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FAKULTÄT FÜR PHYSIK
METEOROLOGIE

Upscale error growth in simulations with resolved and (stochastically) parametrized convection: A comparison

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Outline

Motivation

Upscale error growth from convective uncertainty:
A three stage conceptual model

Results from convection permitting simulations - the “truth”

Results from simulations with parametrized convection:

- Tiedtke convection scheme
- Plant-Craig stochastic convection scheme

Summary and Outlook

Motivation

Atmospheric predictability is basically limited by two major instabilities:

Baroclinic instability

Scale: 1.000km
Predictability: several days

Downscaling →
limited area models

← upscale growth
?

Convective instability

Scale: 10km
Predictability: few hours

- Individual convective cells are intrinsically unpredictable after a few hours (Hohenegger and Schär, 2007)
- From a large-scale perspective convection is a random process
- Global ensemble forecasts that just cover initial condition uncertainty are underdispersive
- Importance of upscale transfer of convective uncertainty is unknown

3-stage upscale error growth model (Zhang et al., 2007)

- Case study on an **idealized** baroclinic wave with “high resolution model” (10km)
- Perturbation with small-scale noise on the temperature field

Three-stage error-growth model:

Stage 1: (convective scale)
Rapid growth in precip. areas, random displacement of cells — 0-6h

↓

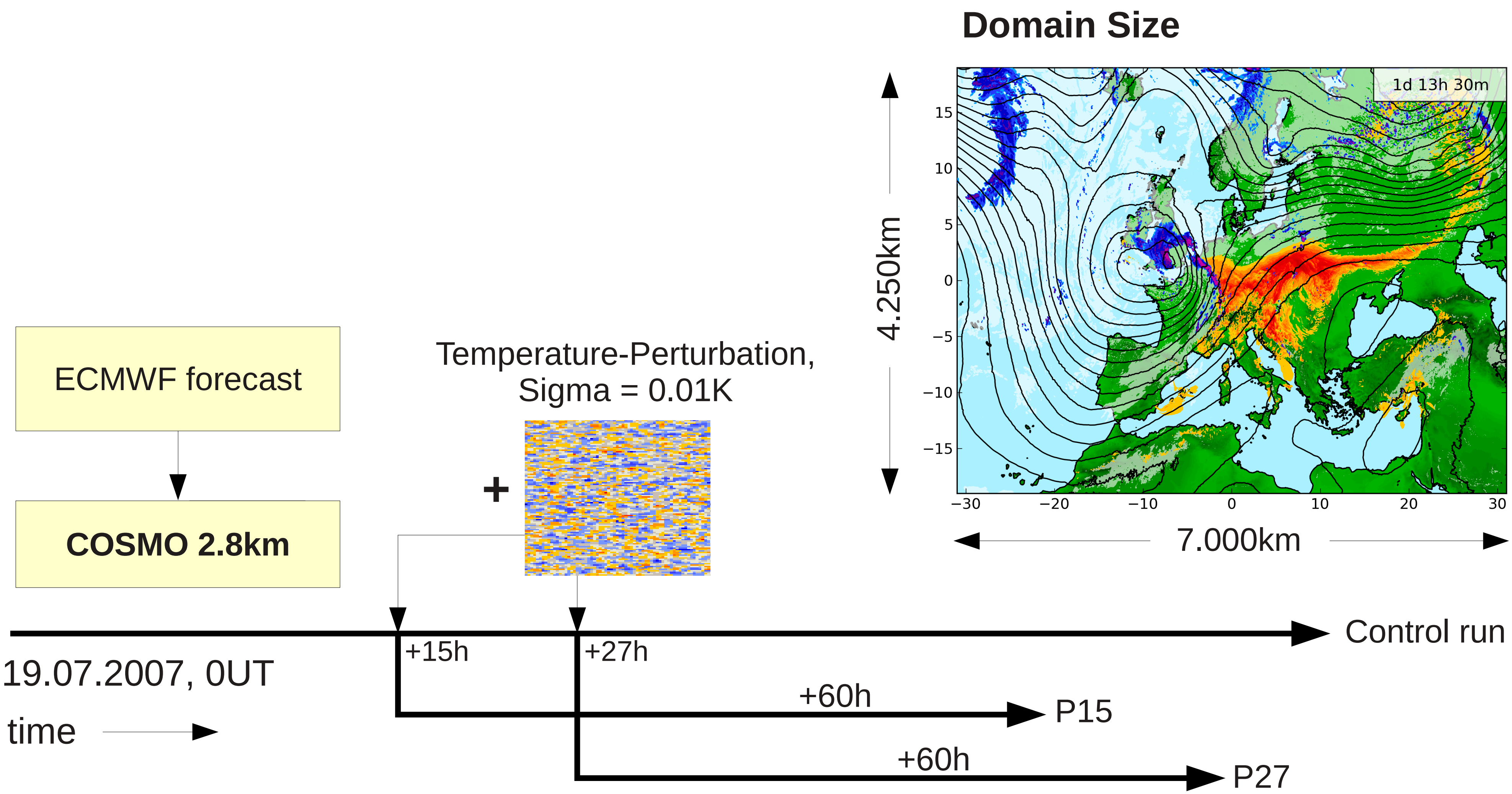
Stage 2:
Transition by gravity waves and adjustment — 3-18h

↓

Stage 3: (synoptic scale)
Baroclinic growth — >12h

Results from convection-permitting error growth simulations

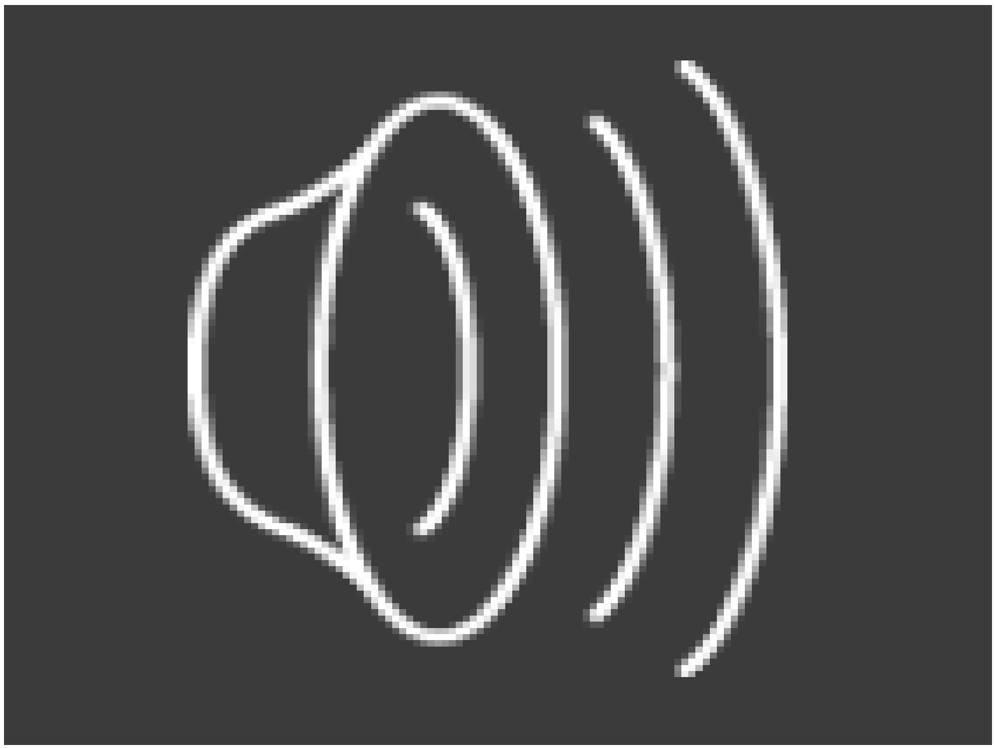
Set-up of convection permitting experiment



- Diagnostics will be averaged over both perturbation experiments
- Animations will show the first perturbation experiment (P15)

Stage 1: Convective Instability and Saturation

Subdomain:



Colored lines:
v difference (P15-ctl)
at 500hPa

Blue shading:
Precipitation (ctl)

Yellow shading:
High CAPE (ctl)

Black lines:
500hPa Geopot. (Ctl)

- Rapid error growth in precipitation regions
- Quick saturation due to complete displacement of convective cells

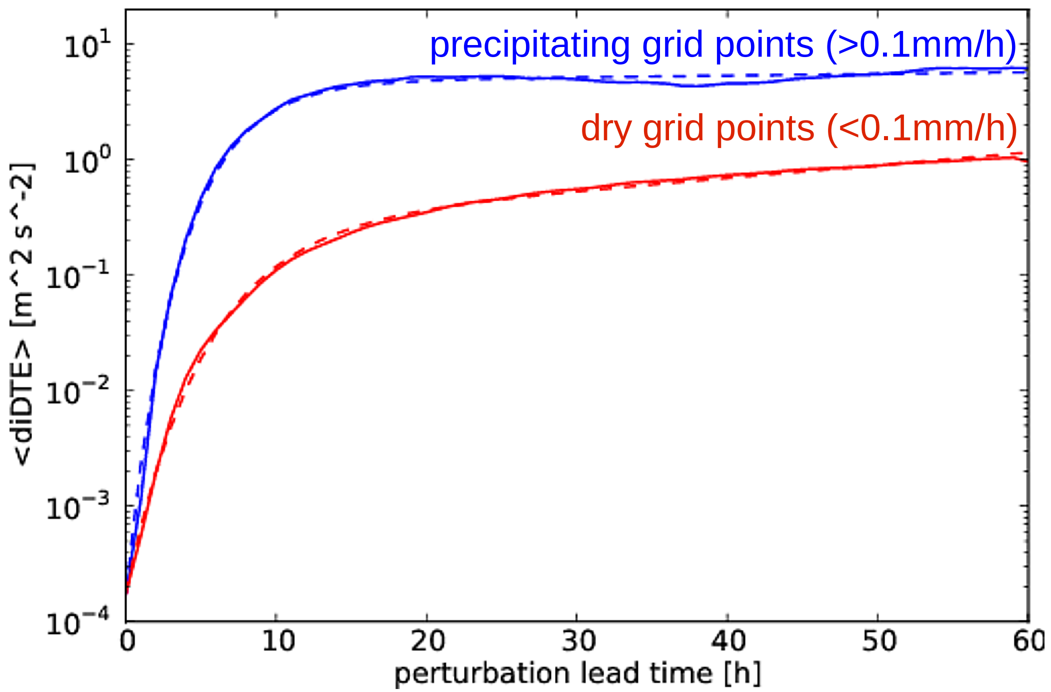
Unfortunately, the animations do not work with pdf. If you are interested in them please contact: tobias.selz@lmu.de

Stage 1: Convective Instability and Saturation

Difference Total Energy (DTE):

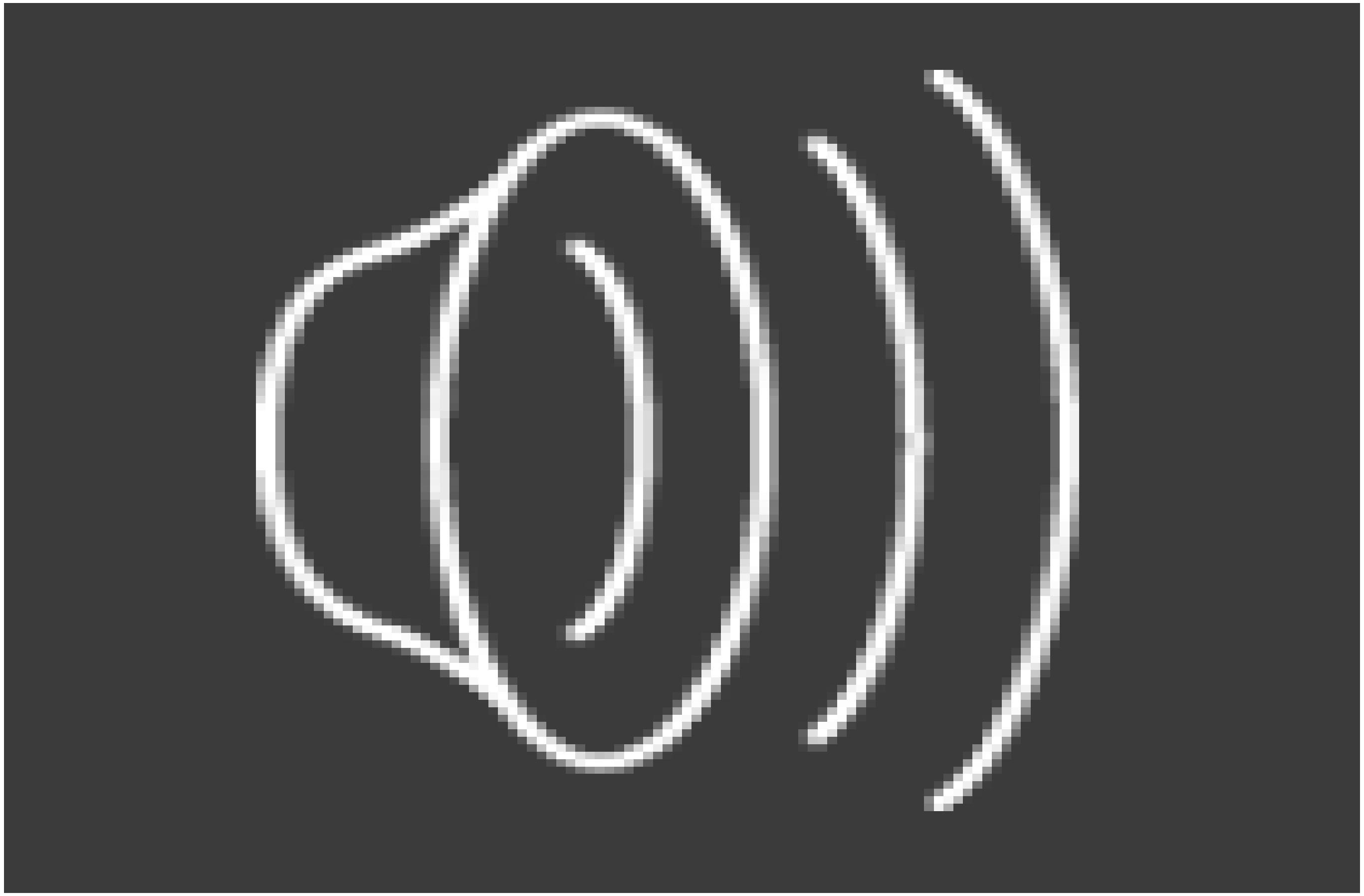
$$DTE := \Delta u^2 + \Delta v^2 + \frac{c_p}{T_0} \Delta T^2$$

Integrate DTE separately over precipitating and non-precipitating gridpoints:



- Much faster error growth in precipitating areas
- Clear saturation after about 10 hours
- Saturation due to complete displacement of individual convective cells

Stage 2: Transition and adjustment



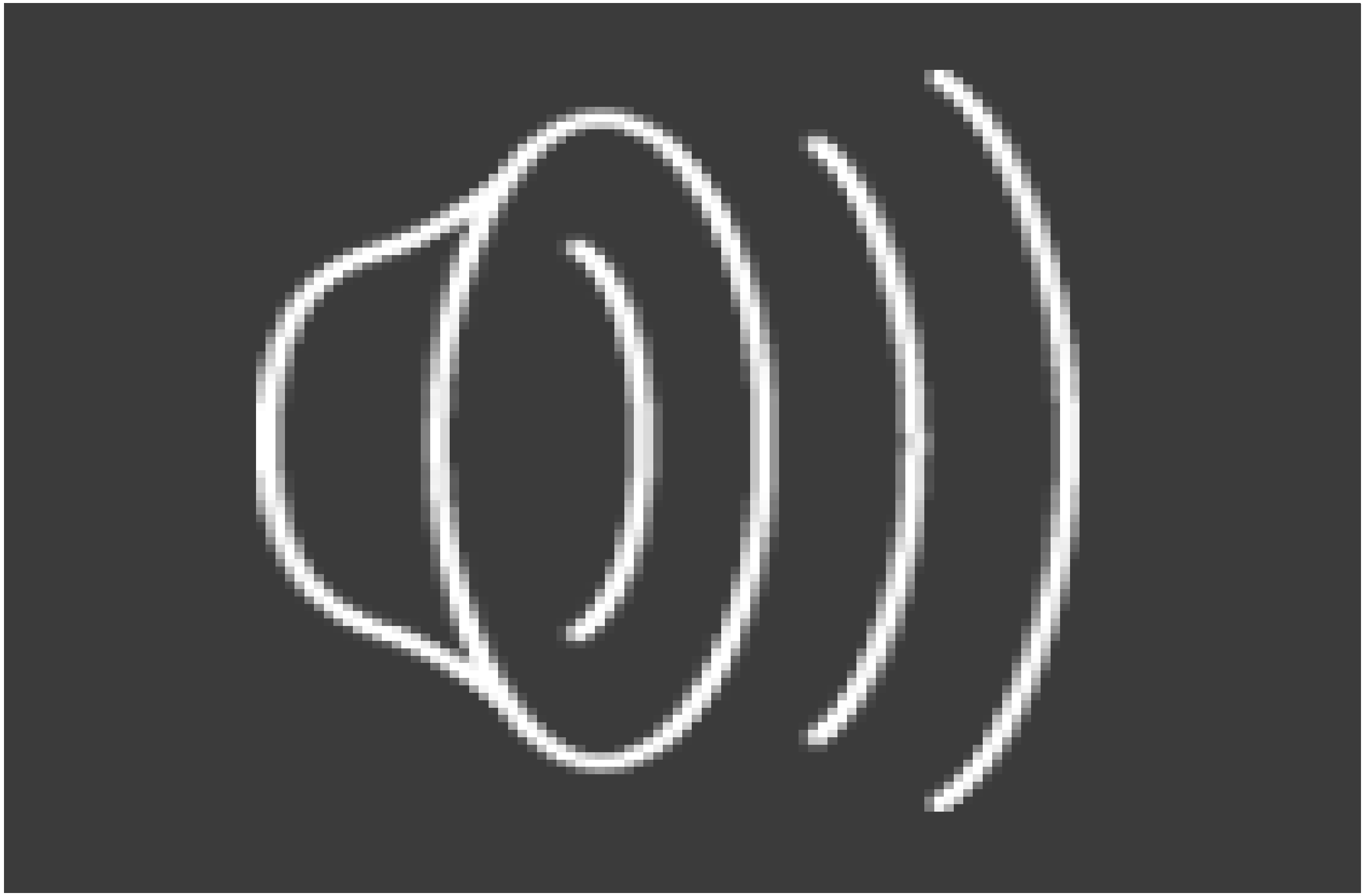
yellow shading:
log(DTE), 500hPa

blue shading:
precipitation (ctl)

black lines:
500hPa geopotential (ctl)

- Gravity waves in the difference field spread out from convective areas
- They may get trapped by the earth's rotation and spin up balanced motions

Stage 3: Baroclinic error growth



yellow shading:
log(DTE), 500hPa

colored lines:
500hPa geopotential difference (Δ=5m²/s²)

blue shading:
precipitation (ctl)

black lines:
500hPa geopotential (ctl) (Δ=250m²/s²)

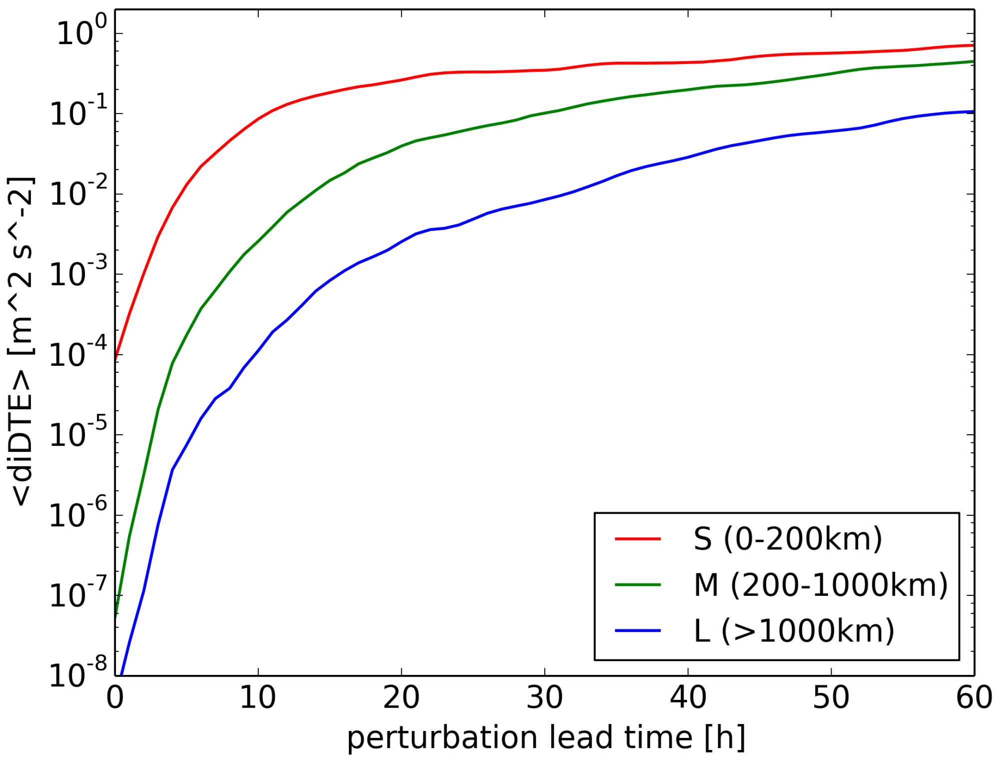
A large-scale perturbation develops and grows driven by baroclinic instability

Difference total energy

Difference Total Energy (DTE):

$$DTE := \Delta u^2 + \Delta v^2 + \frac{c_p}{T_0} \Delta T^2$$

Separate three scales and integrate DTE over whole domain:



- Fast initial growth and saturation at small scales
- Continuous error growth at large scales until the end of our simulation

Rossby number diagnostic

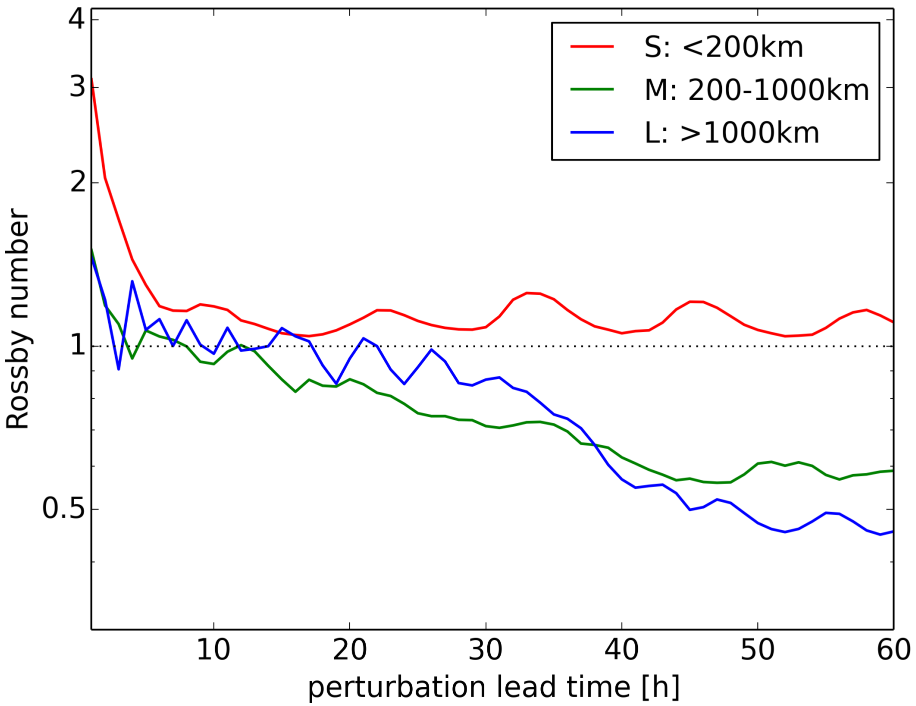
Norm of divergence and vorticity of the horizontal **difference** wind

$$\|\Delta D, \Delta \zeta\| = \frac{1}{V} \int dV (\Delta D)^2, (\Delta \zeta)^2$$

Rossby number from square root of ratio:

$$Ro = \sqrt{\frac{\langle \|\Delta D\| \rangle}{\langle \|\Delta \zeta\| \rangle}} = \frac{RMS(D)}{RMS(\zeta)}$$

➔ Provides a measure for the degree of balance in the difference field



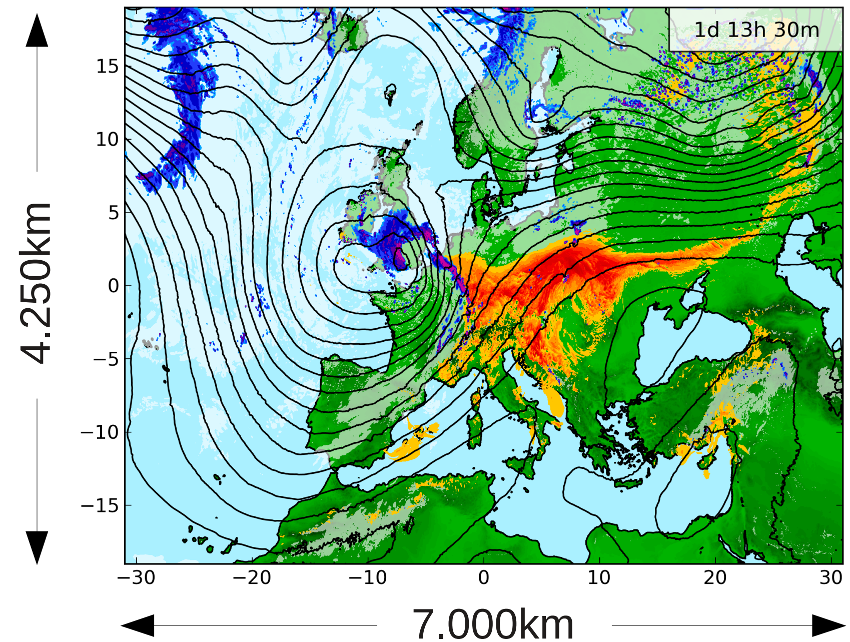
- Large-scale baroclinic growth after 24 hours indicated by drop of large-scale Rossby number
- Medium-scale Rossby number drops earlier

➔ Indicates upscale error growth

What happens
when the resolution is reduced?

Set-up of lower resolution experiments

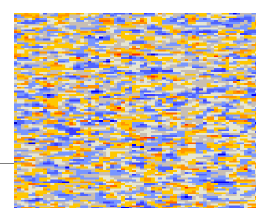
Domain Size



ECMWF forecast

COSMO
7km, 14km, 28km
Tiedtke conv. scheme

Temperature-Perturbation,
Sigma = 0.01K

+ 

19.07.2007, 0UT

time →

+15h

+27h

Control run

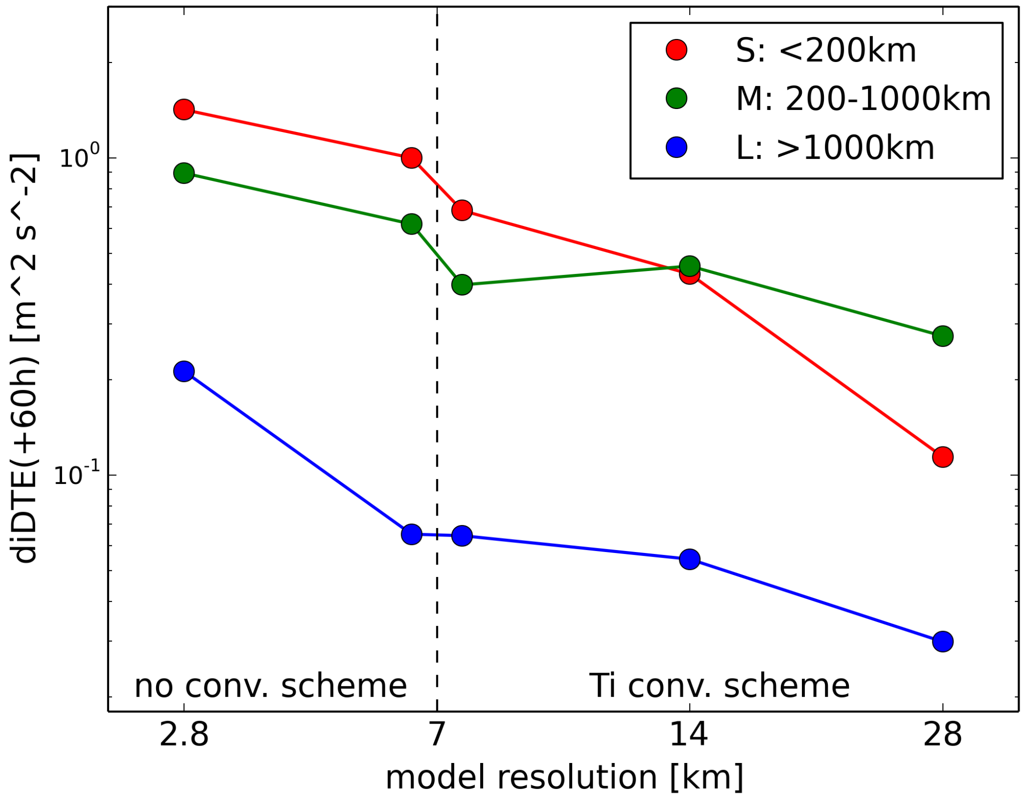
+60h

P15

+60h

P27

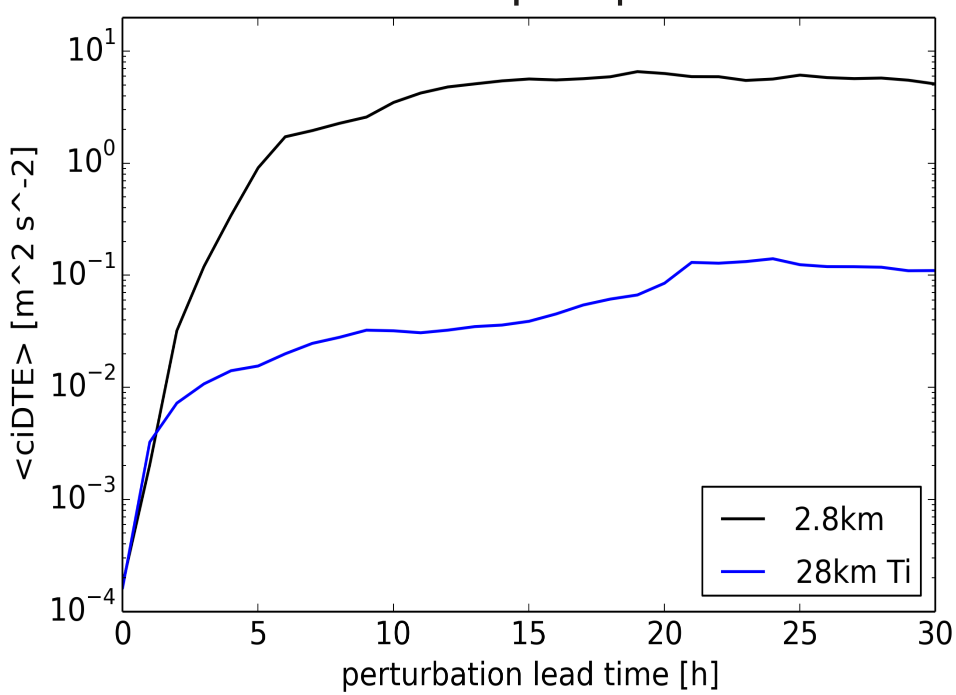
DTE after 60h perturbation lead time



- Strongly reduced upscale error growth at all coarser resolutions
- Overconfidence with respect to upscale growth of convective uncertainty

Probable reasons for reduced upscale growth

DTE, integrated over areas with convective precipitation



Stage 1:

Rapid growth in precip. areas, random displacement of cells

Stage 2:

Transition by gravity waves and adjustment

Stage 3:

Baroclinic growth

Coarser simulations fail to simulate stage 1:
No or too weak convective cells present
“It drizzles everywhere”

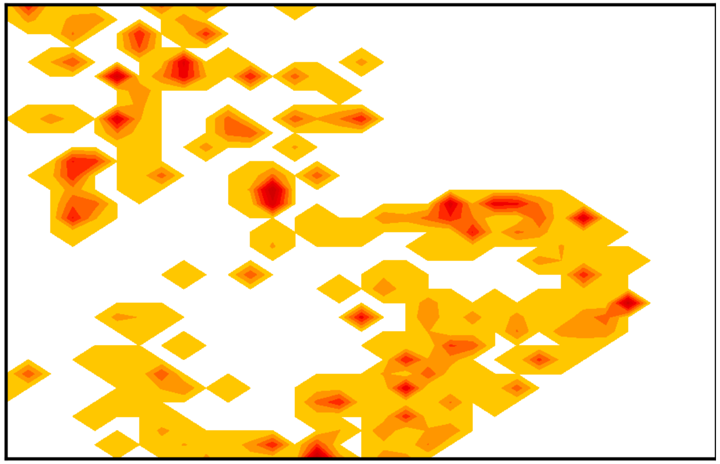
Possible solution:
Stage 1 needs to be parametrized

Can we parameterize “Stage 1”?

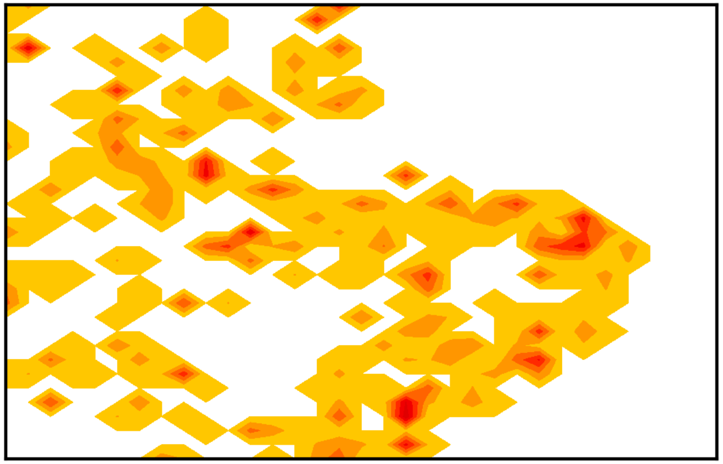
The Plant-Craig stochastic convection scheme

- The Plant-Craig stochastic convection scheme draws clouds randomly from a distribution
- The properties of the distribution are determined by convective instability (at larger scales)

Draw some clouds...



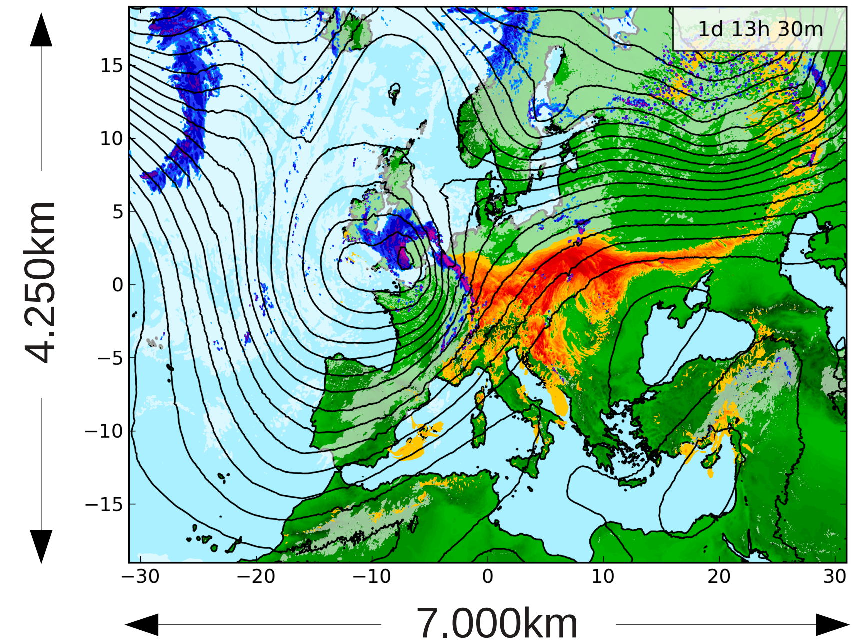
Draw again...

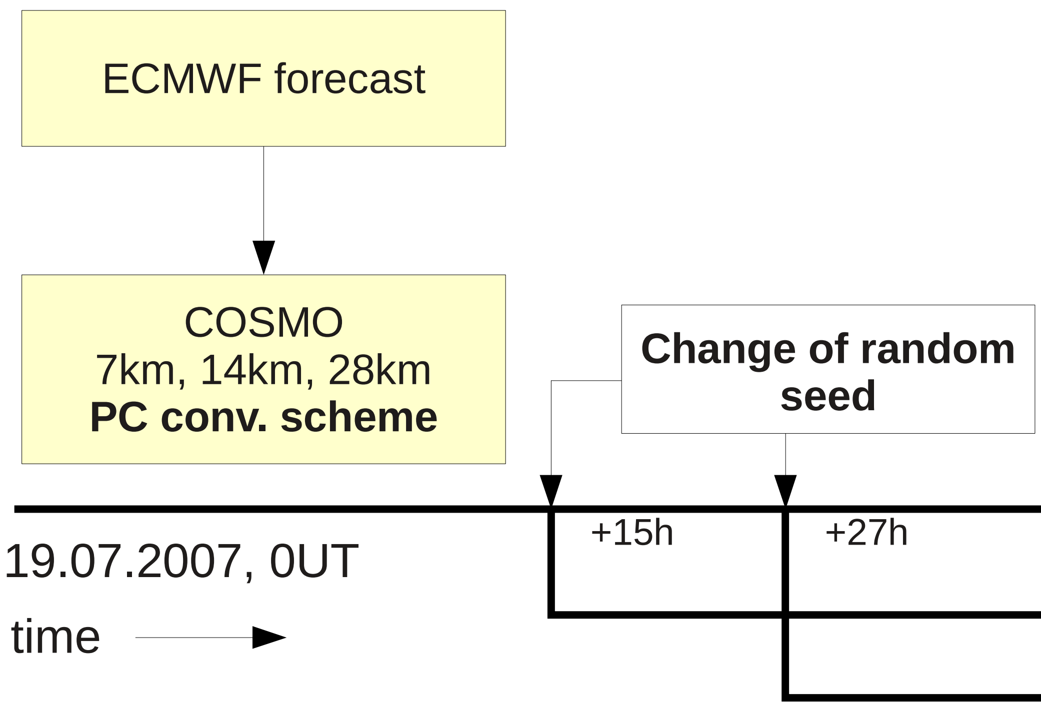


Change of the random seed in the PC-scheme seems appropriate to parametrize “Stage 1”

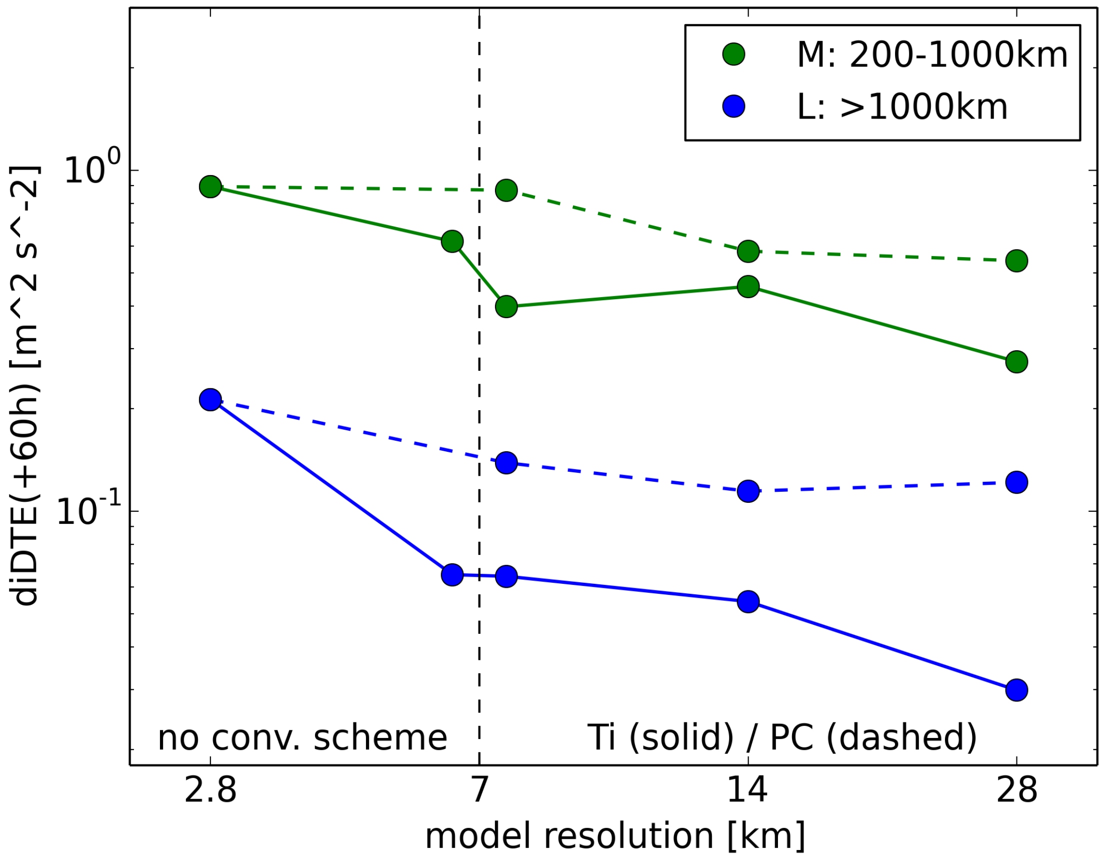
Set-up of Plant-Craig convection scheme experiments

Domain Size





DTE after 60h perturbation lead time



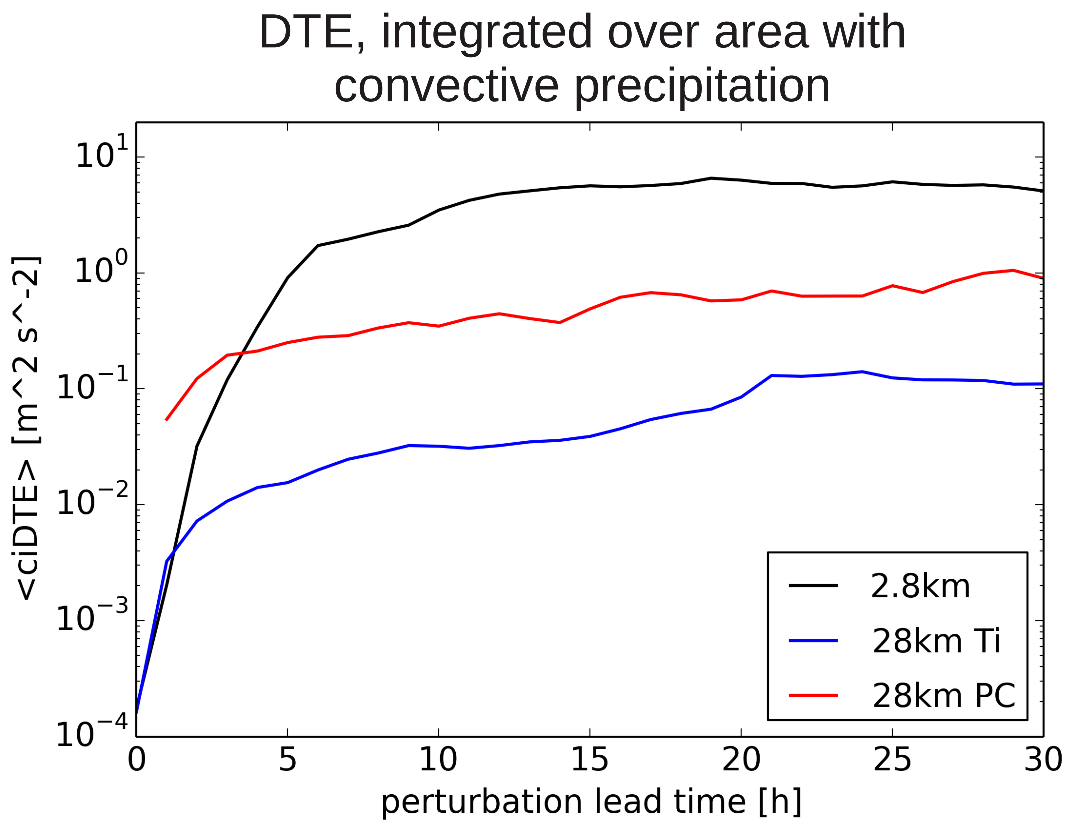
- Much improved upscale error growth
- Significant reduction of the overconfidence

Further comparison of the highest and the lowest resolution

HR = 2.8km resolution without convection scheme

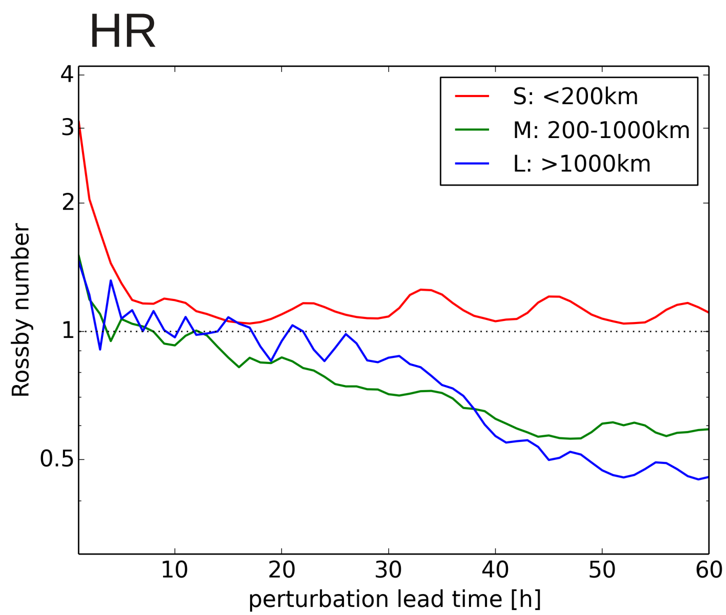
LR-Ti = 28km resolution with Tiedtke convection scheme

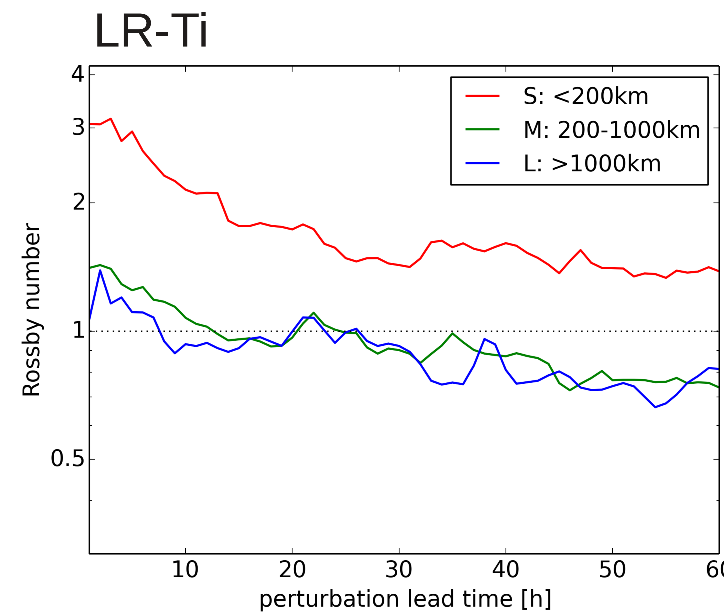
LR-PC = 28km resolution with Plant-Craig convection scheme

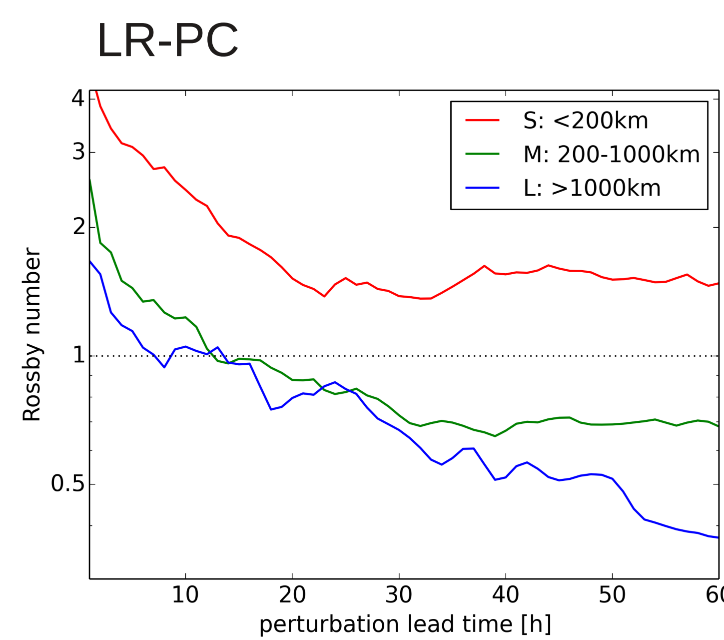


- Higher variability of cloud sizes in the PC scheme
- Much larger DTE in the parameterized clouds with PC than with Tiedtke

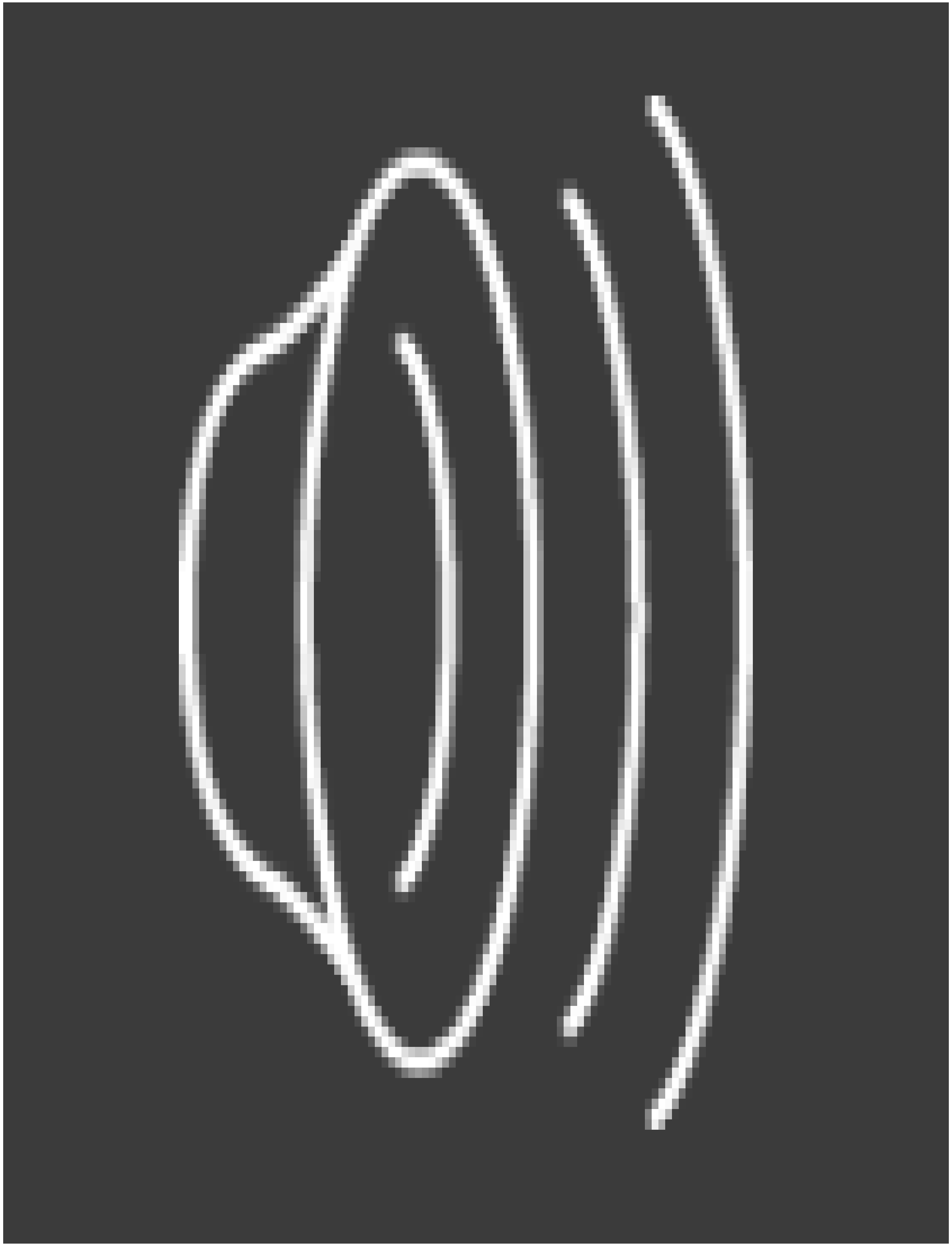
Rossby number diagnostic







- LR simulations show stronger divergent component at small scales
- Drop of large-scale Rossby number is even more pronounced in LR-PC than in HR
- Medium-scale Rossby number is initially much higher in LR-PC than in LR-Ti and HR



yellow shading:
log(DTE), 500hPa

colored lines:
500hPa geopotential difference (Δ=5m²/s²)

blue shading:
precipitation (ctl)

black lines:
500hPa geopotential (ctl) (Δ=250m²/s²)

Gravity waves present in both simulations

Similar structure and amplitude in DTE

yellow shading:
log(DTE), 500hPa

colored lines:
500hPa geopotential difference (Δ=5m²/s²)

blue shading:
precipitation (ctl)

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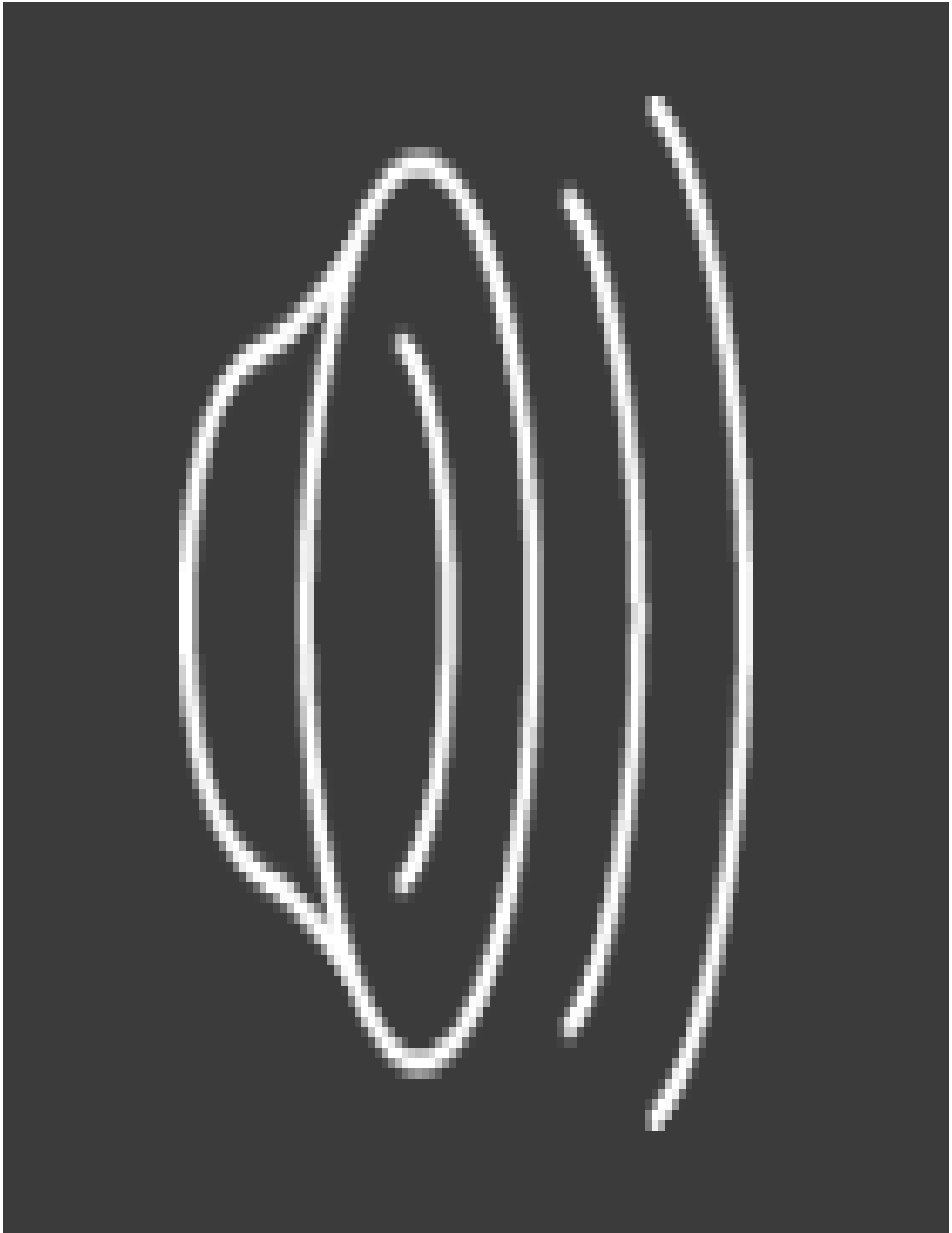

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Significantly amplified final large-scale perturbation of PC compared to Tiedtke

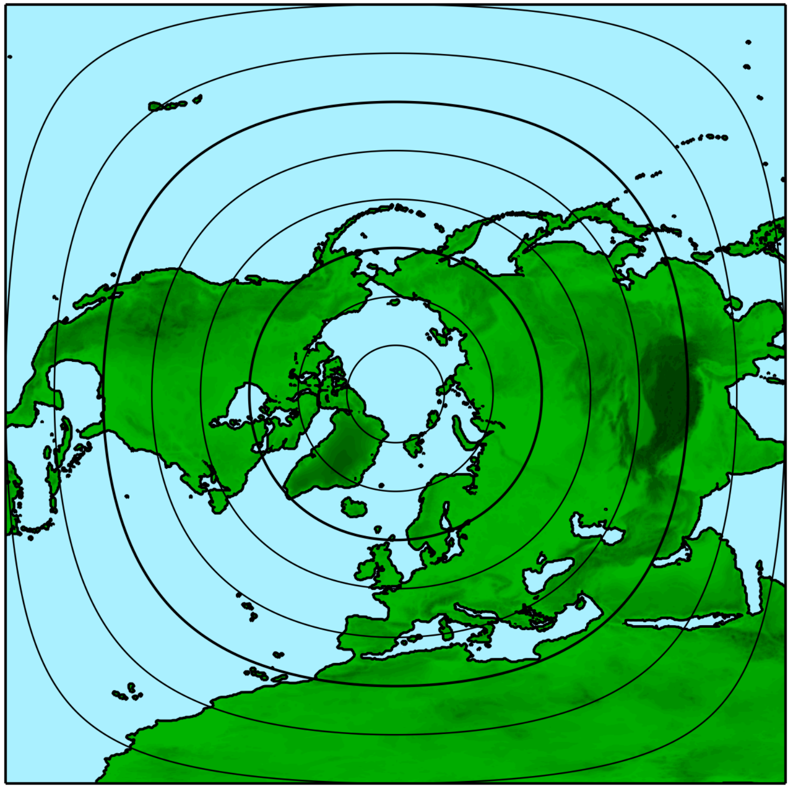
Summary

- Coarser resolution models loose the ability to simulate upscale growth from convective uncertainty -> overconfidence
- Stage 1 of the error growth model has to be parametrized. This can be done physically based e.g. with the Plant-Craig scheme
- The Plant-Craig scheme eliminates most of the overconfidence and produces large-scale perturbations that are similar to the HR run at all tested resolutions (7-28km)
- Further evidence that gravity waves play an important role in upscale error growth

Outlook

28km resolution permits much larger domains:
e.g. the whole northern hemisphere with COSMO or **ICON**?

- Study upscale error growth over a week or more: Whole range from displacement of convection to displacement of Rossby wave
- How important is upscale error growth from convective uncertainty?
- Compare ensembles with Tiedtke and PC: What is the impact on the spread?
- Compare ensembles with SPPT-scheme and PC: How much spread is coming from convection?



Thank you for your attention!