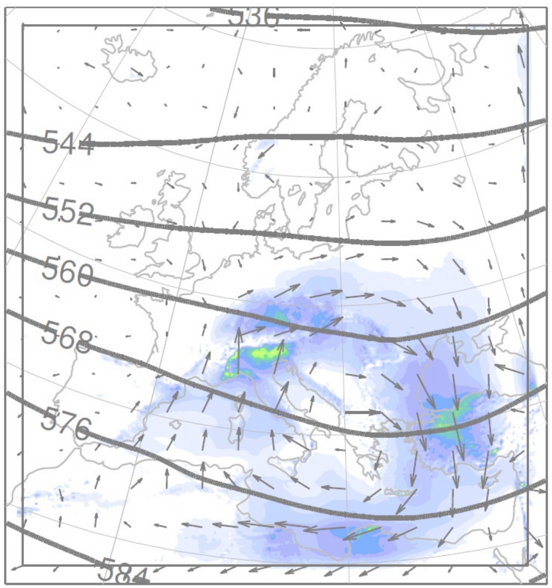

Large-scale secondary circulations in the COSMO-CLM

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COSMO / CLM / ART User Seminar 2016
Offenbach, 09.03.2016

Motivation

What is the aim of an RCM?

- "[...] having **fine-scale features** at scales that are absent in the initial and lateral boundary conditions." *(Antic 2004)*

However...

- RCM simulations also show **large-scale deviations** from the driving data!
- Controversial discussion whether this is desired in RCMs *(e.g. von Storch et al. 2000)*
  - ➔ RCMs are able to improve the large scales *(Diaconescu et al. 2013)*
  - ➔ But large-scale deviations can cause **problems at the lateral boundaries**

Which mechanisms are responsible for large-scale deviations of RCMs from their driving data?

Outline

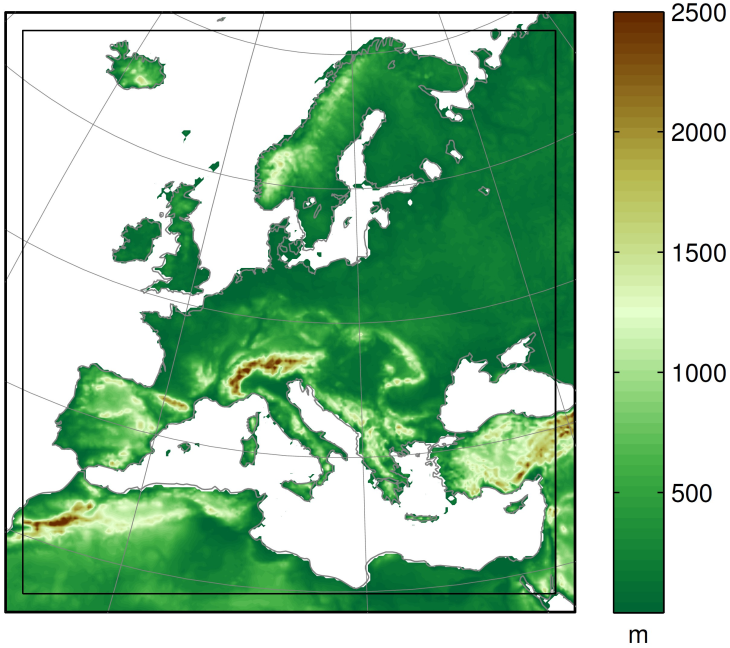
1) Splitting of the RCM wind fields

→ Definition of the **Primary** and **Secondary Circulation (SC)**

2) Does the SC depend on the large-scale flow?

RCM
40-year CLM3 simulation
(consortial simulations, Hollweg et al. 2008)
Resolution: 0.165° (~18 km)

GCM
ECHAM5/MPIOM
(Roeckner et al. 2006)
Resolution: T63 (~200 km)



3) Does the SC depend on the location of the lateral boundaries

CCLM 4.8 ensemble simulations with different model configurations

1.1 Splitting of the RCM wind fields

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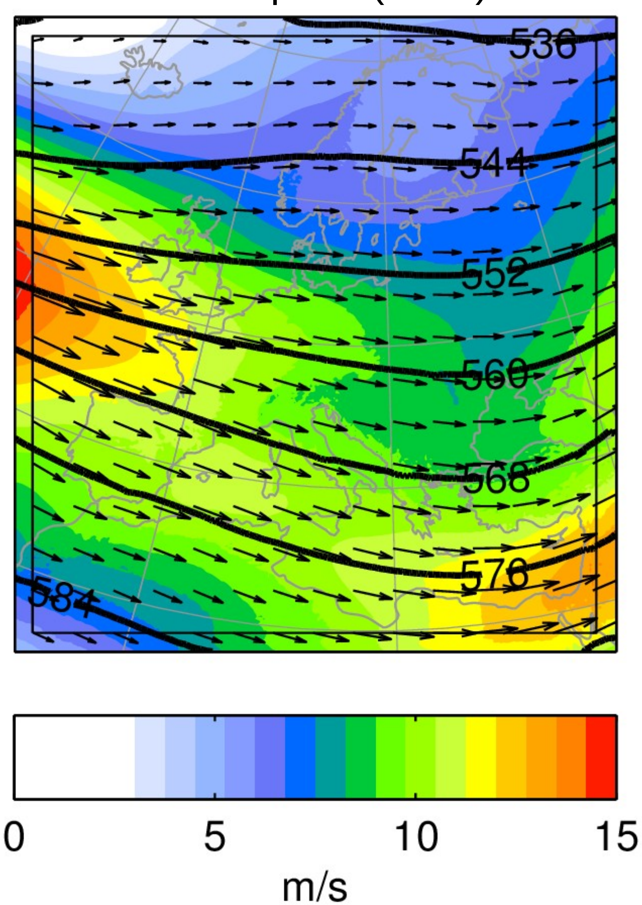
$$\vec{v}_{RCM} = \vec{v}_{GCM} + \vec{v}_{sec}$$

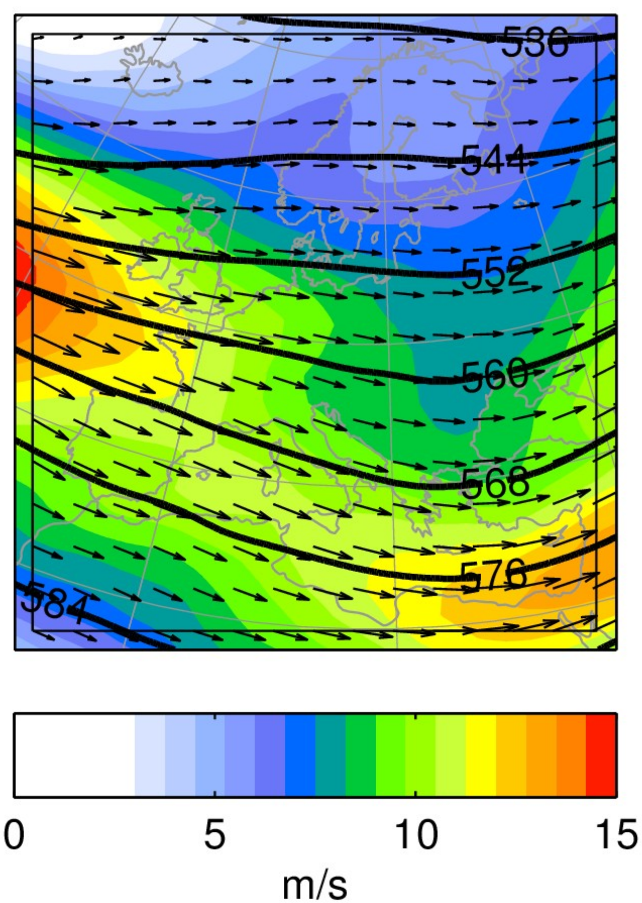
RCM = **Primary Circulation** + **Secondary Circulation**

40-year average at 500 hPa

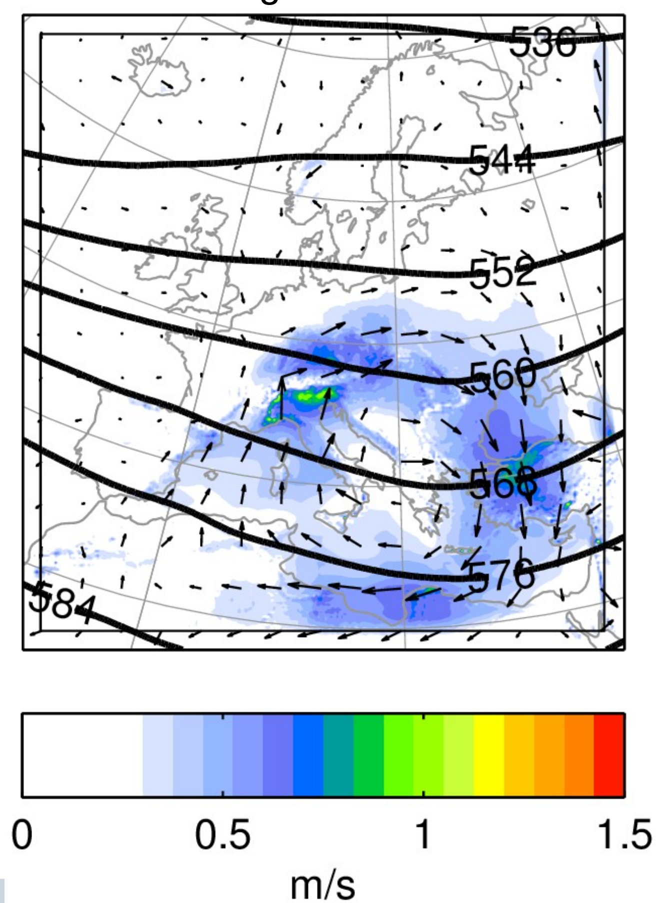
Geopot. height (RCM)
Wind vectors (RCM)
Wind speed (RCM)



Geopot. height (GCM)
Wind vectors (GCM)
Wind speed (GCM)



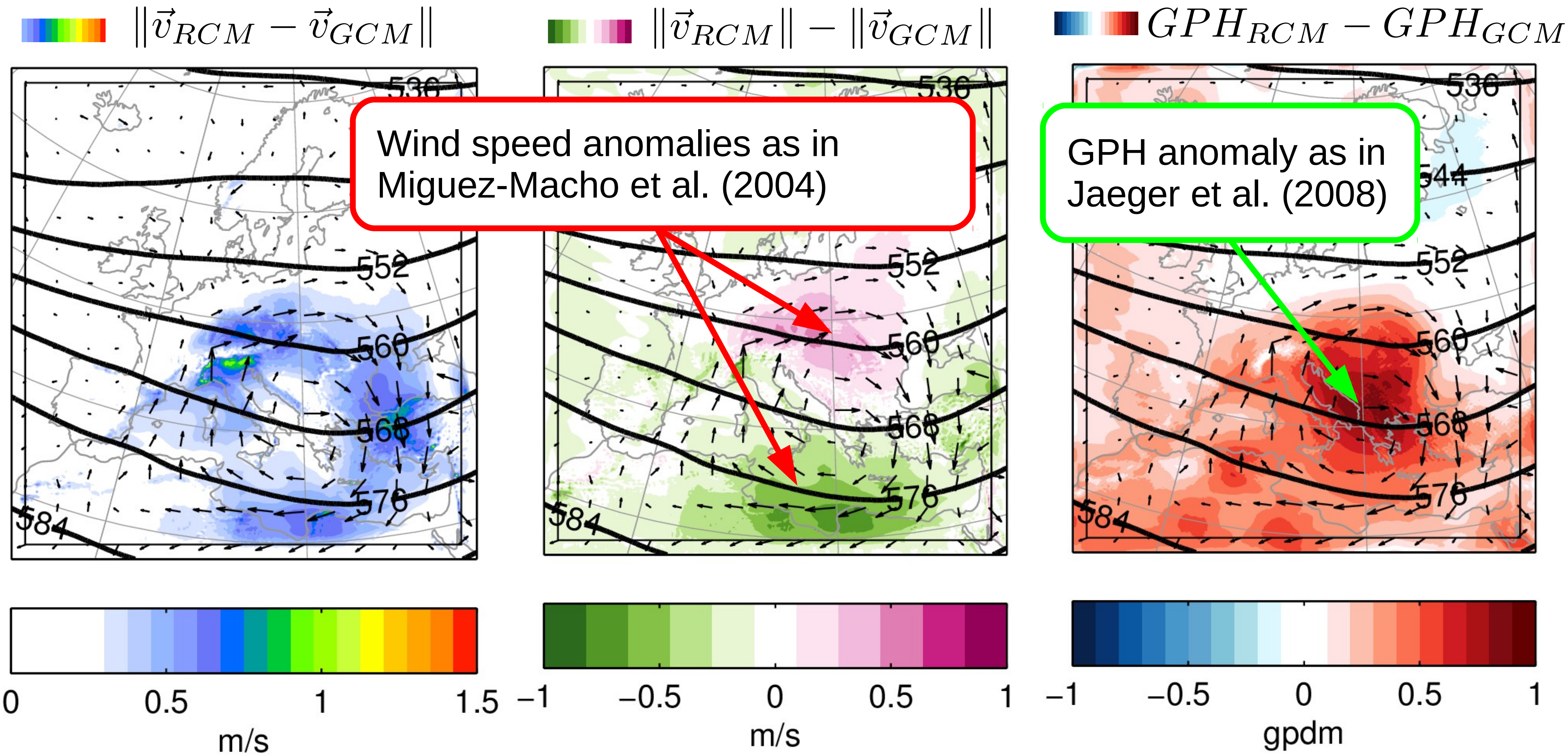
Geopot. height (GCM)
Secondary circulation
Strength of SC



1.2 The Secondary Circulation

40-year average at 500 hPa

- Geopotential height (GCM) → Primary circulation
- Wind vector difference (RCM-GCM) → Secondary circulation



2.1 Clustering approach

Does the secondary circulation depend on the large-scale flow?

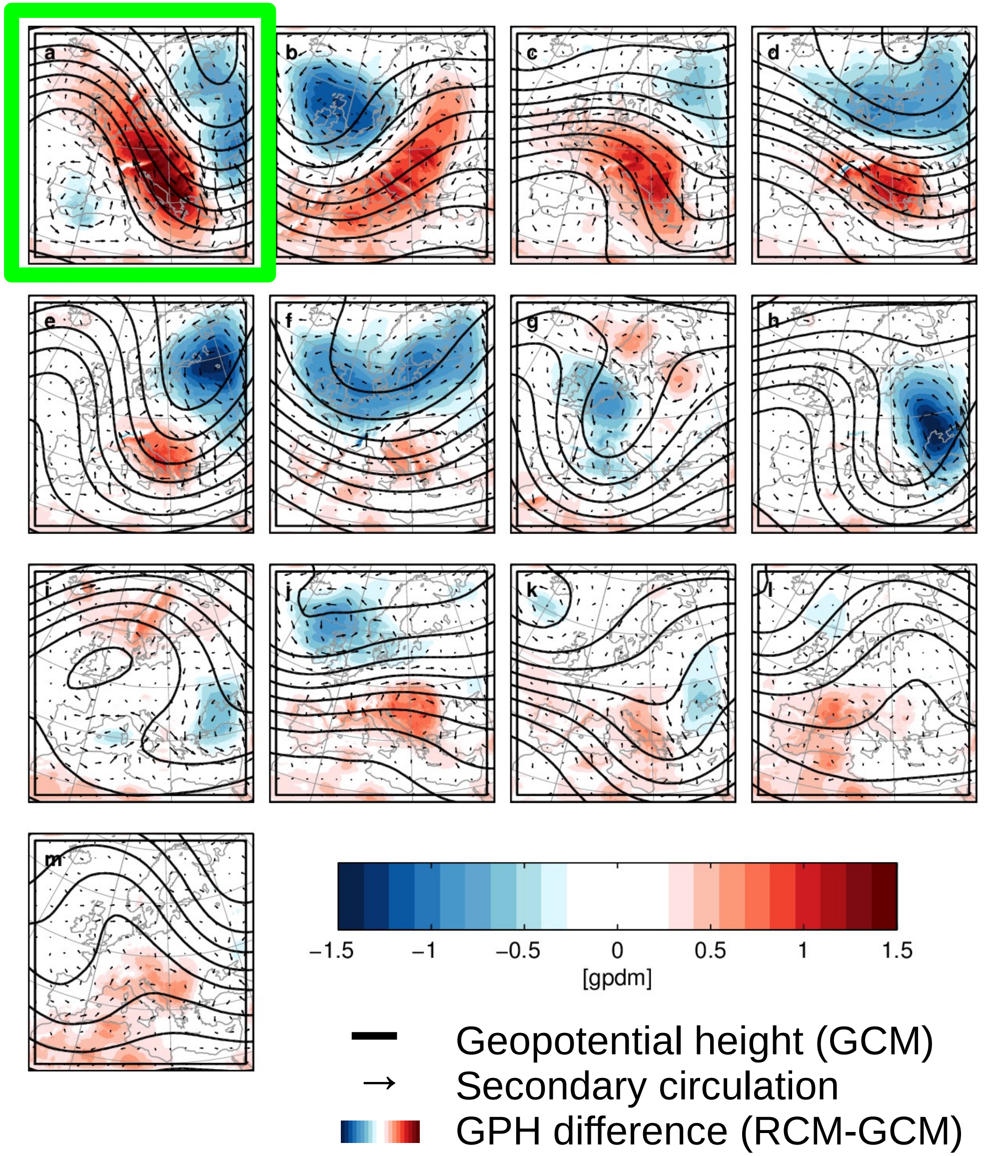
Step 1:

- **Clustering of the large scale flow**
- <u>Method:</u>
  - ➔ Simulated Annealing and Diversified Randomization *(Philipp et al. 2007)*
  - ➔ Clusteranalysis based on *k*-means
- <u>Data used for clustering:</u>
  - ➔ Primary Circulation (GCM)
  - ➔ ECHAM5 GPH at 500 hPa

Step 2:

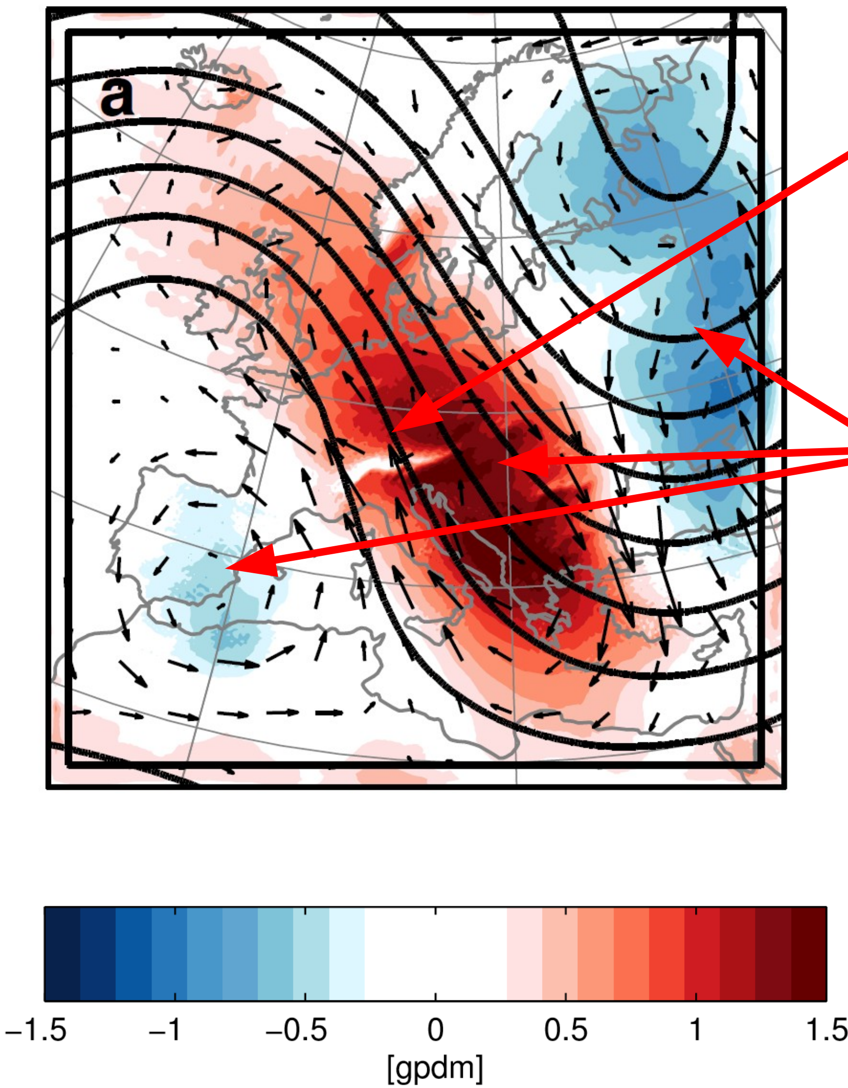
- **Calculating the average SC fields for each cluster of the large-scale flow**

13 clusters, 500 hPa, for DJF



2.2 Clustering approach

Cluster (*a*) with the strongest SC (500 hPa)



Contours:

- Strong north-westerly flow crossing the Alps

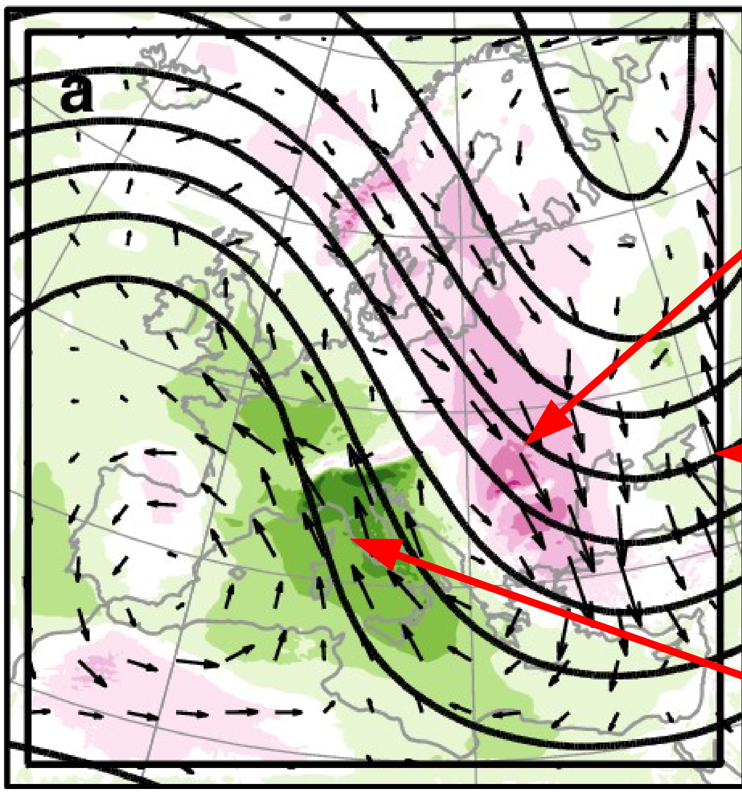
Vectors and colors:

- Tripole pattern in the SC field

Geopotential height (GCM)
→ Secondary circulation (RCM-GCM)
GPH difference (RCM-GCM)

2.3 Clustering approach

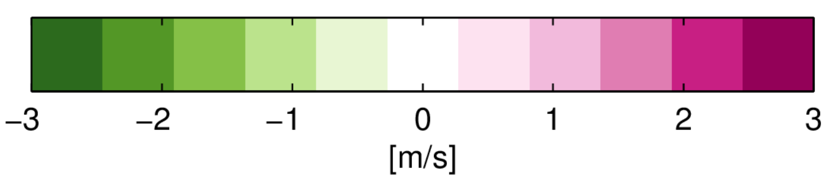
Cluster (*a*) with the strongest SC (500 hPa)



Higher wind speeds in RCM due to stronger flow around the Alps

Secondary circulation **parallel to model boundary**

Lower wind speeds in the RCM downstream of the Alps (increased orographic drag)



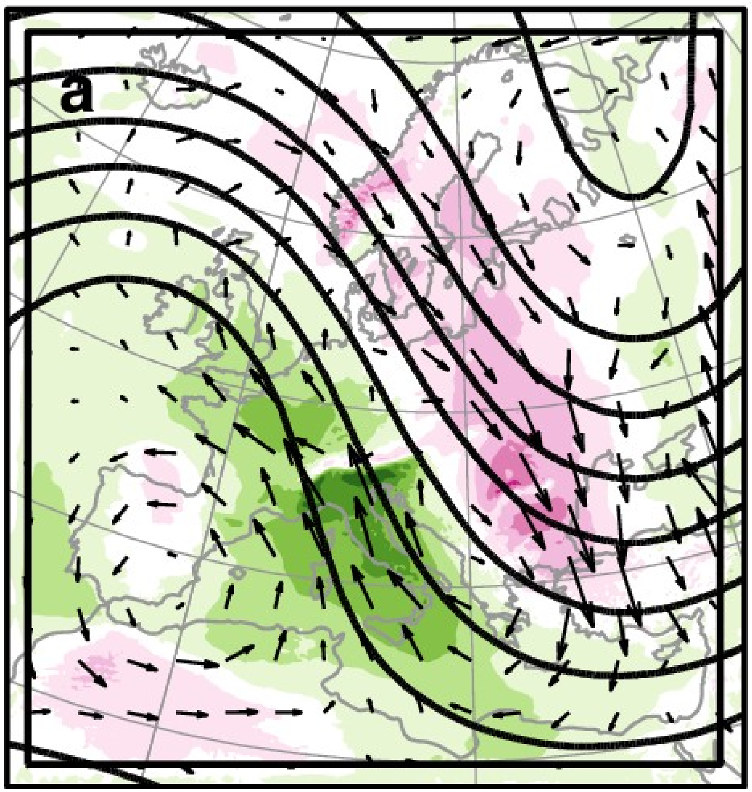
Geopotential height (GCM)

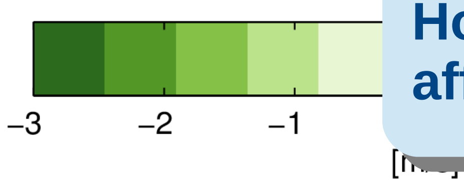
→ Secondary circulation (RCM-GCM)

Wind speed differences (RCM-GCM)

2.4 Driving mechanism

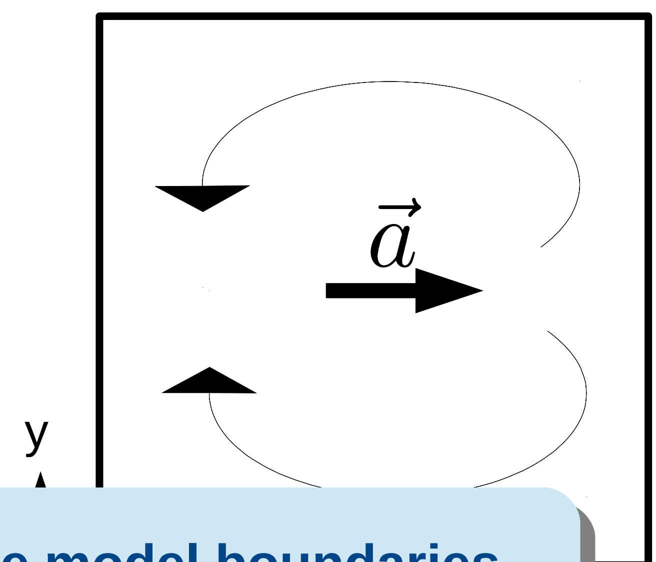
What causes the secondary circulation?





Thought experiment

- Idealized 2D model domain
- Solid boundaries
- Non-rotating system
- Accelleration in the center
- A **“balancing flow”** evolves



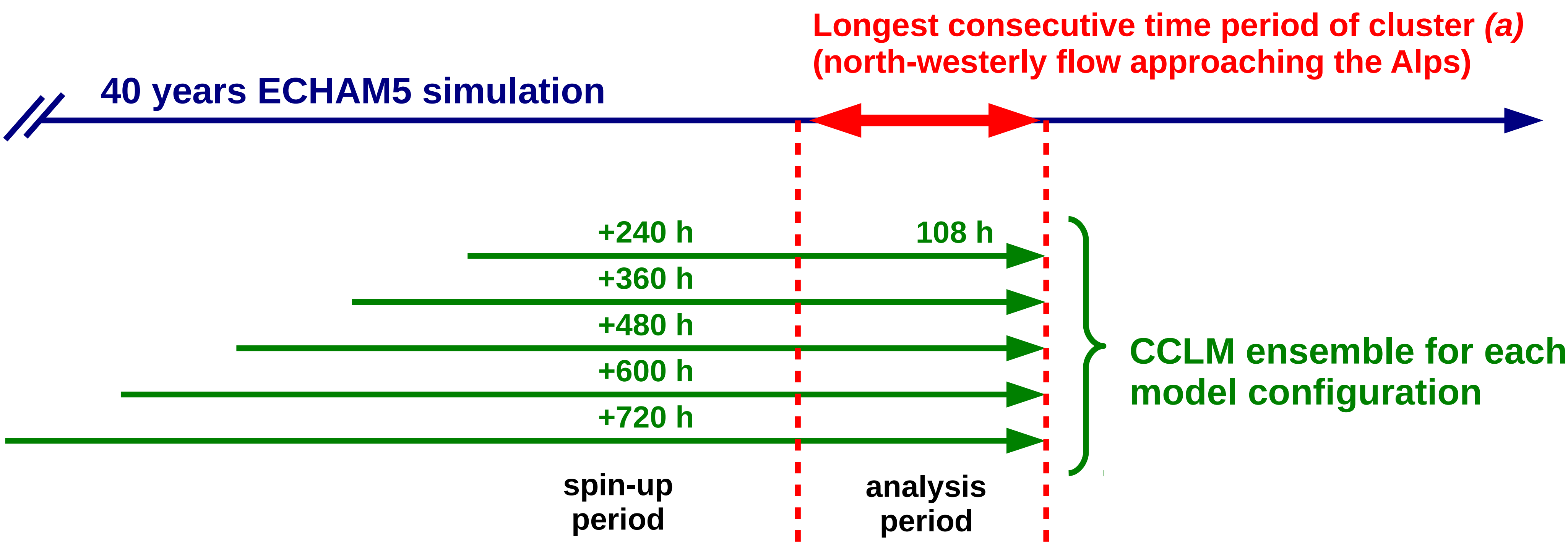
How does the loaction of the model boundaries affect the SC?

3.1 Impact of the model boundaries

CCLM 4.8 simulations with different model configurations

- incremental shifts of the eastern model boundary
- incremental shifts of the southern model boundary
- ...

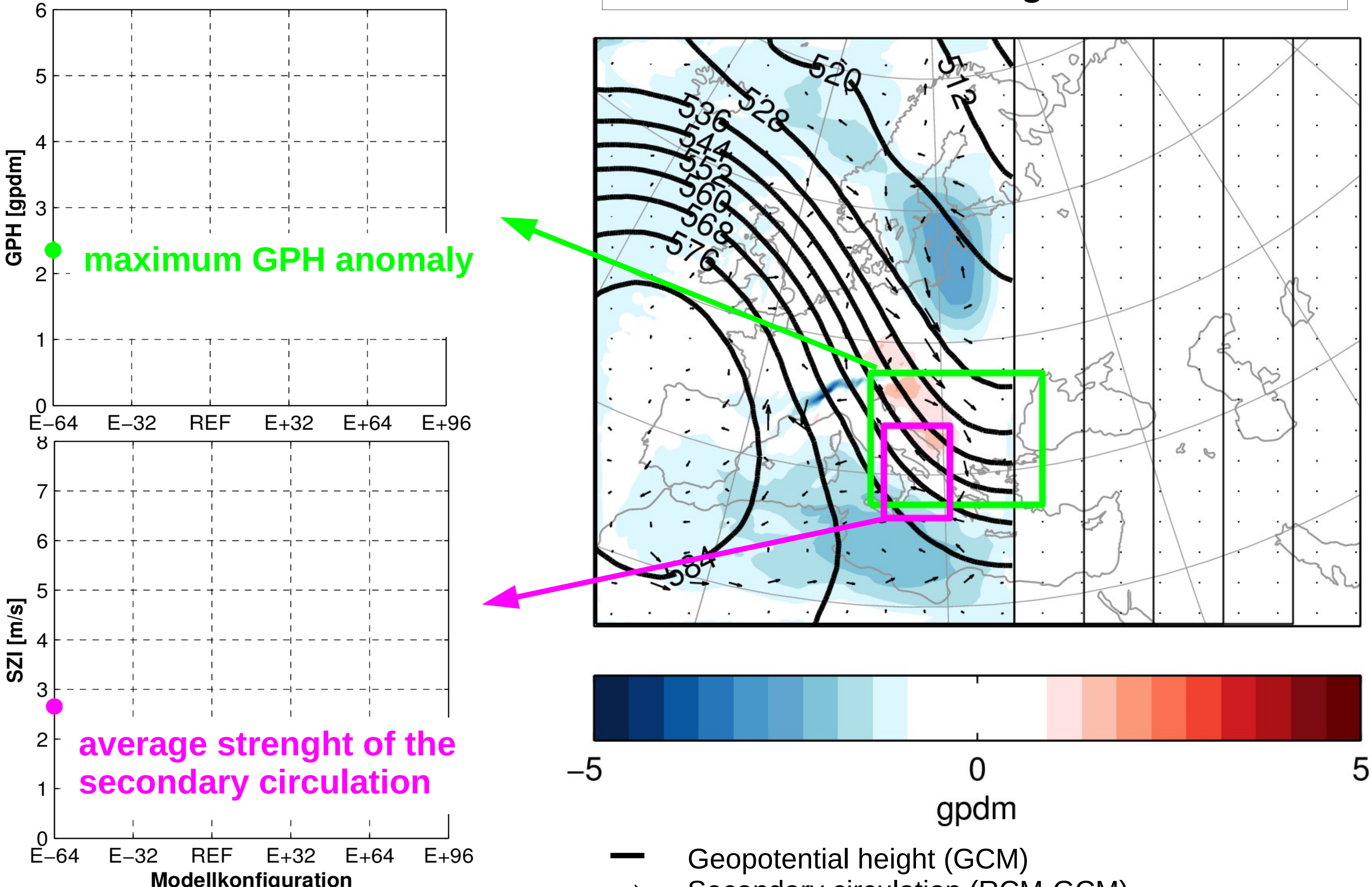
How to select an appropriate simulation period?



3.2 Impact of the model boundaries

Shifting the eastern boundary

Standard domain – 64 grid boxes



— Geopotential height (GCM)

→ Secondary circulation (RCM-GCM)

GPH difference (RCM-GCM)

3.2 Impact of the model boundaries

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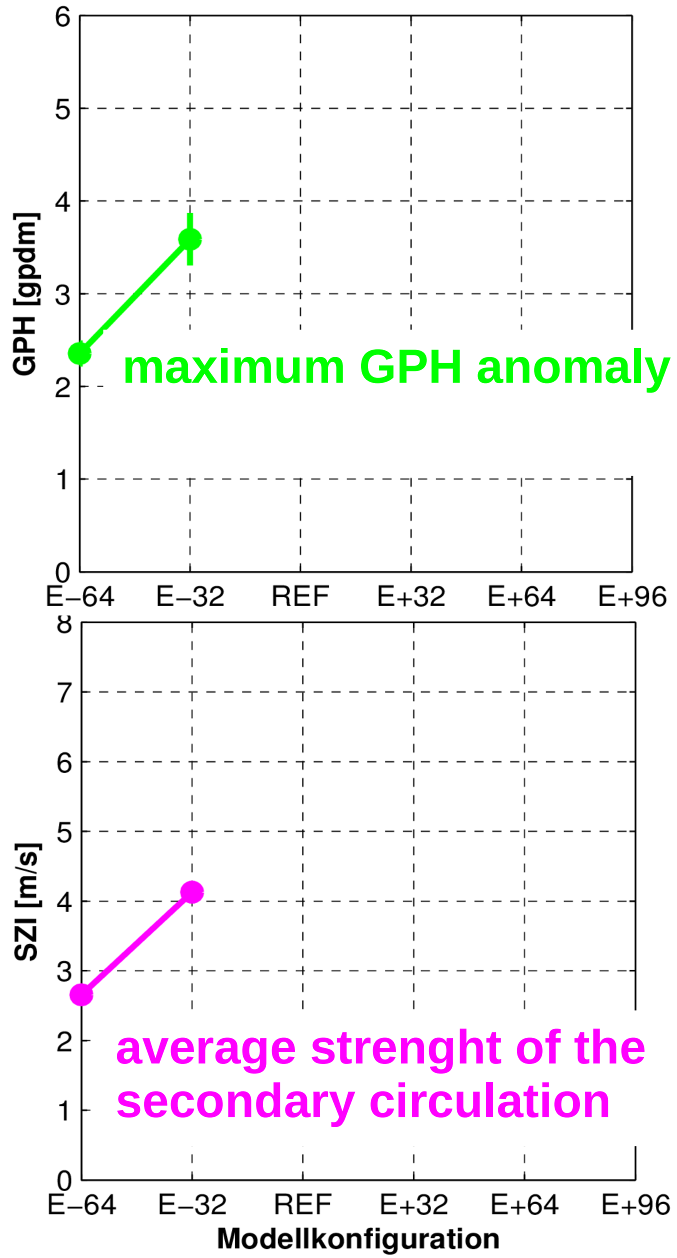
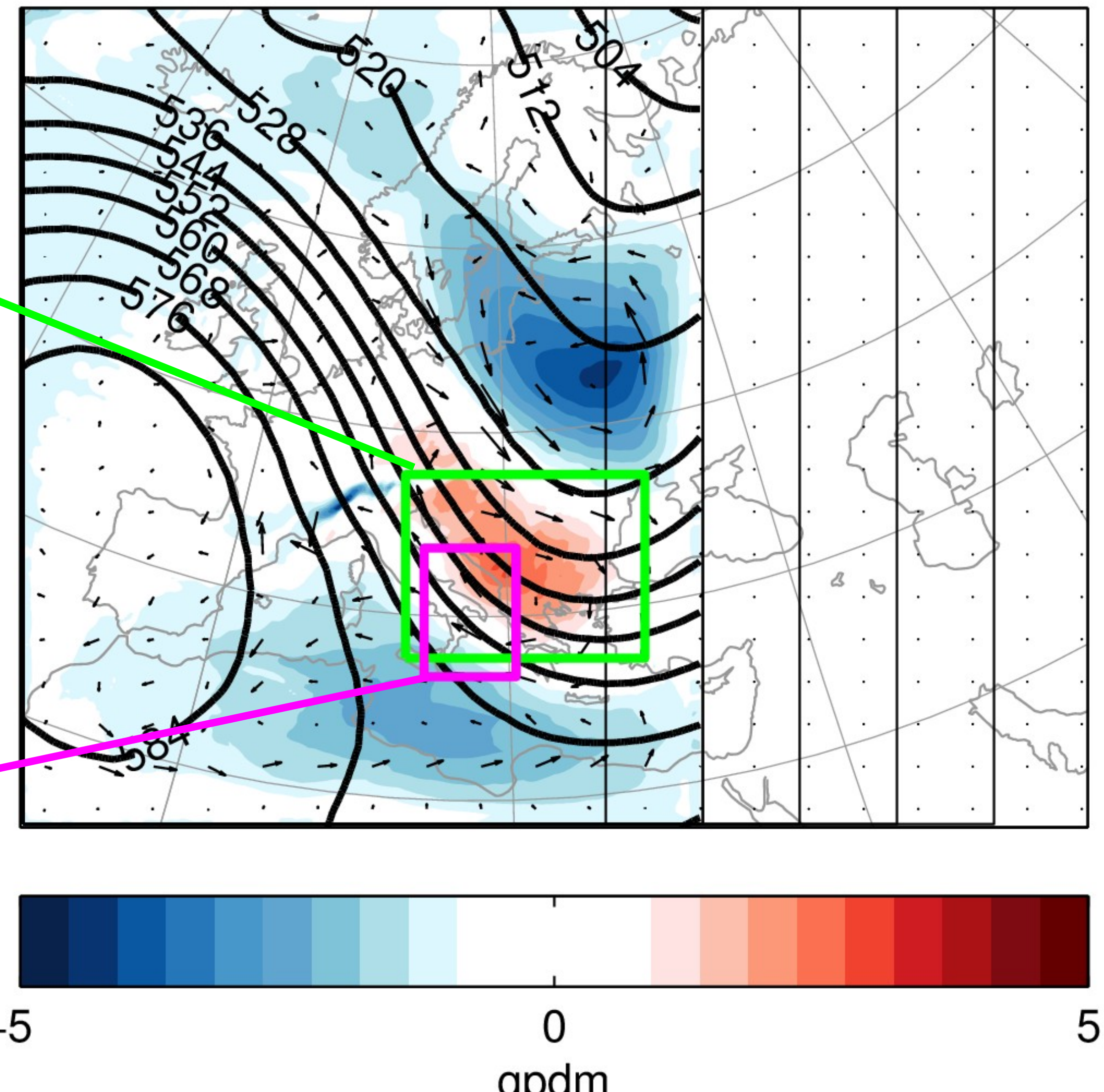
Shifting the eastern boundary



Standard domain – 32 grid boxes



Geopotential height (GCM)

→ Secondary circulation (RCM-GCM)

GPH difference (RCM-GCM)

3.2 Impact of the model boundaries

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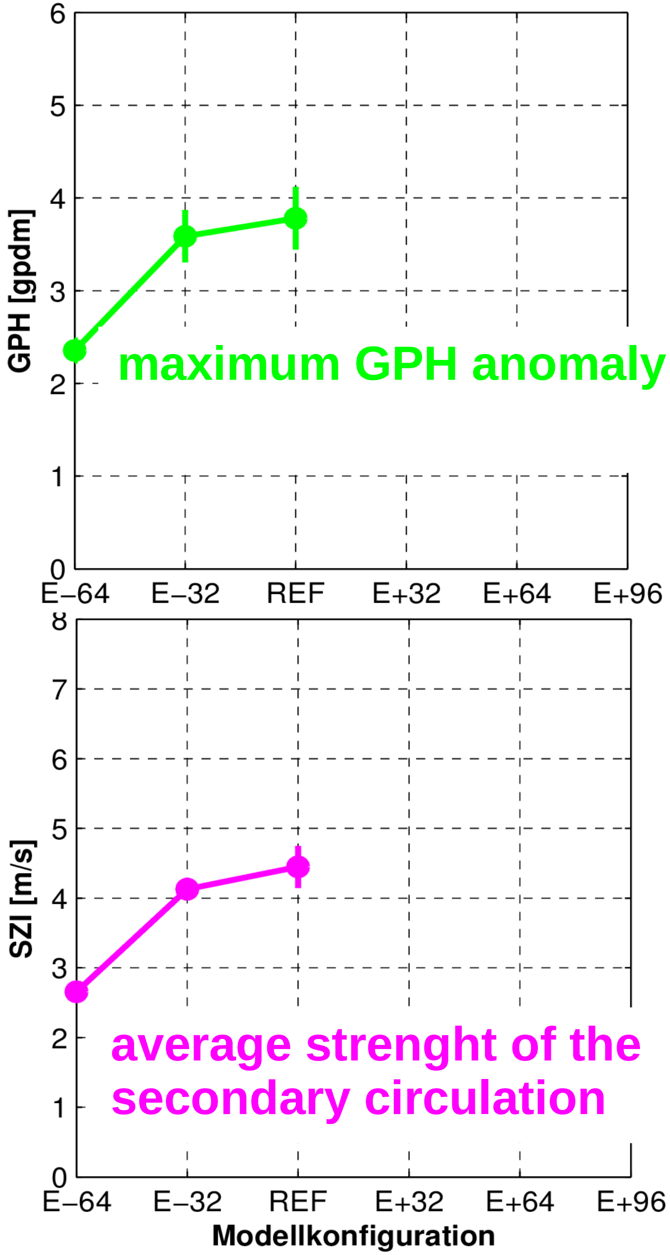
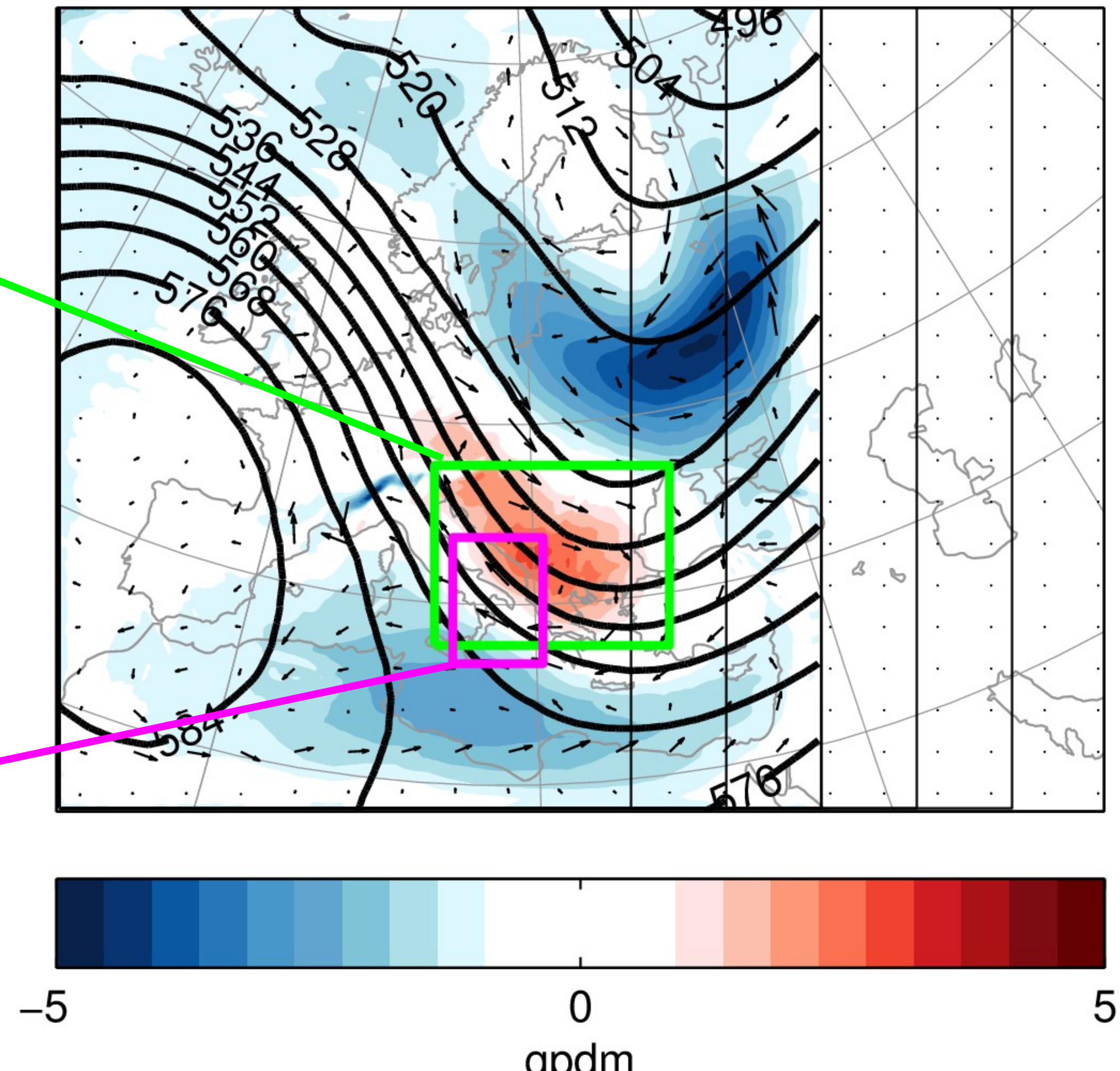
Shifting the eastern boundary



Standard domain



— Geopotential height (GCM)

→ Secondary circulation (RCM-GCM)

GPH difference (RCM-GCM)

3.2 Impact of the model boundaries

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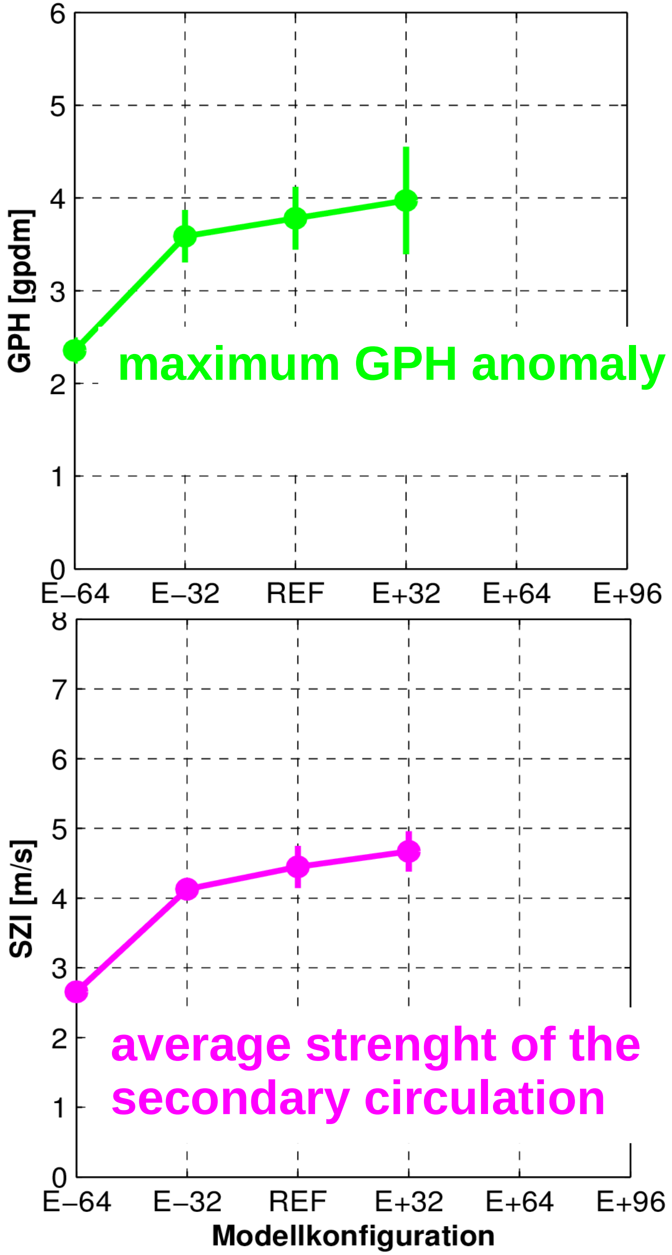
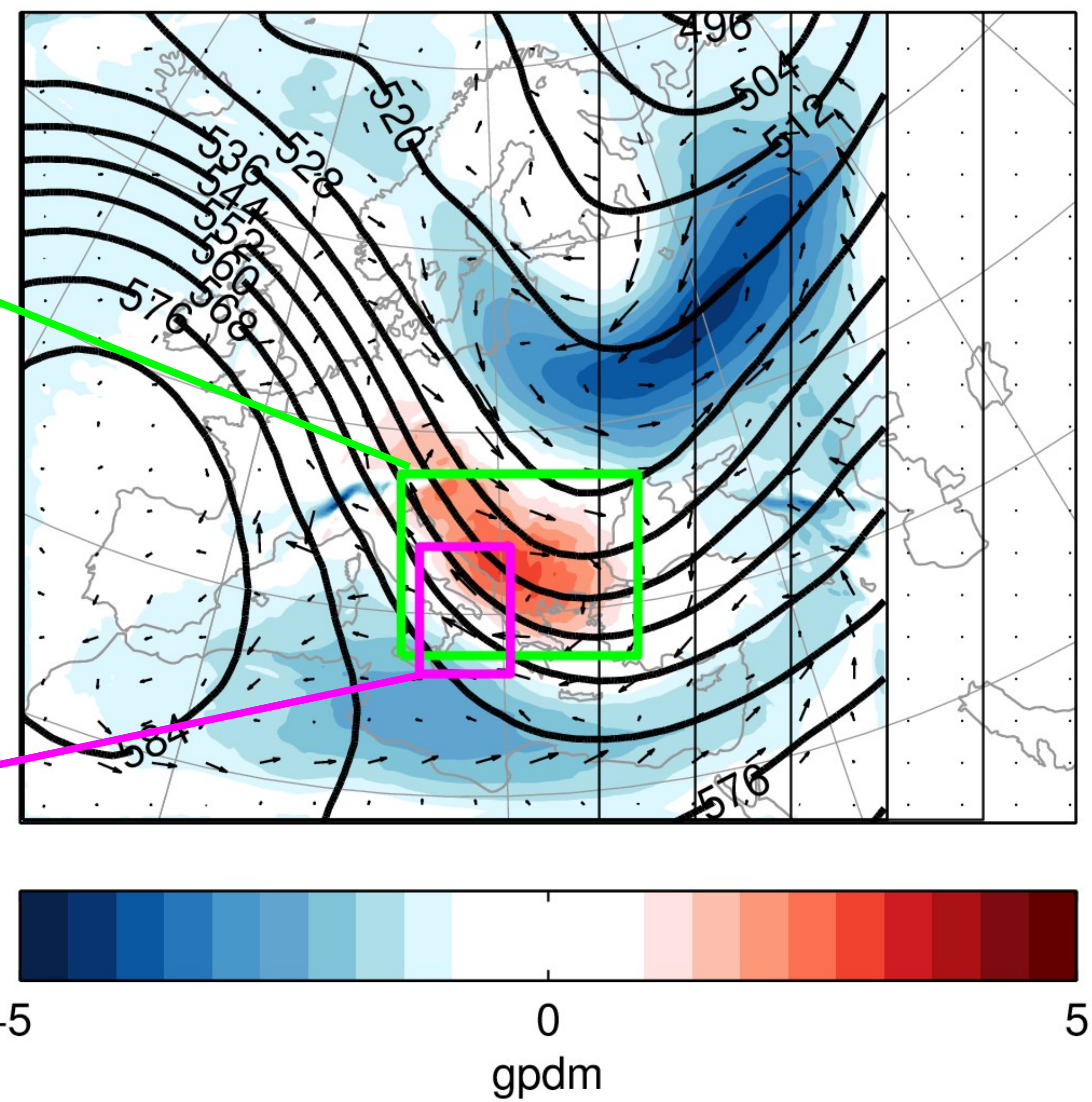
Shifting the eastern boundary



Standard domain + 32 grid boxes



— Geopotential height (GCM)

→ Secondary circulation (RCM-GCM)

GPH difference (RCM-GCM)

3.2 Impact of the model boundaries

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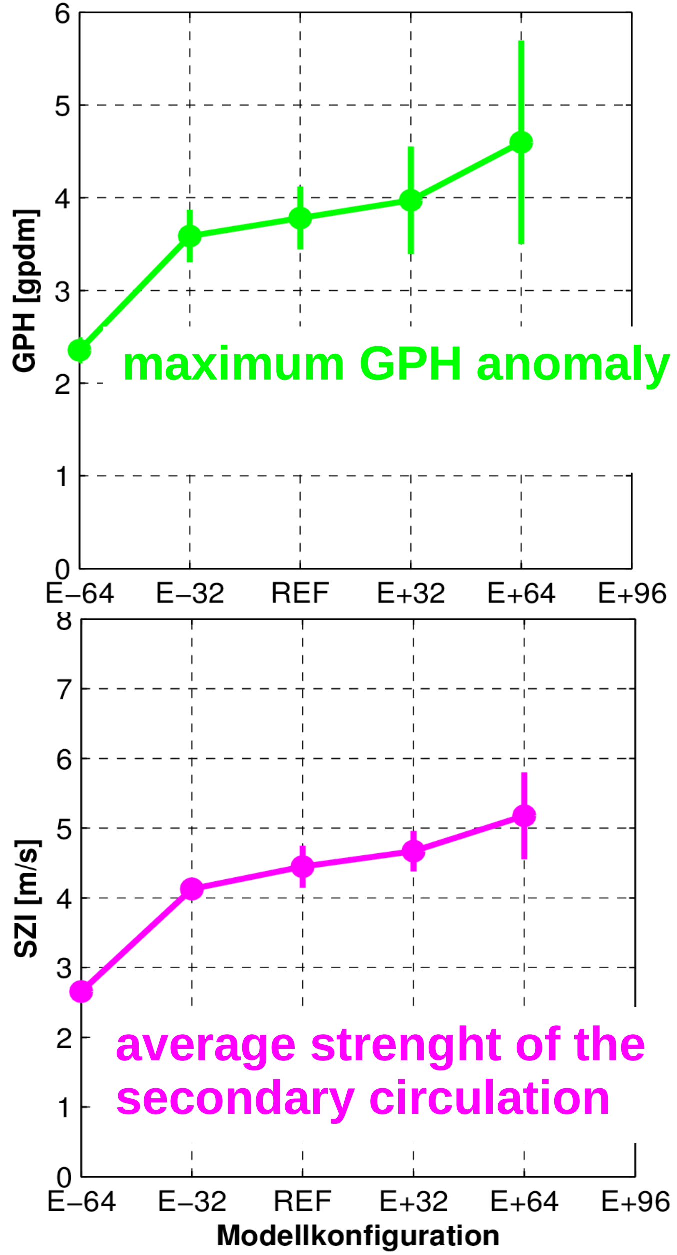
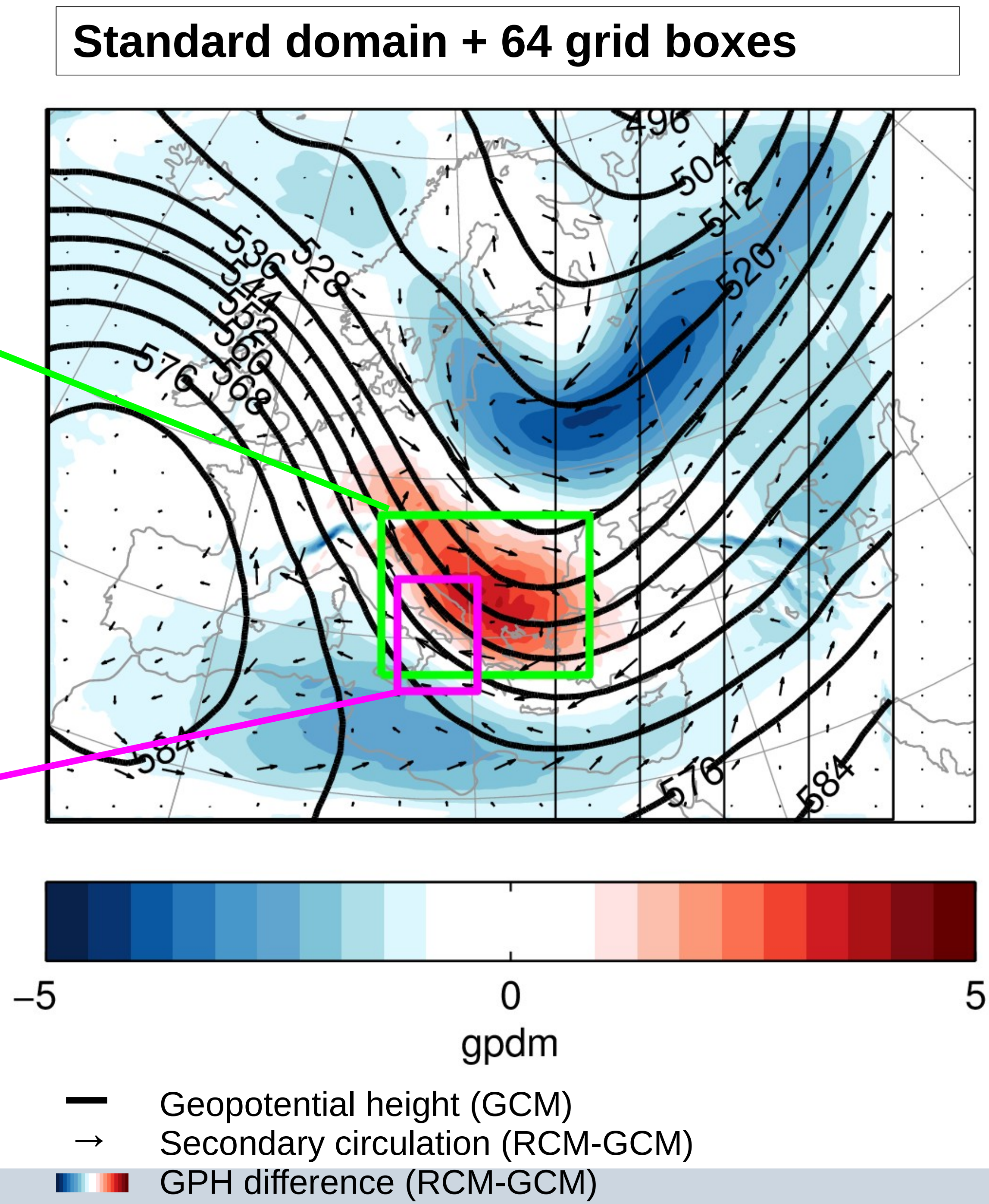
Shifting the eastern boundary





3.2 Impact of the model boundaries

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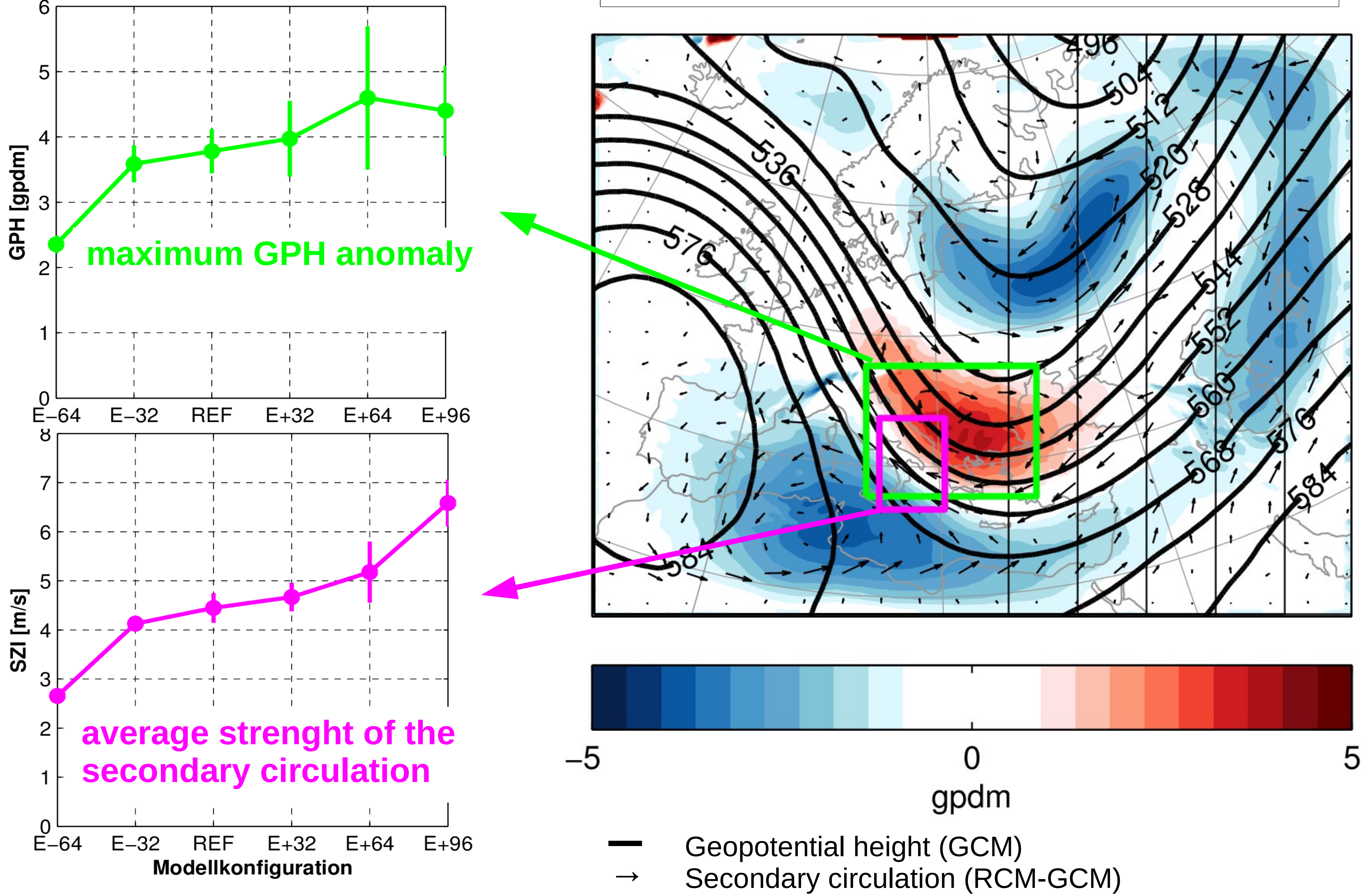
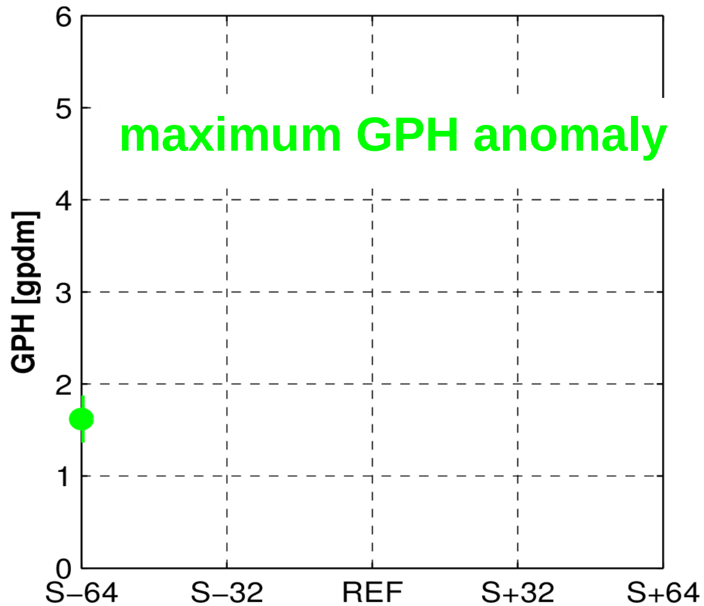
Shifting the eastern boundary

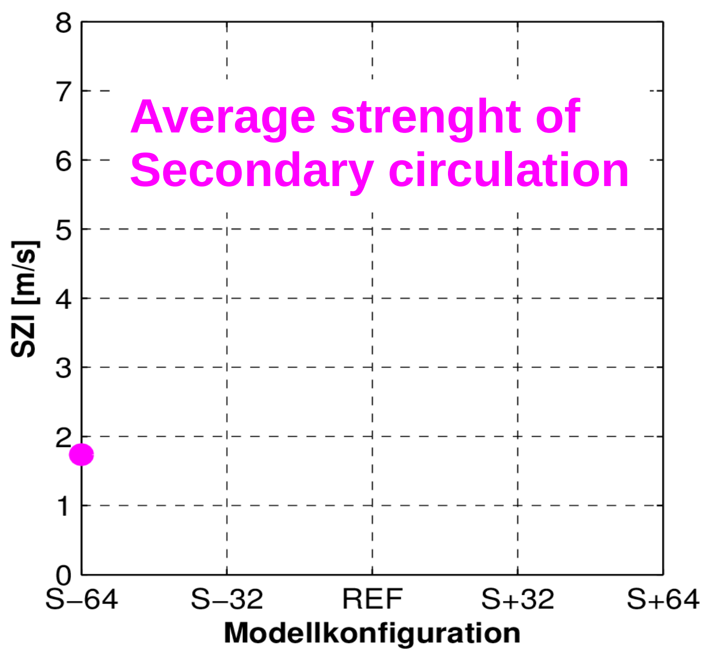
Standard domain + 96 grid boxes

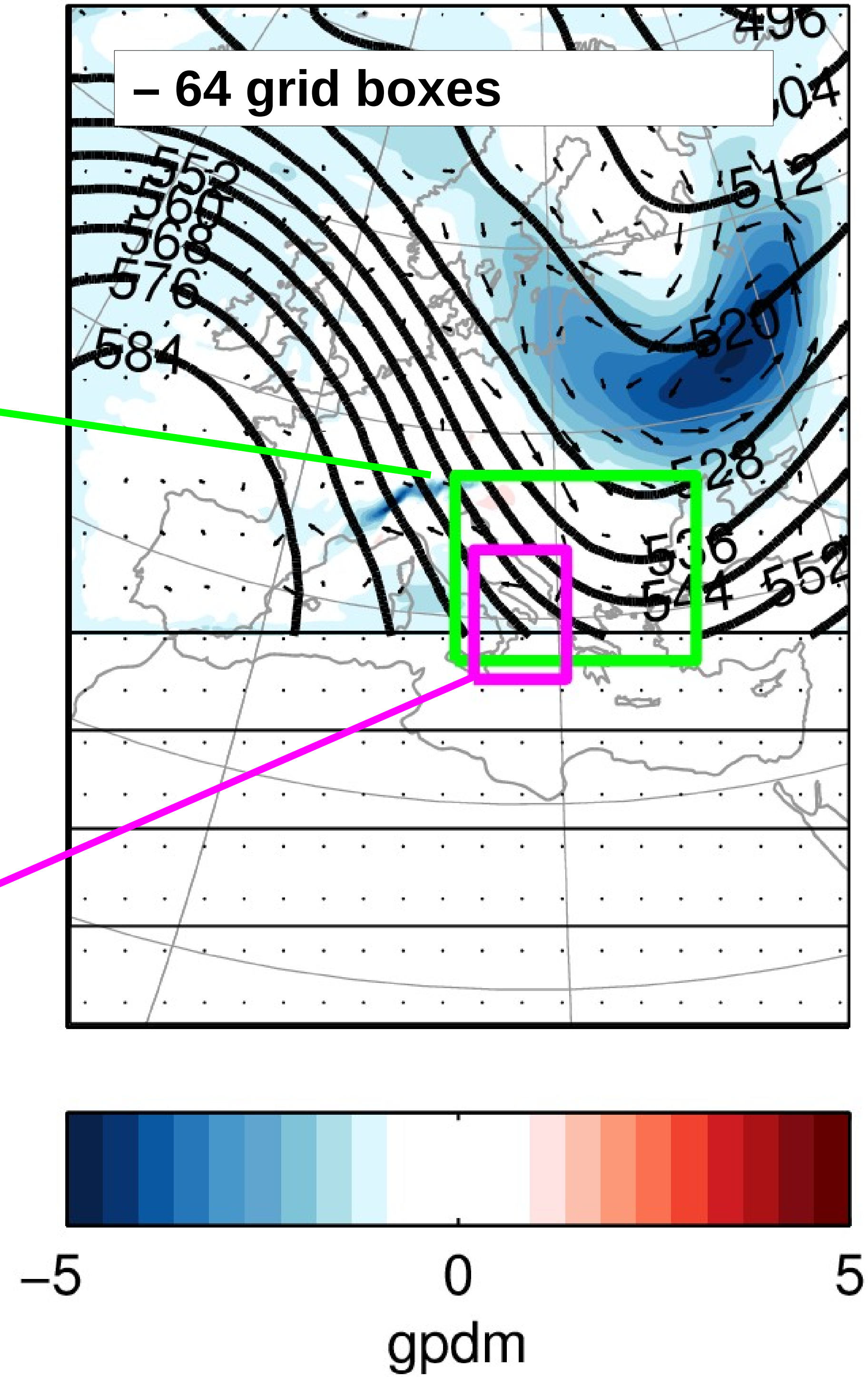


3.3 Impact of boundaries

Shifting the southern boundary

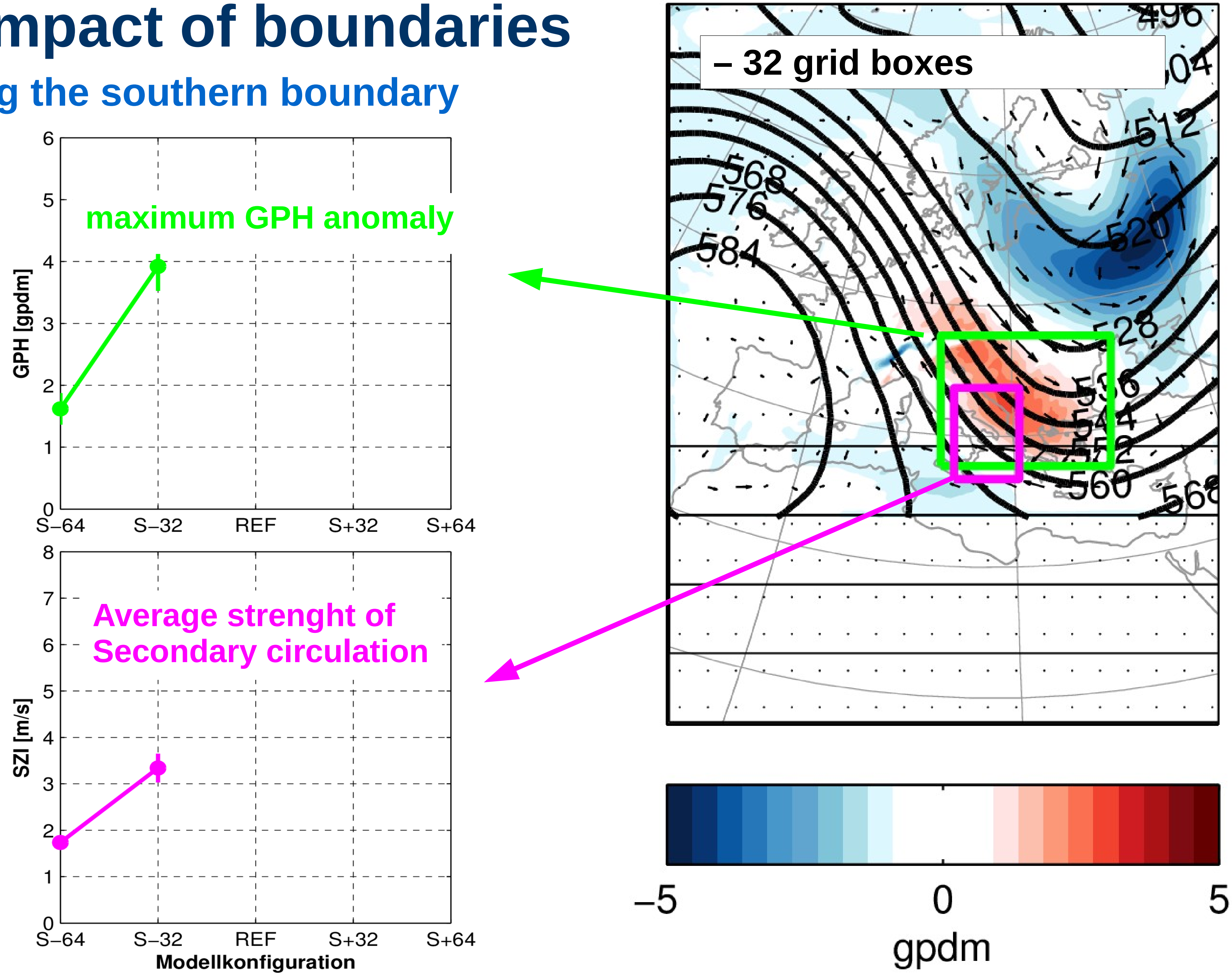






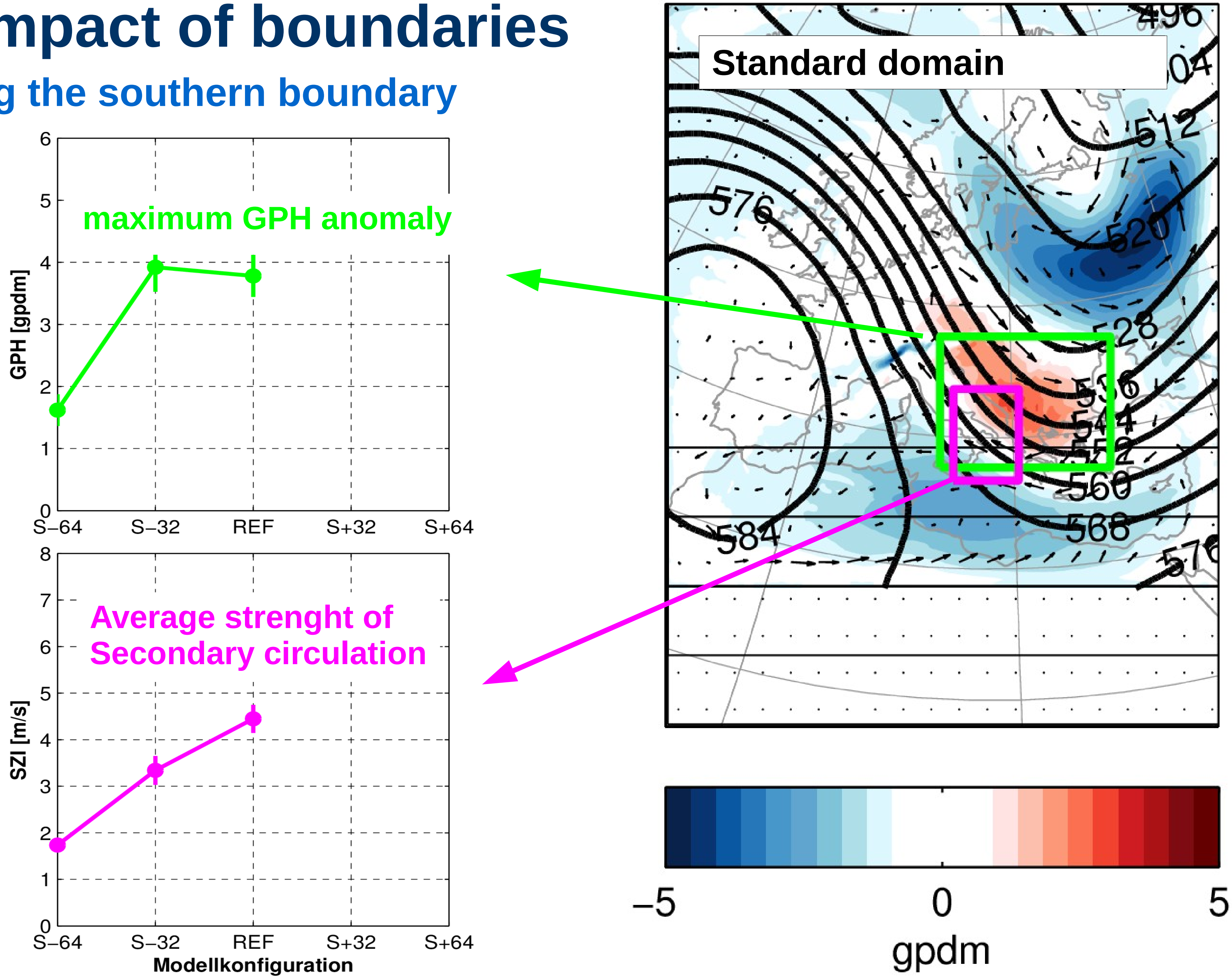
3.3 Impact of boundaries

Shifting the southern boundary



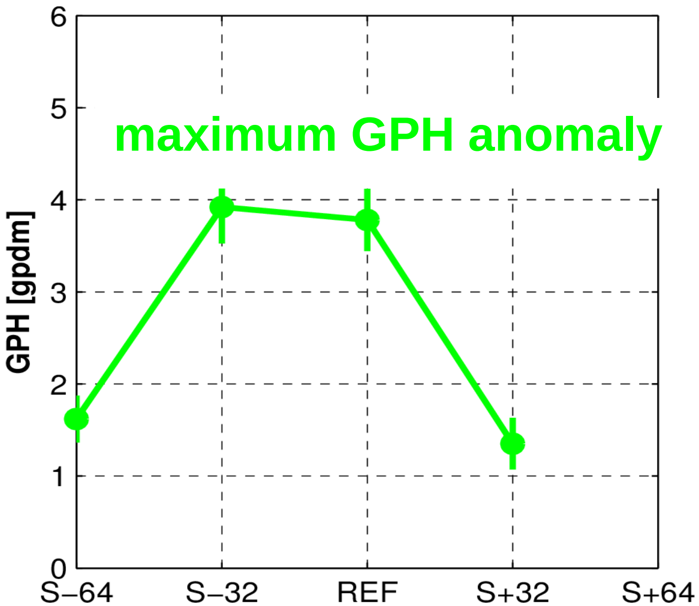
3.3 Impact of boundaries

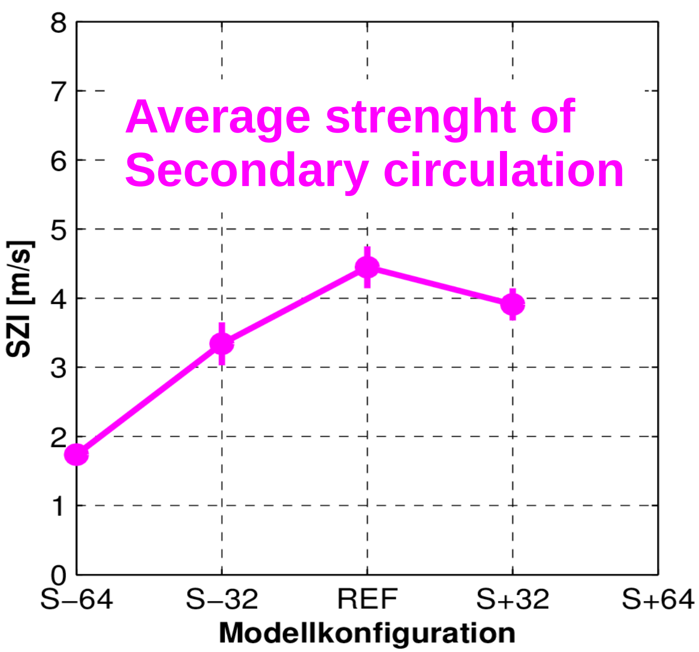
Shifting the southern boundary

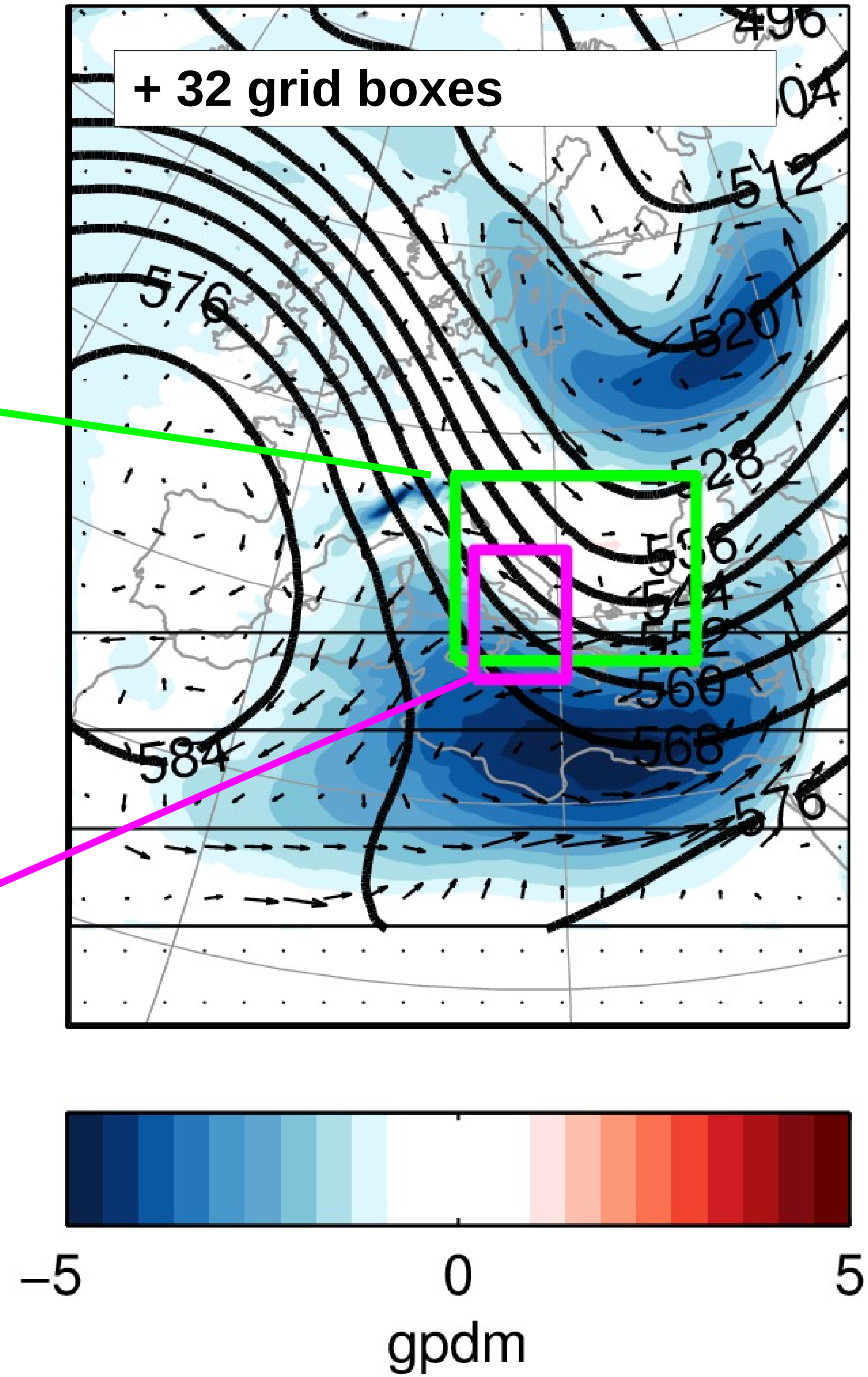


3.3 Impact of boundaries

Shifting the southern boundary

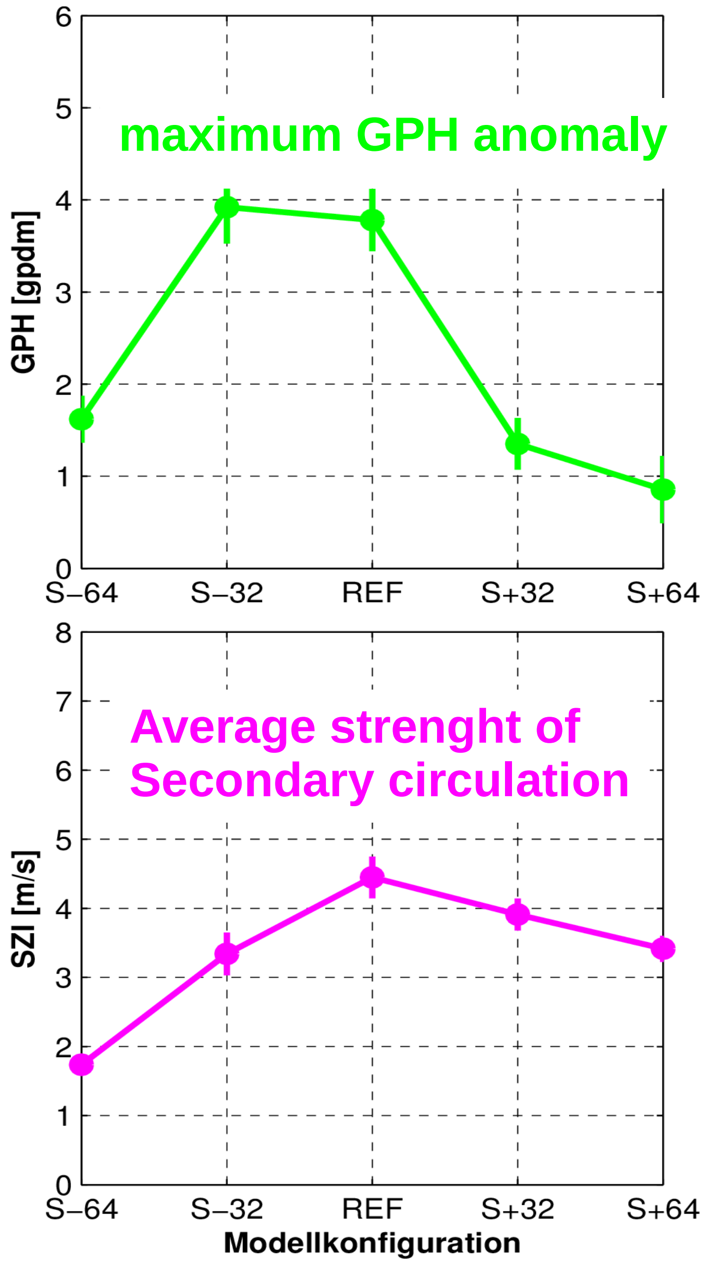


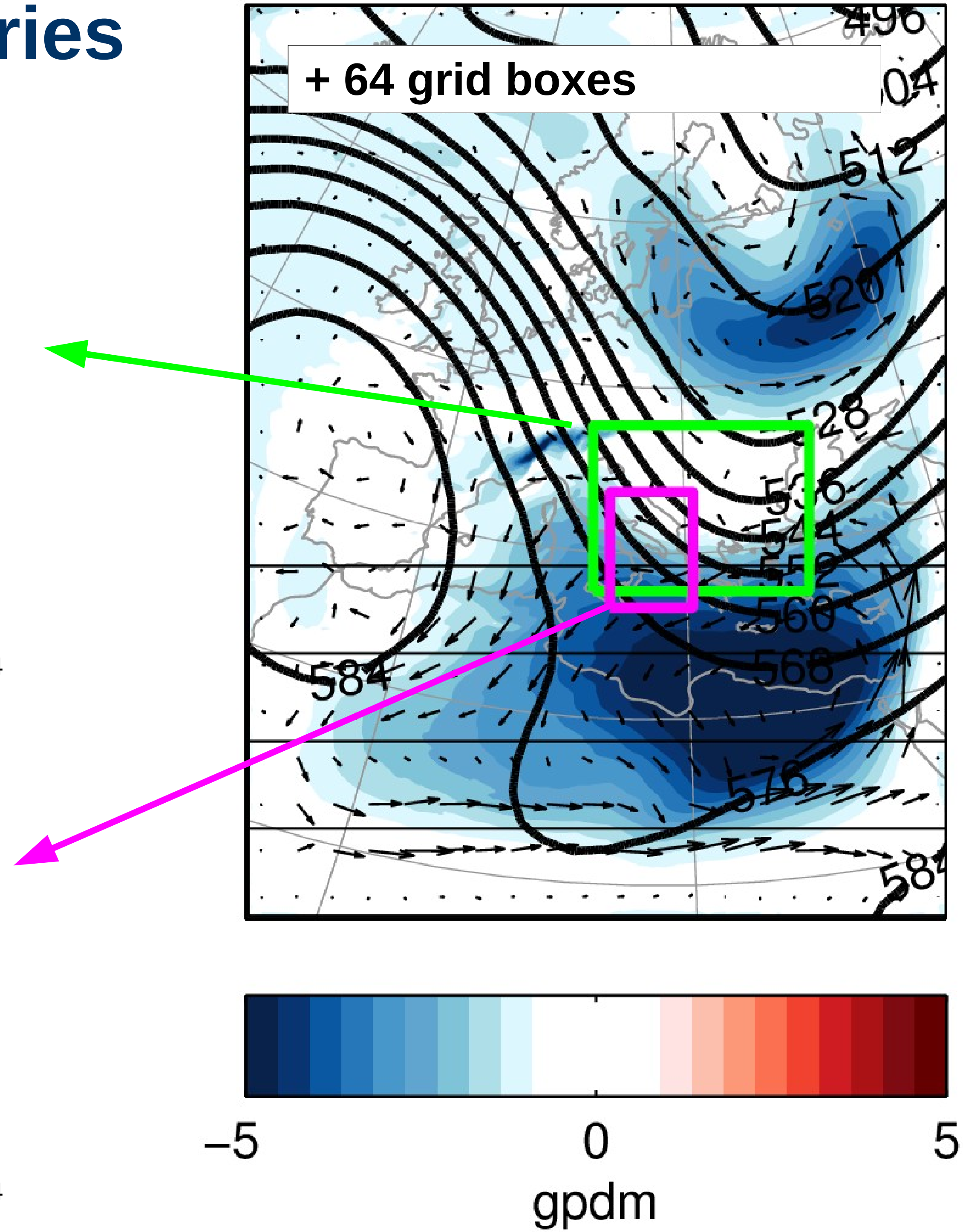




3.3 Impact of boundaries

Shifting the southern boundary

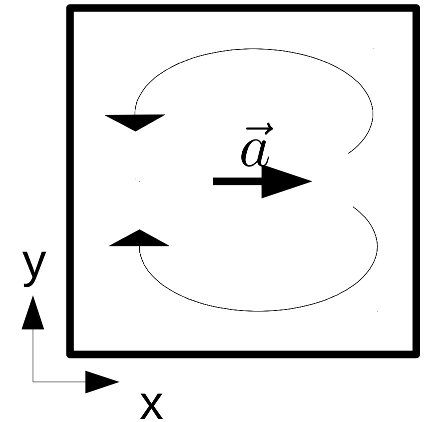




Summary

- A **secondary circulation** exists in COSMO-CLM relative to the forcing data

- **Driving mechanism** of the secondary circulation:
  - ➔ **Modifications of the mass flux** in the RCM
  - ➔ e.g. due to different **orographic drag effects**
  - ➔ Mass flux modifications **cannot exit the RCM**
  - ➔ A **balancing flow** develops



- **"Added value"** and **"artefacts"** of the RCM are **directly linked** via the SC
  - ➔ added value → effects of a higher resolution
  - ➔ artefacts → interaction with the model boundary

Is the secondary circulation relevant for regional climate modelling in general?

Discussion and Outlook

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- **Common assumption:**
  - ➔ Boundary effects occur in areas „close to the lateral boundaries“
- **The SC demonstrates:**
  - ➔ The lateral boundaries affect the simulations **within the whole domain**!
  - ➔ Is it necessary to run **RCM ensembles** with different positions of the boundaries?
- The driving mechanisms indicate that the SC is a **general feature of all one-way nested RCMs**
- The effects of the SC have a similar order of magnitude as **climate change signals**
- It could be useful to include the SC into the **evaluation process of RCMs**

Publications:

- Becker et al. 2015: Large-scale secondary circulations in a regional climate model, *Geophys. Res. Lett., 42* (*http://onlinelibrary.wiley.com/doi/10.1002/2015GL063955/abstract*)
- Becker 2015: Großskalige Sekundärzirkulationen im regionalen Klimamodell COSMO-CLM, *PhD-Thesis* (*http://www.diss.fu-berlin.de/diss/receive/FUDISS_thesis_000000101443*)