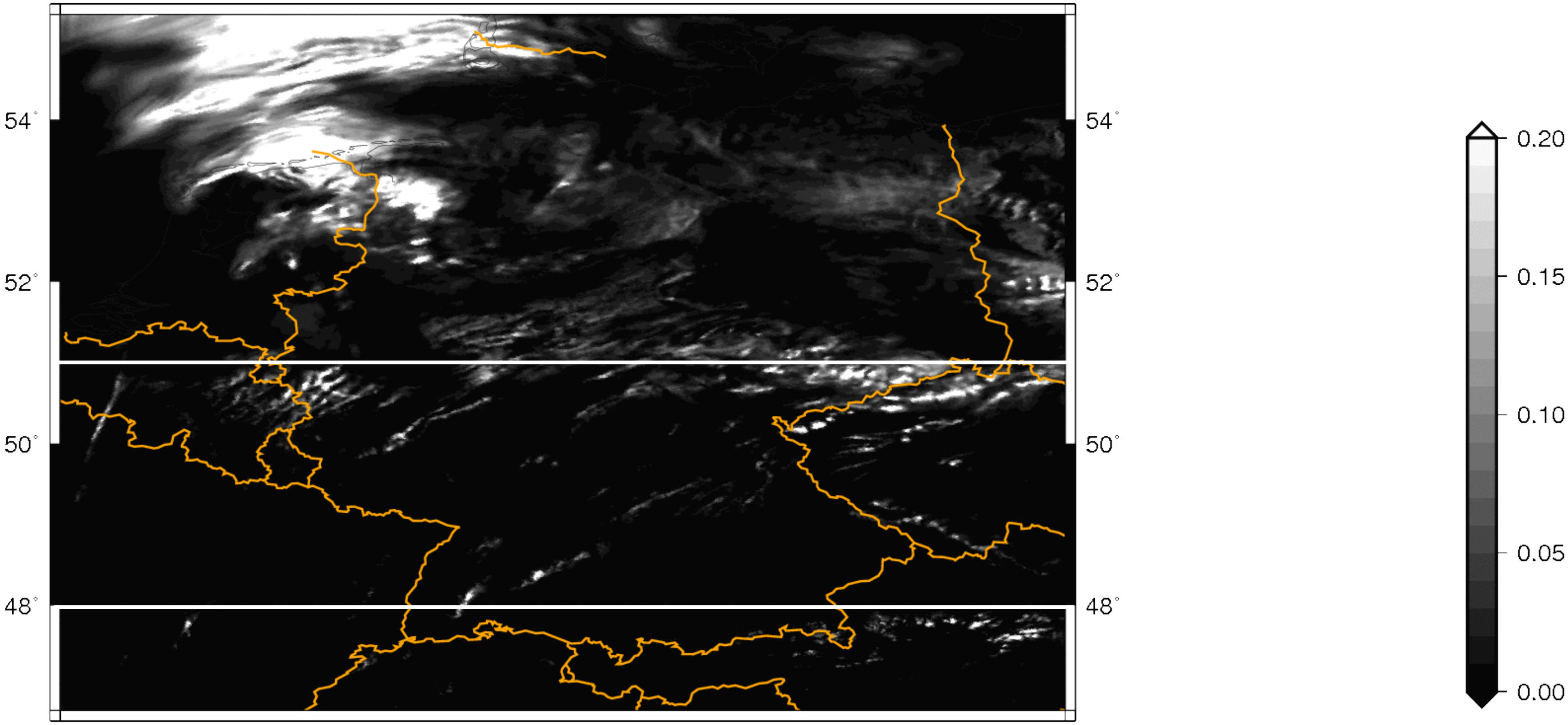


- COSMO 2.8km initial and boundary conditions
- ICON nest: region around Germany
  - 1249m 10s / 2s
  - 625m 5s / 1s
  - 312m 2.5s / 0.5s

  time step: adv / dyn
- 150 levels, top 21km
- perturbation at 12UTC:
  - T' < 0.01K
  - Level 150-120 (1500m)

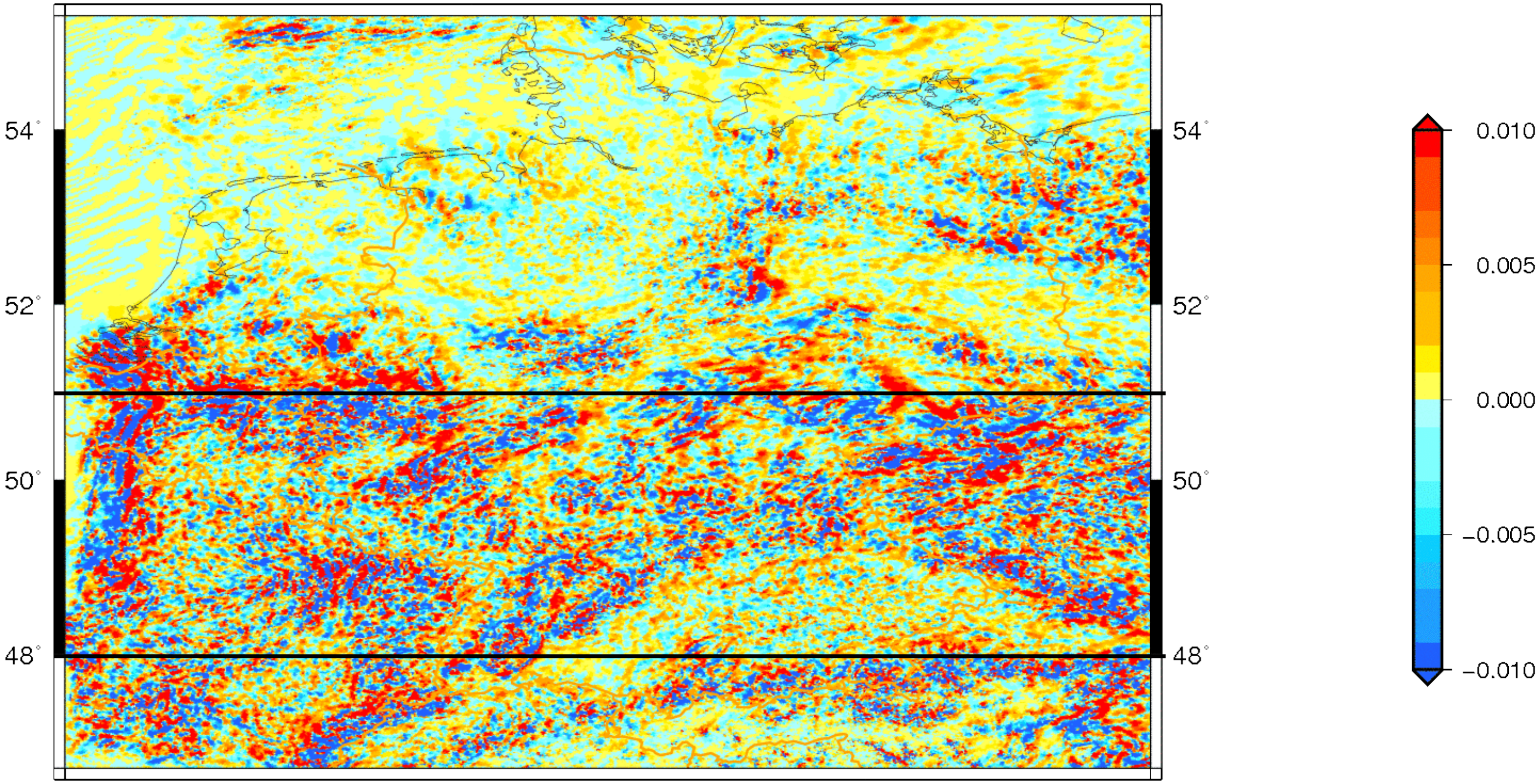
LWP control simulation

14UTC 25.4.2013



WVP diff between two simulations

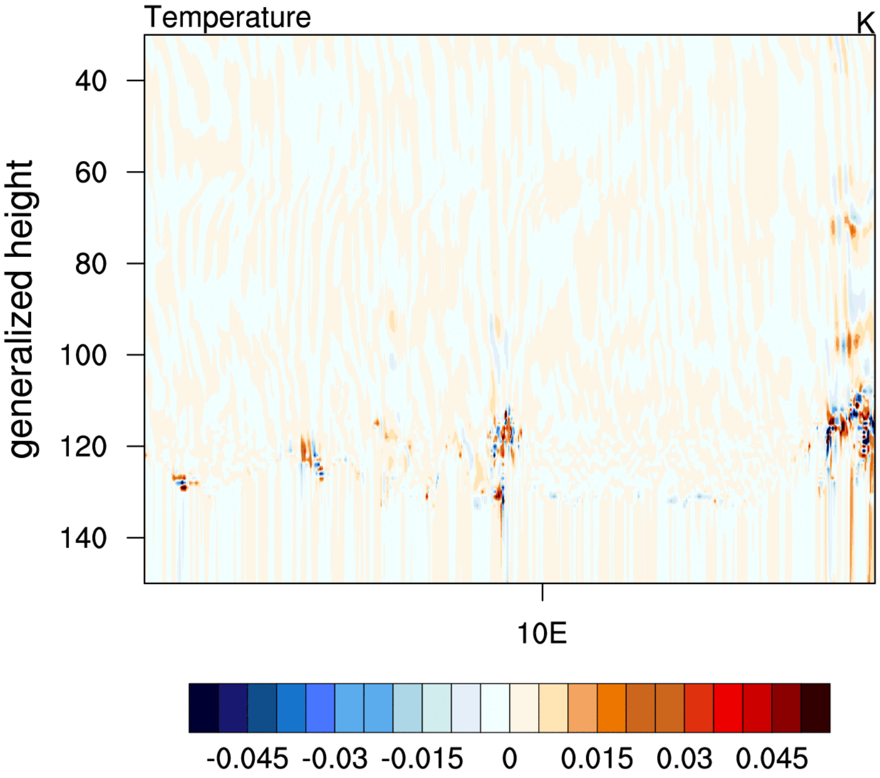
14UTC 25.4.2013



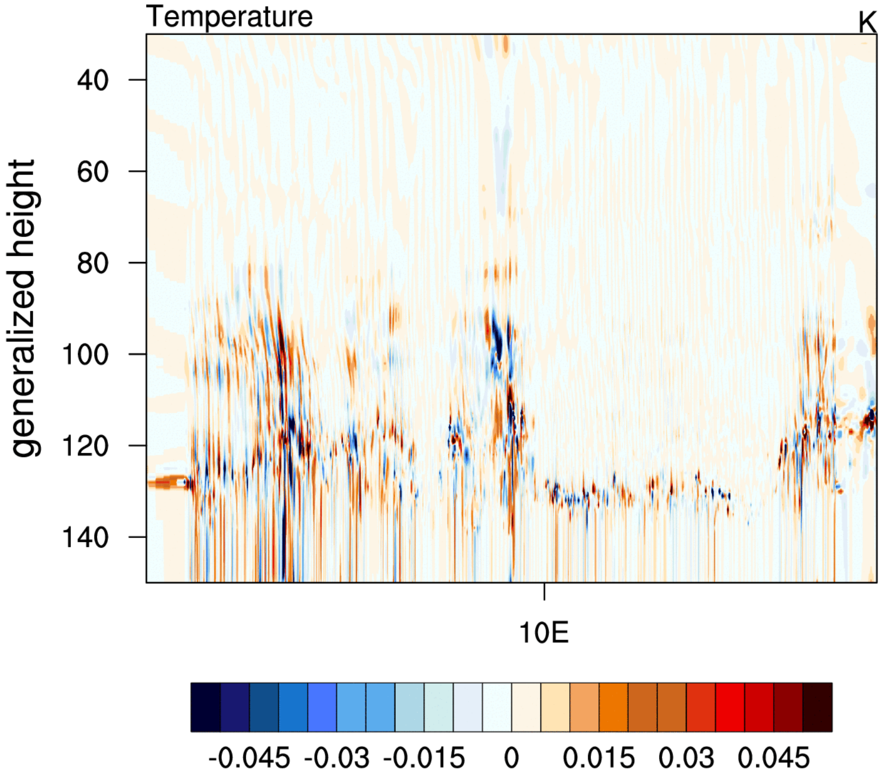
T diff between two simulations: 48.5N cross-section

14UTC 25.4.2013

1200m resolution

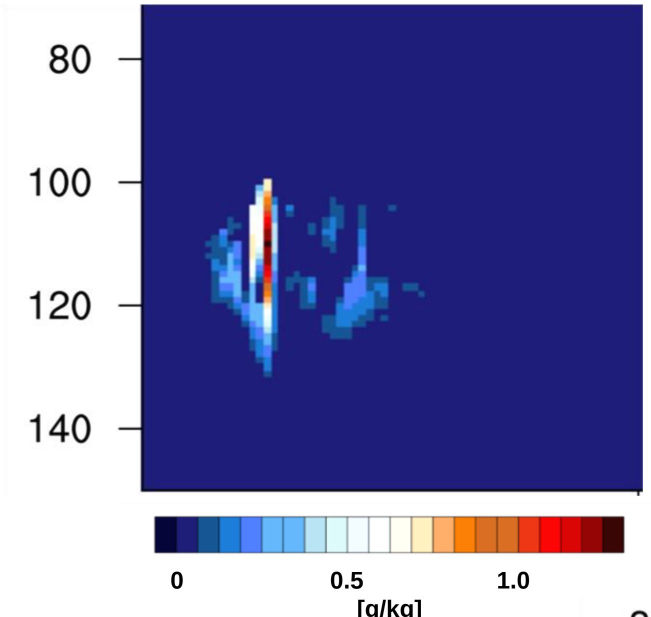


300m resolution

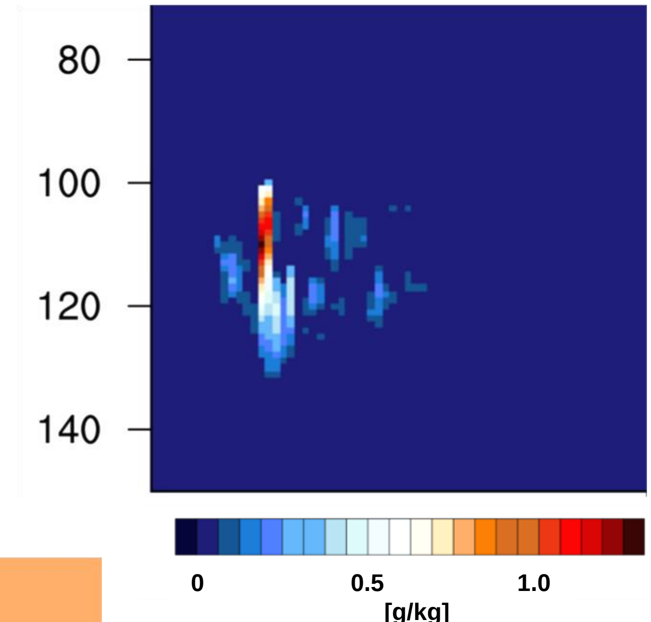


Q_l difference after 4 hours

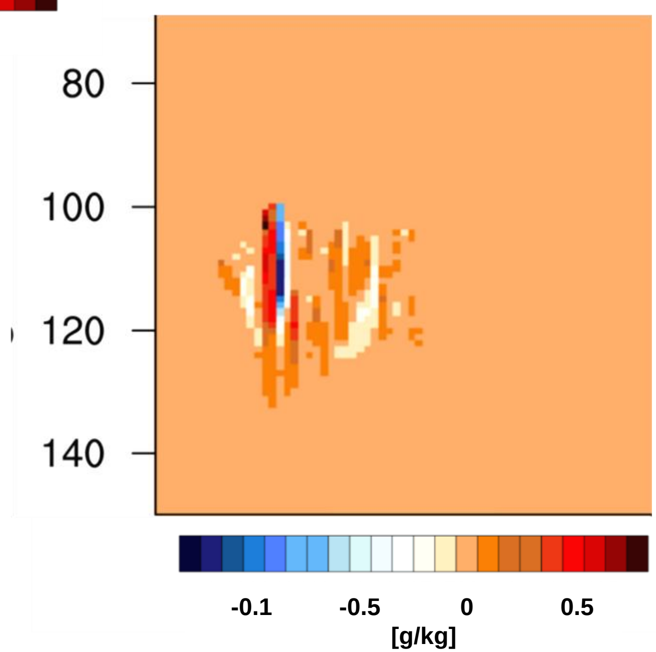
control



perturbed



difference



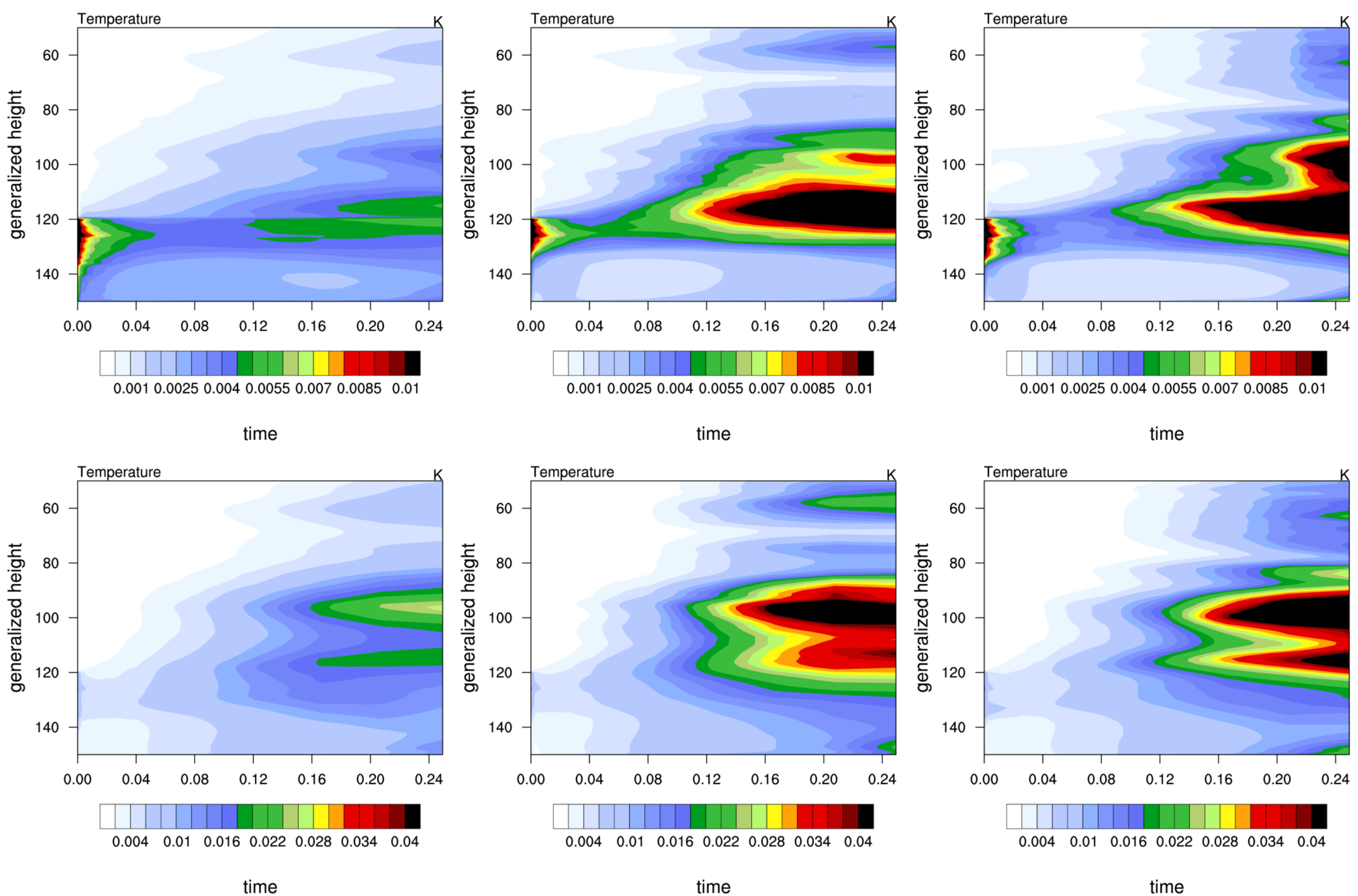
Rhein valley (SW Germany)
48.1N 8-9E
16UTC
300m resolution

T diff between two simulations

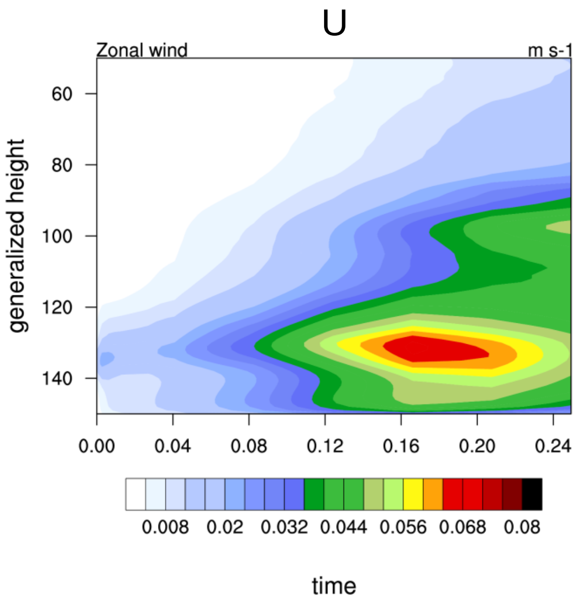
Full Domain | Shallow 51N | System 48.5N

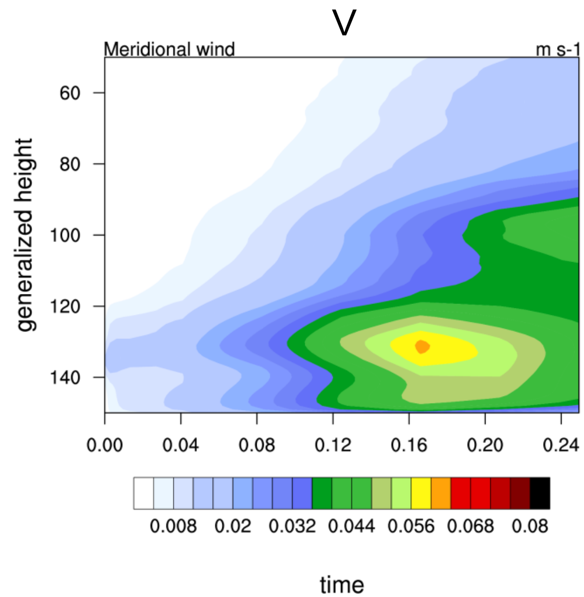
1200m

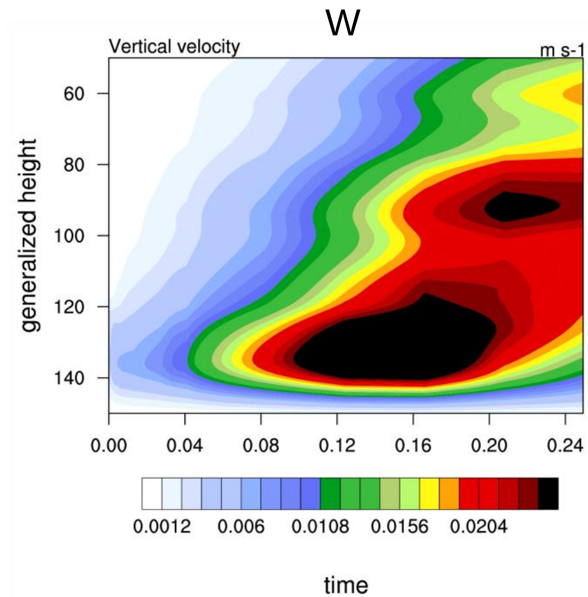
300m

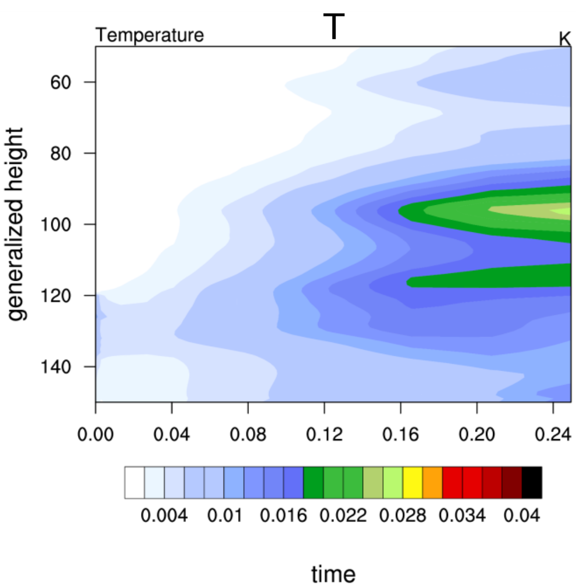


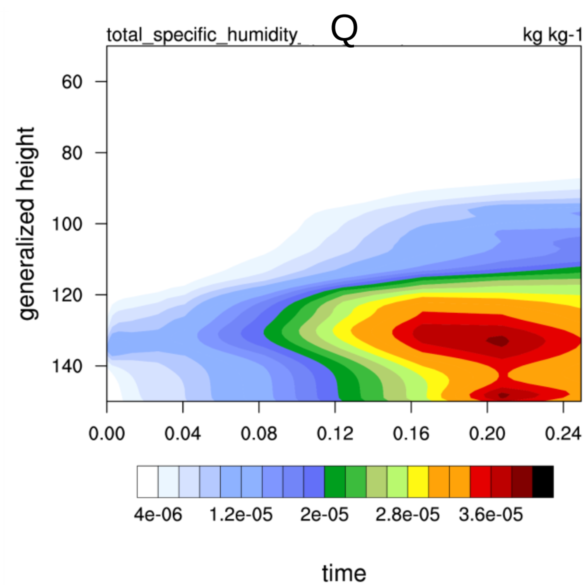
U, V, W, T, Q diff between two simulations











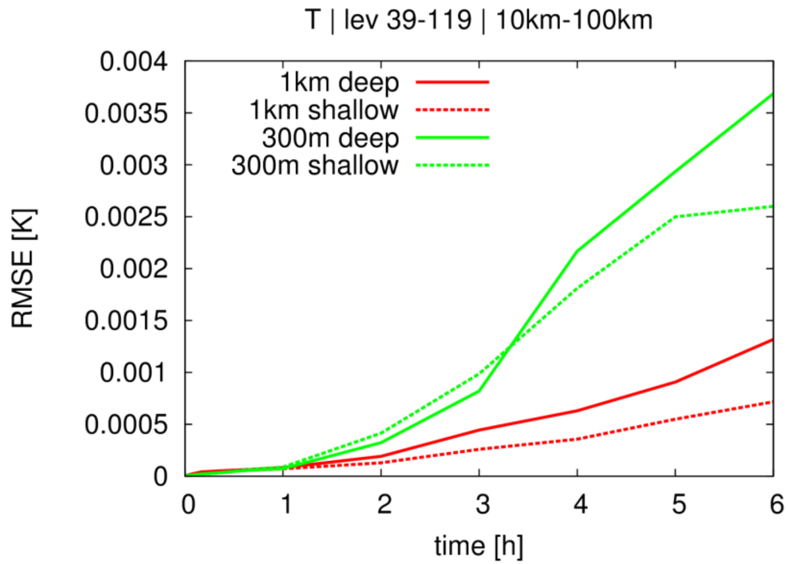
Full Domain
300m

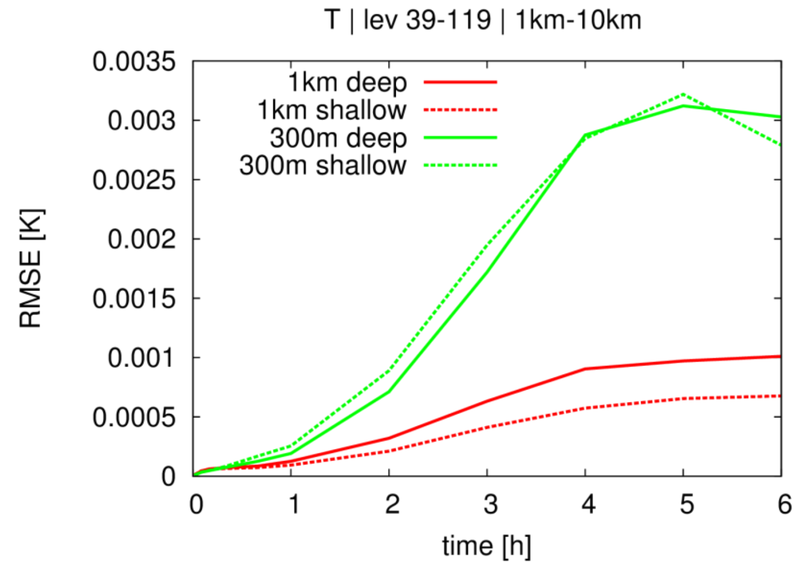
RMSE(T_{pert}-T_{ctrl})

10-100km Scale

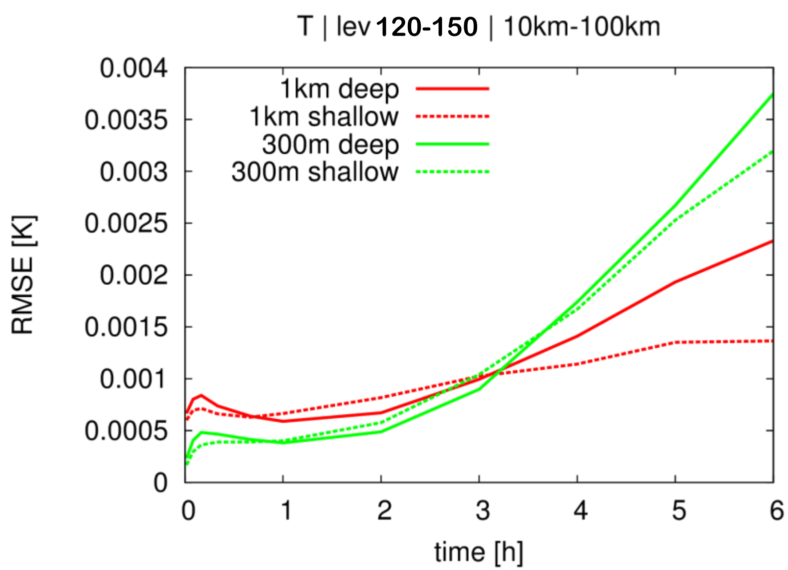
1-10km Scale

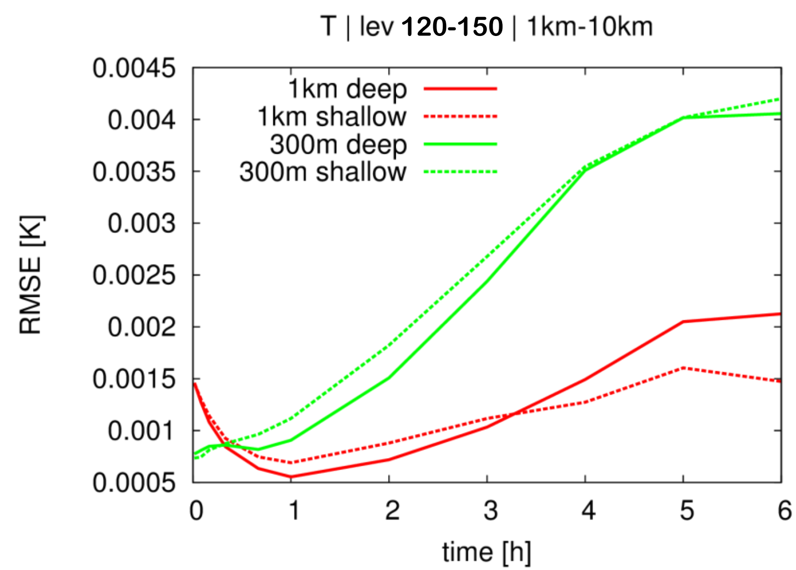
Above PBL





In PBL



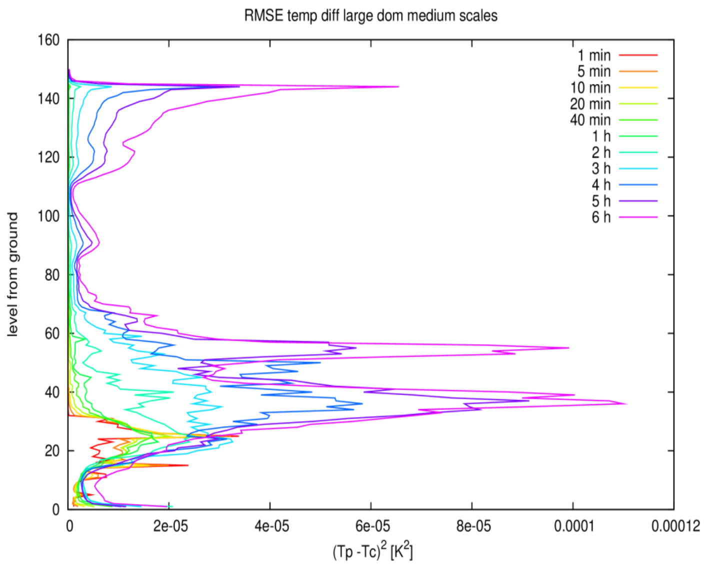


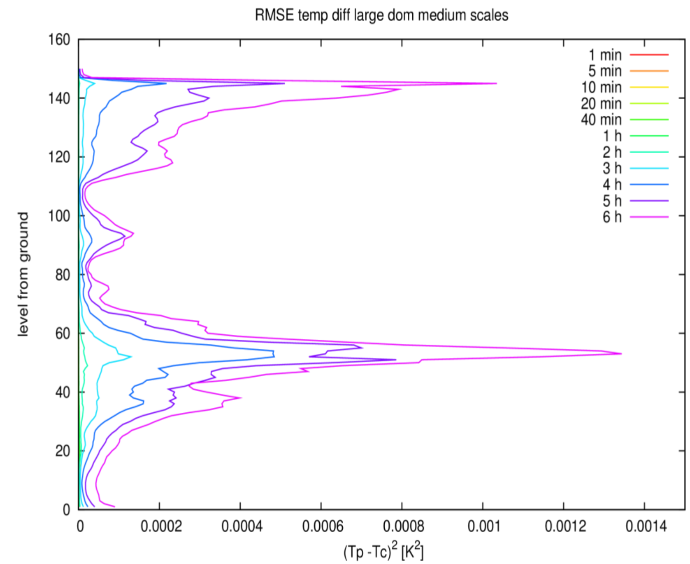
$(T_{pert}-T_{ctrl})^2$

1249m resolution

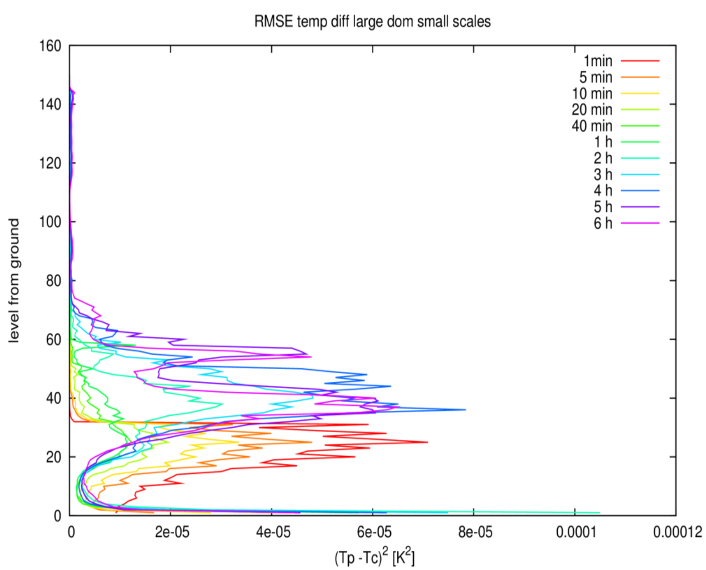
312m resolution

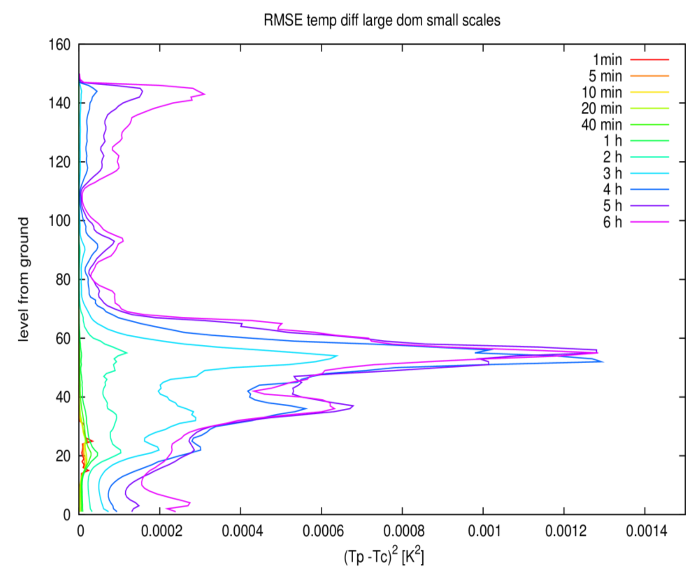
10-100km scale





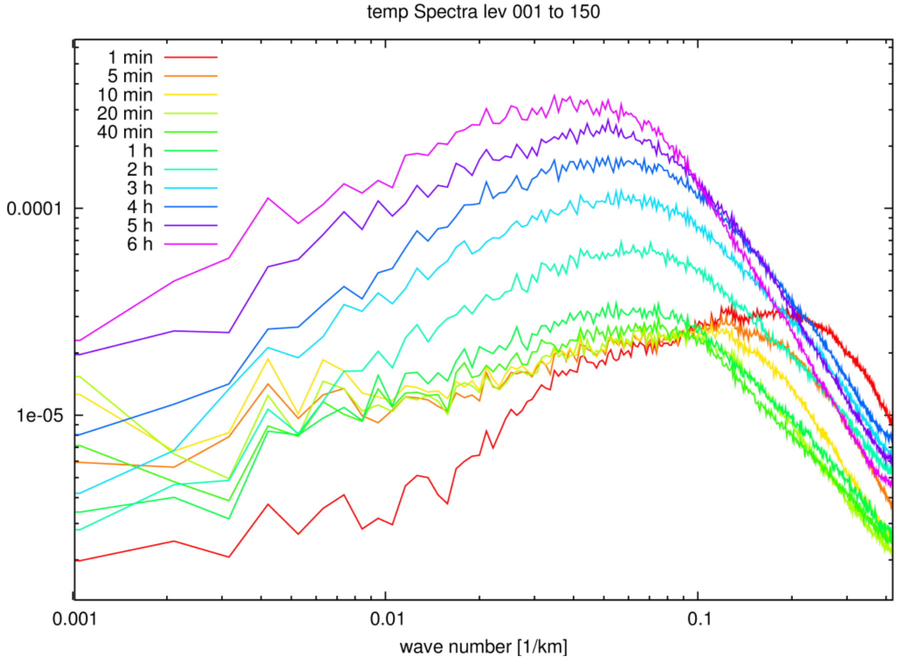
1-10km scale





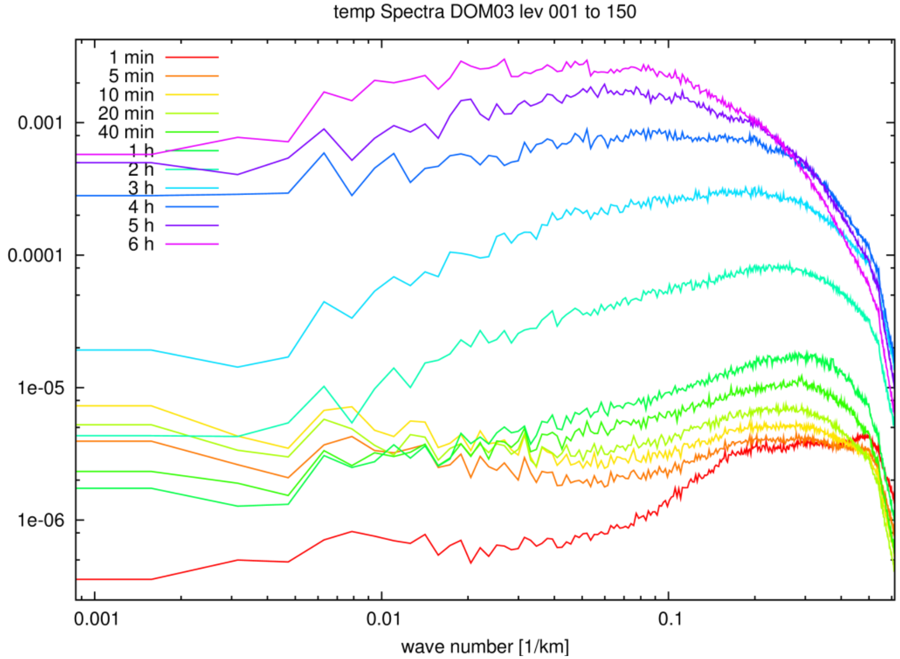
T diff spectra (vertical mean)

1249m resolution



1000km 100km 10km

312m resolution



1000km 100km 10km

Conclusions

- Resolution O(1000m) underestimates convective error growth rate
- Convective error growth (Zhang stage 1) has three phases
  - **5min**: fast upscale cascade of initial grid-scale uncertainty (maybe by sound and gravity waves)
  - **5min-1hour**: convective growth at scales of 1-10km
  - **1-6hours**: upward error growth to scales of 100km (gravity waves)
- Future Work: Anvil (ICON-LES, ICON parameterized – macro/micro-scales)

Height of coordinate half levels and layer thickness [m]

1	21000.000	419.907
2	20580.093	359.250
3	20220.842	337.152
4	19883.690	322.457
5	19561.233	311.208
6	19250.025	301.972
7	18948.053	294.062
8	18653.991	287.096
9	18366.896	280.839
10	18086.057	275.135
11	17810.922	269.876
12	17541.046	264.983
13	17276.063	260.399
14	17015.664	256.077
15	16759.587	251.983
16	16507.604	248.087
17	16259.517	244.367
18	16015.150	240.804
19	15774.345	237.382
20	15536.964	234.086
21	15302.878	230.906
22	15071.972	227.832
23	14844.140	224.855
24	14619.285	221.967
25	14397.318	219.162
26	14178.157	216.434
27	13961.723	213.777
28	13747.946	211.188
29	13536.758	208.661
30	13328.096	206.194
31	13121.902	203.782
32	12918.120	201.423
33	12716.698	199.113
34	12517.585	196.850
35	12320.736	194.631
36	12126.104	192.455
37	11933.649	190.320
38	11743.329	188.222
39	11555.107	186.162
40	11368.946	184.136
41	11184.810	182.144
42	11002.666	180.183
43	10822.483	178.254
44	10644.229	176.354
45	10467.876	174.482
46	10293.394	172.637
47	10120.757	170.818
48	9949.939	169.025
49	9780.914	167.255
50	9613.659	165.509
51	9448.150	163.785
52	9284.365	162.083
53	9122.282	160.402
54	8961.880	158.740
55	8803.140	157.099
56	8646.041	155.475
57	8490.566	153.870
58	8336.695	152.283
59	8184.412	150.712
60	8033.700	149.158
61	7884.542	147.619
62	7736.923	146.096
63	7590.827	144.588
64	7446.239	143.093
65	7303.146	141.613
66	7161.533	140.146
67	7021.387	138.692
68	6882.696	137.250
69	6745.445	135.820
70	6609.625	134.403
71	6475.222	132.996
72	6342.226	131.600
73	6210.626	130.215
74	6080.411	128.840
75	5951.571	127.475
76	5824.097	126.119
77	5697.978	124.772
78	5573.206	123.434
79	5449.772	122.105
80	5327.667	120.783
81	5206.884	119.470
82	5087.414	118.164
83	4969.251	116.865
84	4852.386	115.573
85	4736.813	114.287
86	4622.526	113.008
87	4509.518	111.735
88	4397.783	110.467
89	4287.317	109.205
90	4178.112	107.947
91	4070.165	106.695
92	3963.470	105.447
93	3858.023	104.203
94	3753.820	102.963
95	3650.857	101.726
96	3549.131	100.493
97	3448.638	99.262
98	3349.376	98.034
99	3251.342	96.809
100	3154.533	95.585
101	3058.948	94.363
102	2964.585	93.142
103	2871.443	91.922
104	2779.521	90.702
105	2688.819	89.483
106	2599.336	88.263
107	2511.073	87.043
108	2424.030	85.822
109	2338.208	84.599
110	2253.610	83.374
111	2170.236	82.147
112	2088.089	80.917
113	2007.172	79.683
114	1927.490	78.445
115	1849.044	77.203
116	1771.841	75.956
117	1695.885	74.703
118	1621.182	73.443
119	1547.739	72.176
120	1475.563	70.901
121	1404.662	69.617
122	1335.045	68.324
123	1266.721	67.019
124	1199.702	65.703
125	1133.999	64.373
126	1069.626	63.029
127	1006.596	61.670
128	944.926	60.293
129	884.634	58.897
130	825.737	57.479
131	768.258	56.039
132	712.219	54.572
133	657.647	53.077
134	604.570	51.550
135	553.020	49.987
136	503.033	48.384
137	454.648	46.736
138	407.912	45.037
139	362.876	43.278
140	319.598	41.450
141	278.147	39.543
142	238.605	37.540
143	201.064	35.423
144	165.641	33.165
145	132.476	30.726
146	101.750	28.051
147	73.700	25.044
148	48.655	21.534
149	27.121	17.121
150	10.000	10.000
151	0.000	0.000