Modelling the large hail hazard in the past, present, near and far future

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The ARCS project is supported by **Munich RE**.

RAIN PROJECT

This project is funded by the European Union

FONA Research for Sustainable Development BMBF

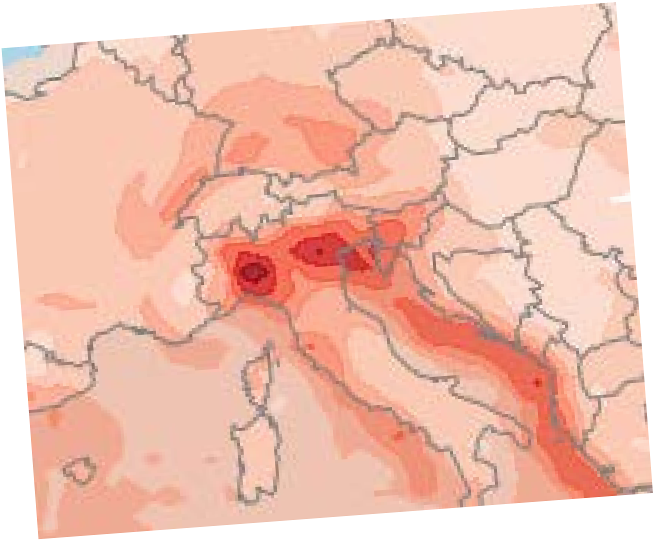
Federal Ministry of Education and Research

Munich RE

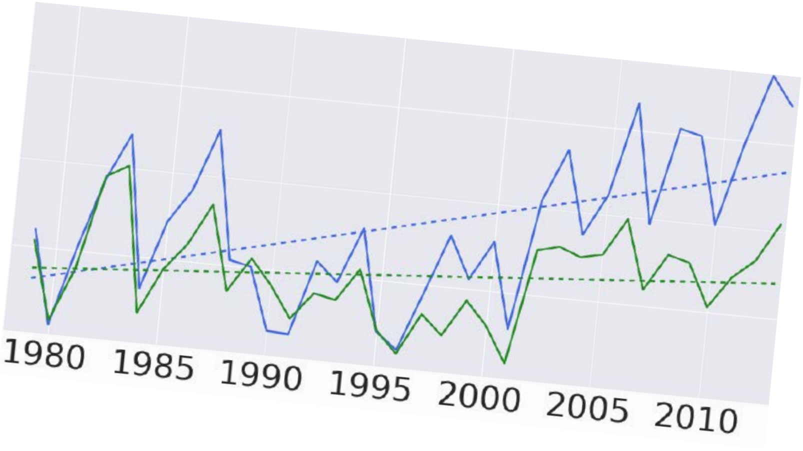
The hail hazard

- Because of the damage hail causes
- we want to know the distribution of hail probability

in space



and in time



The hail hazard

Questions:

1. How is the hail hazard distributed according to the present climatology?

2. Will climate change affect hail probability? How?

3. Is climate change already having a measurable effect?

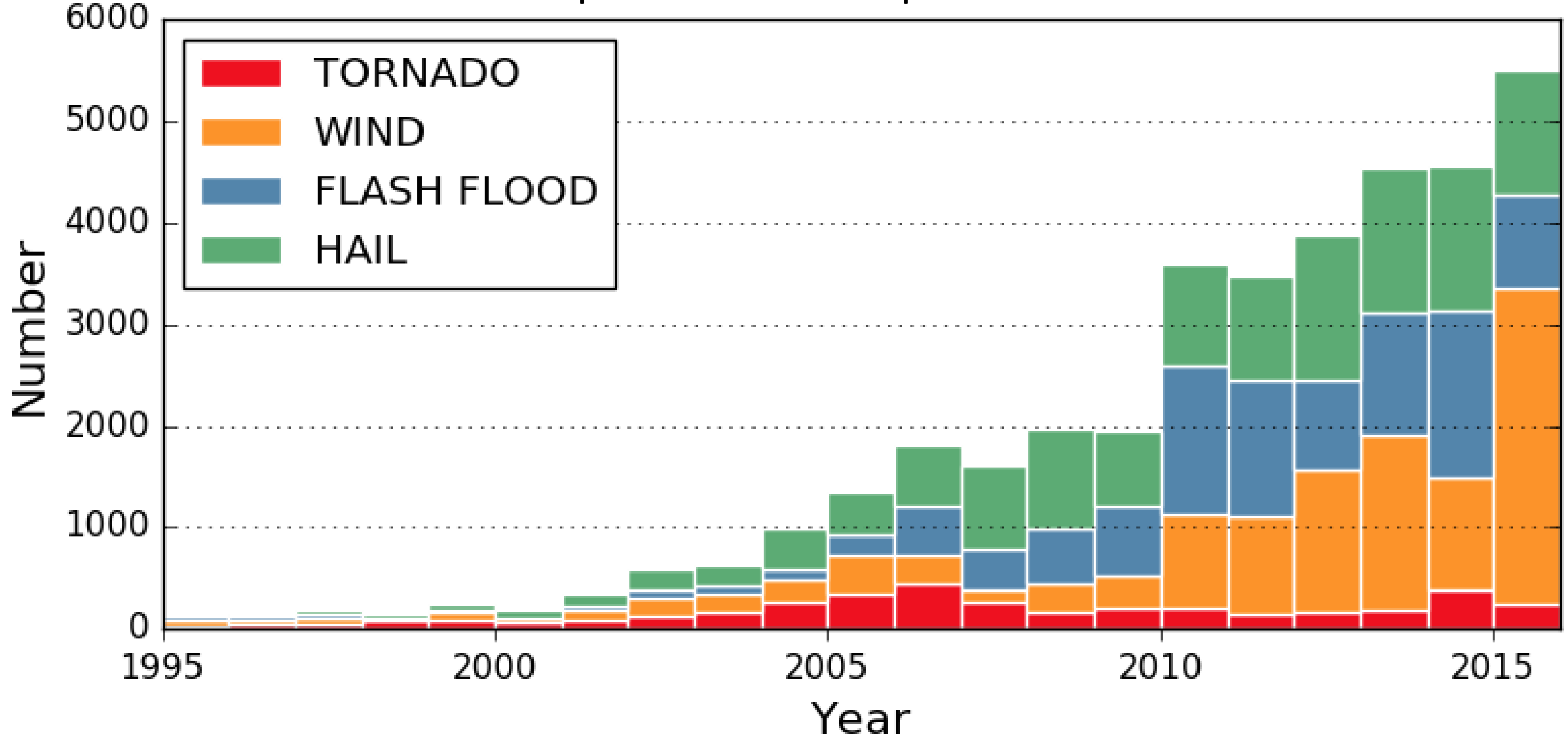
4. Can we improve hail probability forecasts for the next days or weeks using numerical models?

Problems

These are some central problems:

- Observations are not consistent in time and place

Annual number of reports in the European Severe Weather Database



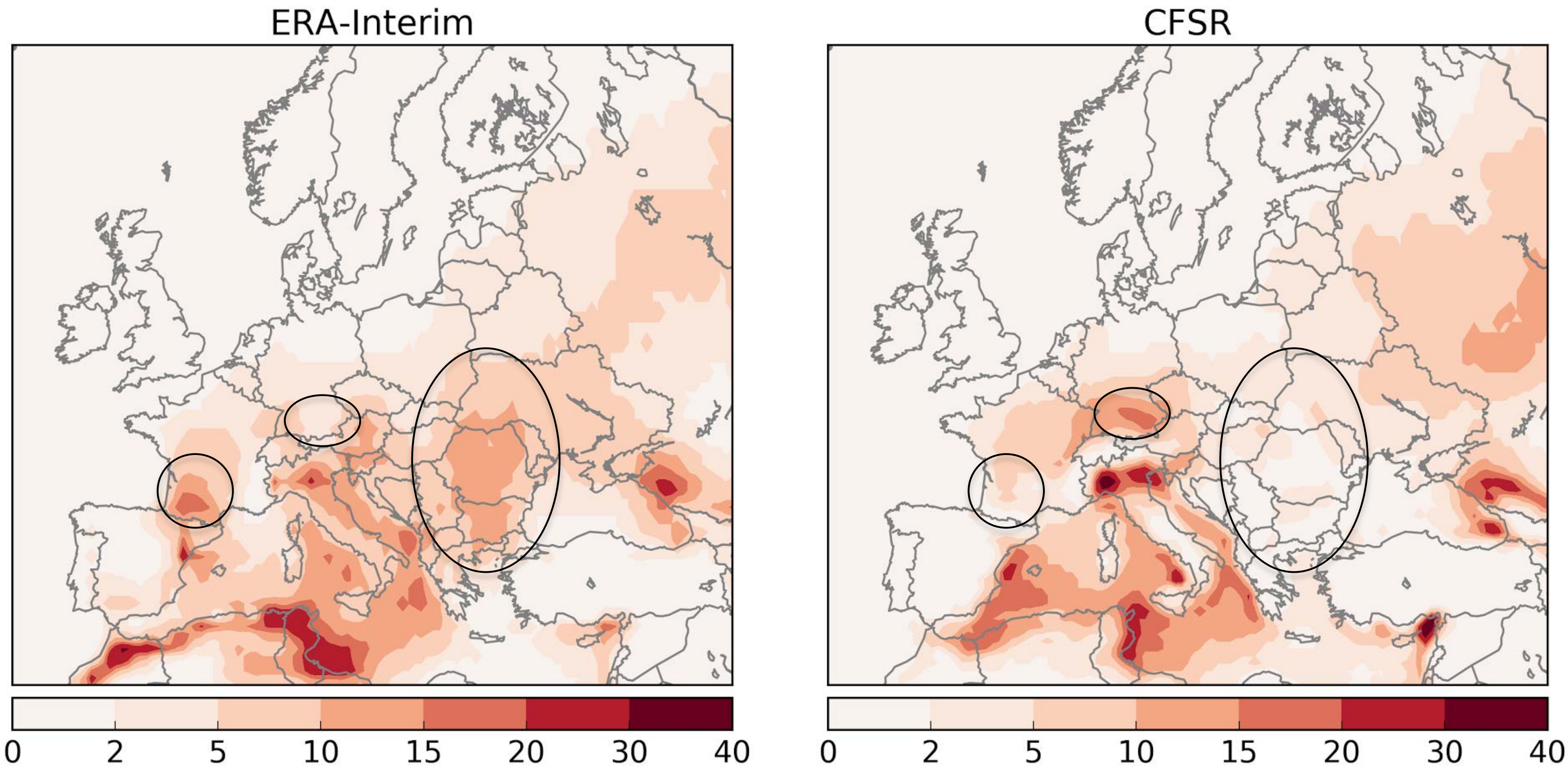
Problems

These are some central problems:

- Observations are not consistent in time and place
- Loss data are influenced by many other factors, such as increased vulnerability or exposure
- Reanalyses and climate models typically do not <u>yet</u> resolve hailstorms
  - we need to work with proxy parameters
- Reanalyses and climate models differ from each other

Differences between reanalyses

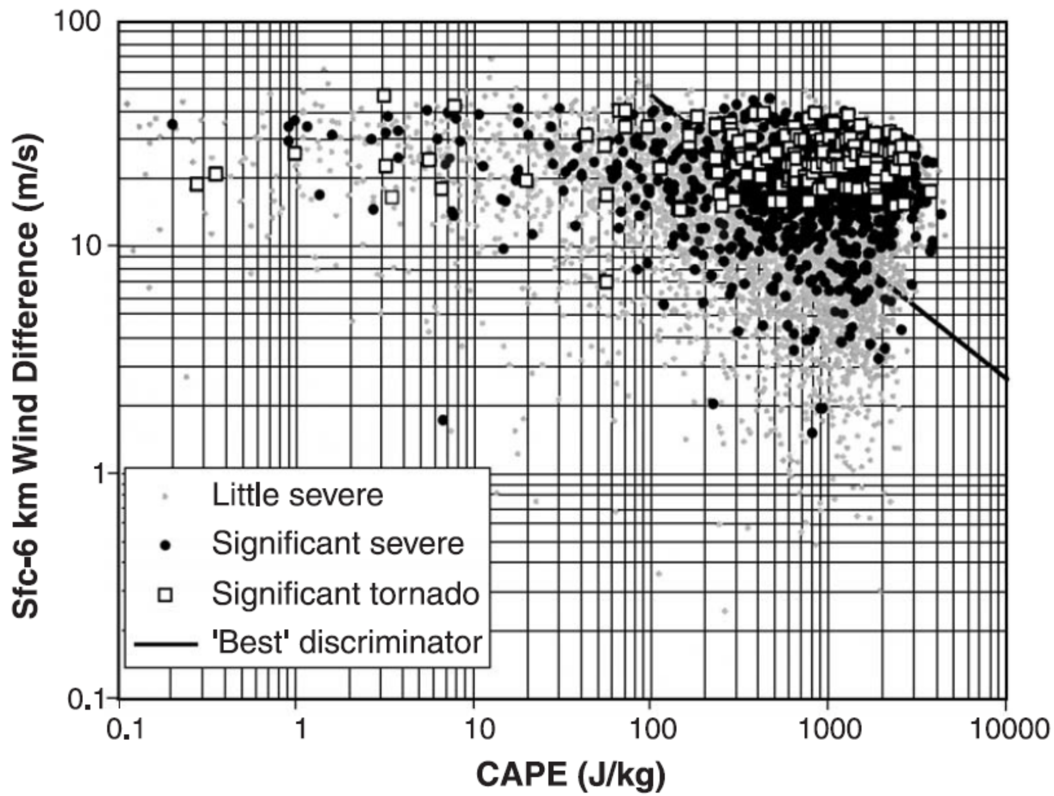
Number of 6-hourly timesteps with CAPE > 1000 J/kg in two reanalysis data sets



Modelling approach

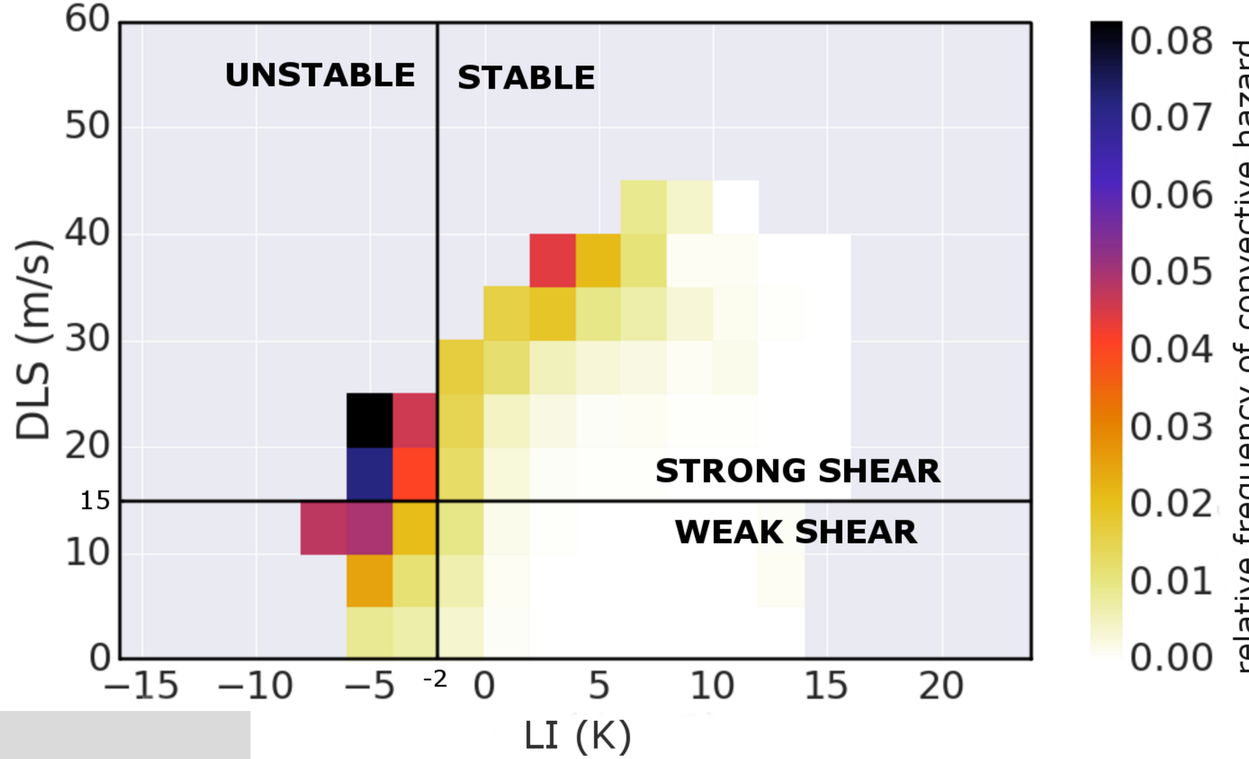
- At ESSL, we have chosen to work with numerical model data nevertheless ☺

- Brooks et al. (2003) pioneered
  this approach and
  defined the first proxy
  for severe convection



Severe thunderstorm environments

Tomáš Púčik



We define a
severe environment
as one that is

1. **unstable** **LI <= -2**
2. **strongly sheared** **DLS >= 15**
3. **precipitating** **Precip >= 1**

Lifted Index (LI)
minimum value from 925, 850 and 700 hPa

Deep layer shear (DLS)
10 m – 500 hPa bulk wind shear

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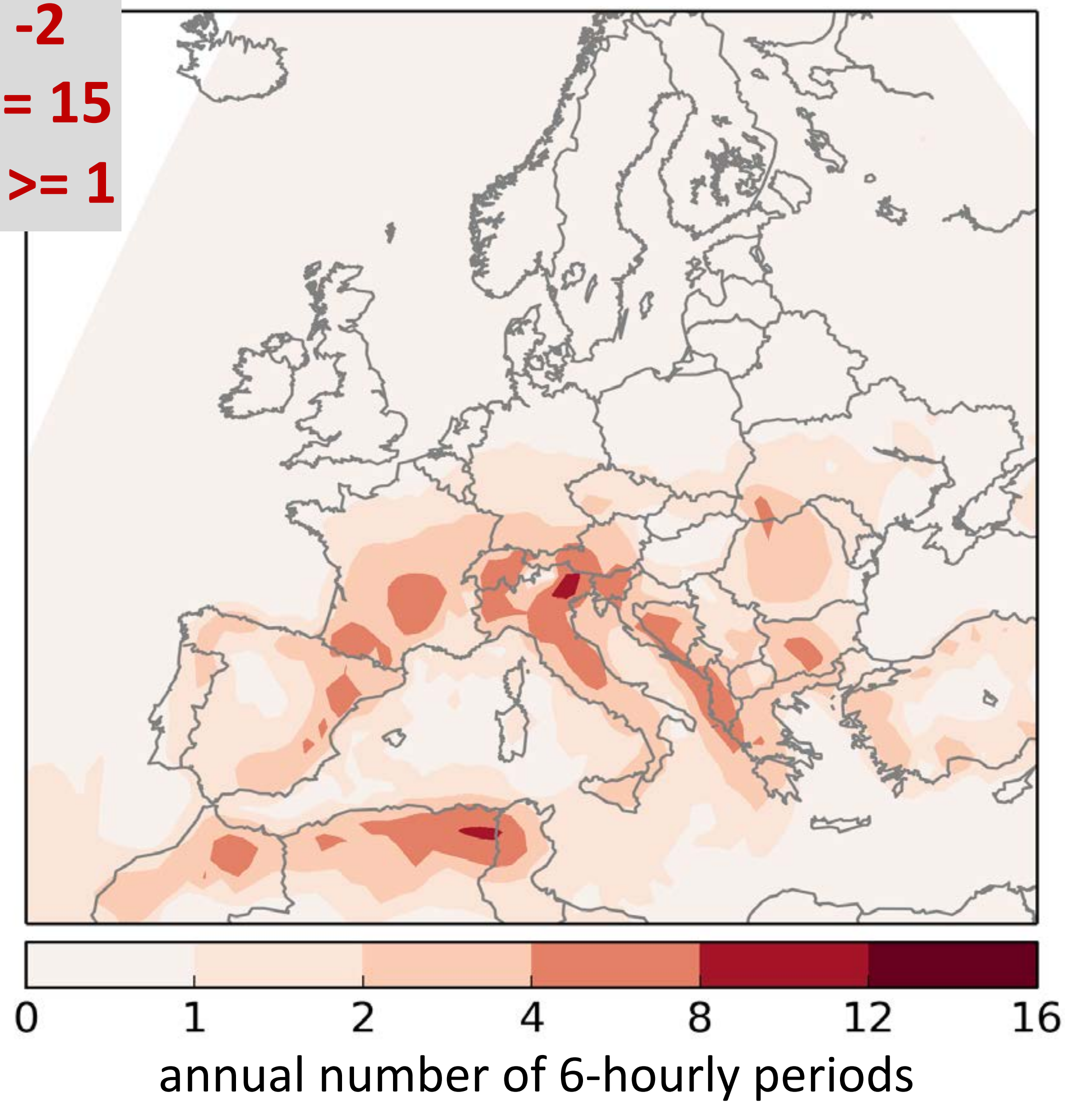
Severe - present

severe environment:

1. **unstable** **LI <= -2**
2. **strongly sheared** **DLS >= 15**
3. **precipitating** **Precip >= 1**

ERA-INTERIM 1979 - 2015



Look into the future using climate models

This project is funded by the European Union

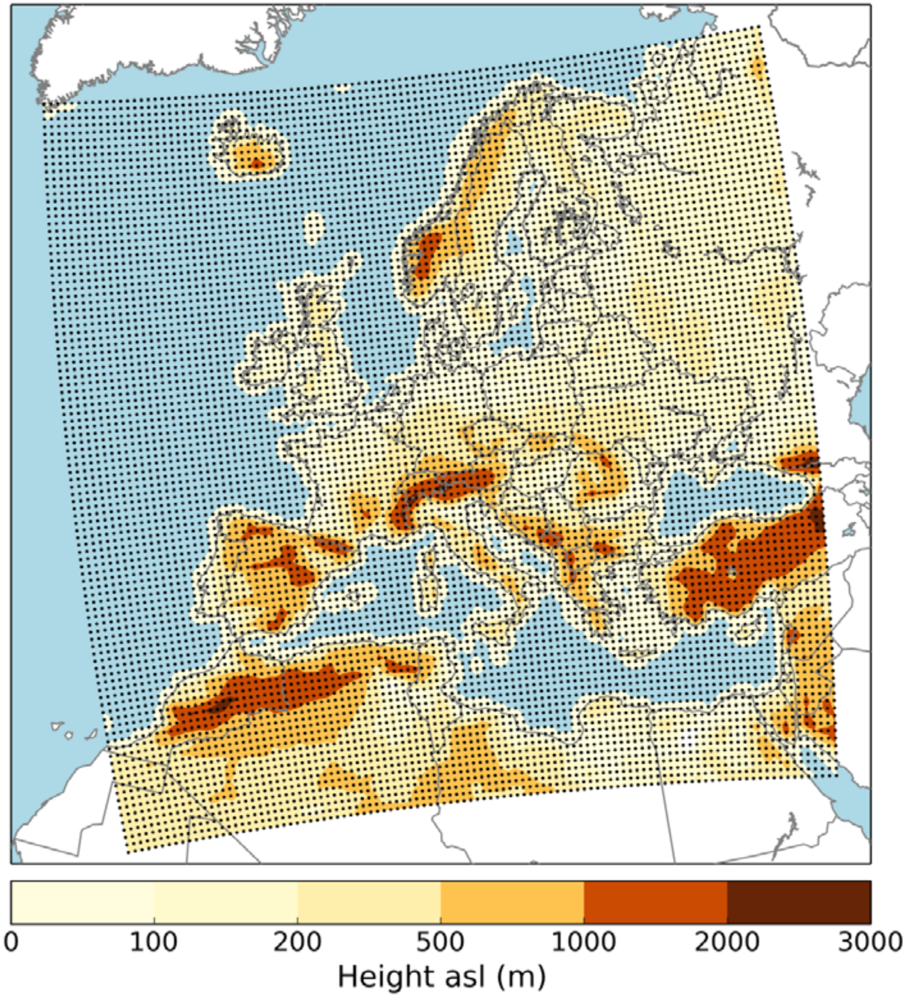
- 14 EURO-CORDEX model ensemble:

5 regional models
10 CMIP5 models

RCP4.5 and **RCP8.5** scenarios

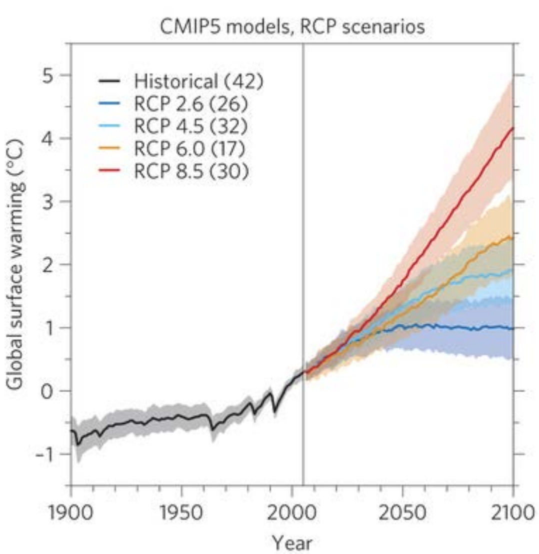
- 0.44 ° resolution

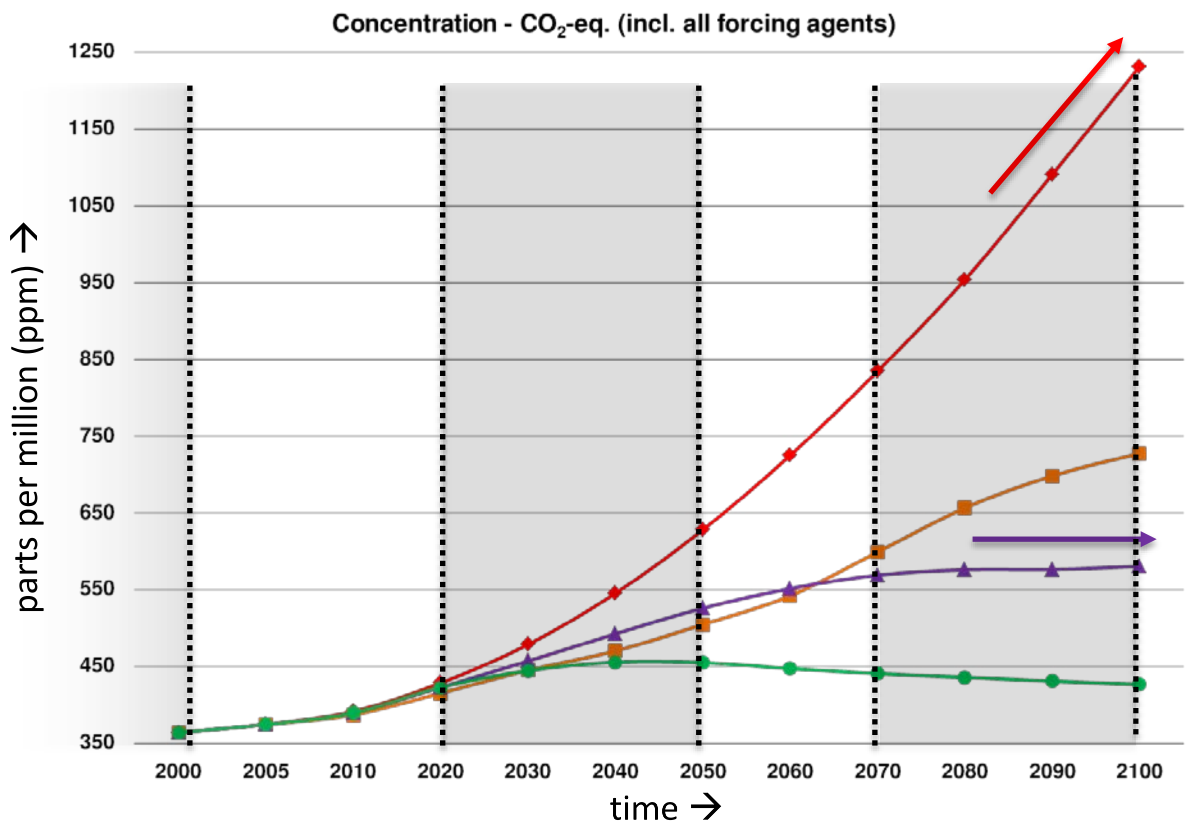
- 6h-ly data



Look into the future using climate models

- Representative Concentration Pathways
  - RCP8.5
  - RCP6
  - RCP4.5
  - ~ RCP2.6
    “Paris Agreement”





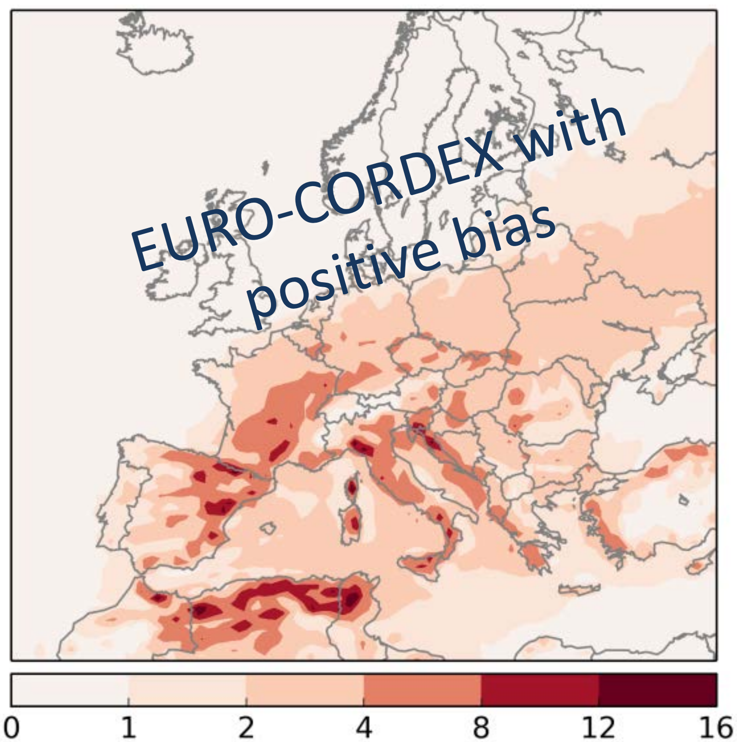
This project is funded by the European Union

Severe - present

severe environment:

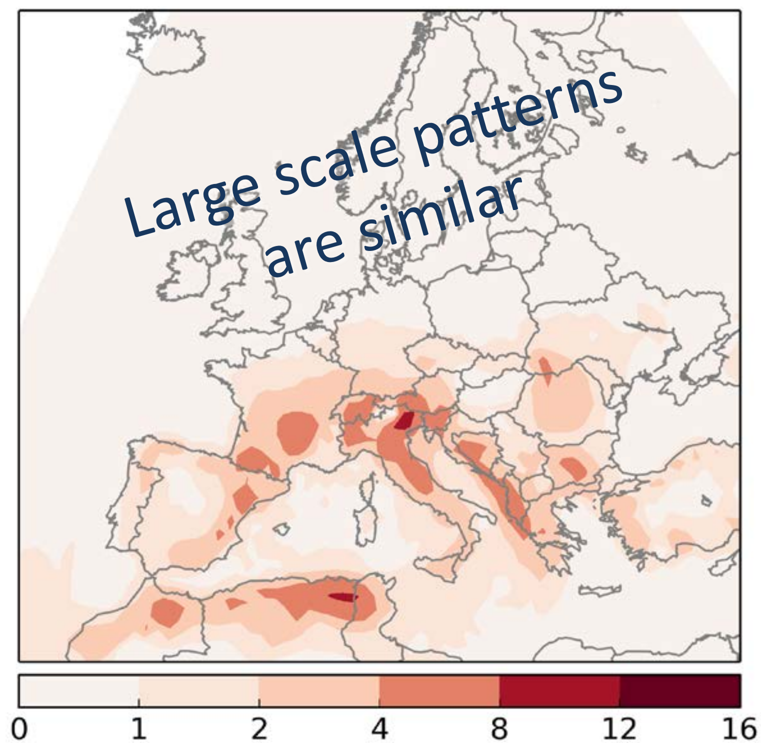
1. **unstable** **LI <= -2**
2. **strongly sheared** **DLS >= 15**
3. **precipitating** **Precip >= 1**

EURO-CORDEX 1971 - 2000



VS

ERA-INTERIM 1979 - 2015



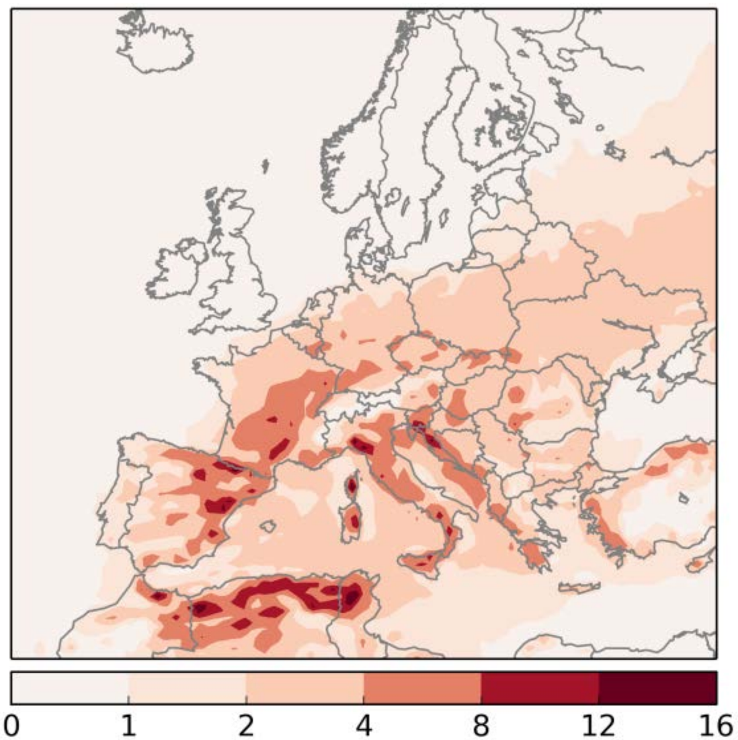
annual number of 6-hourly periods

Severe - future

severe environment:

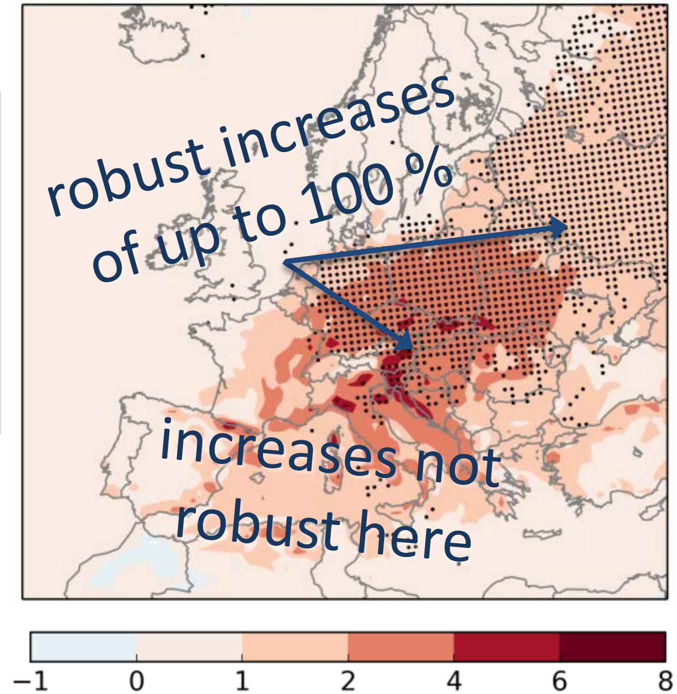
1. **unstable** **LI <= -2**
2. **strongly sheared** **DLS >= 15**
3. **precipitating** **Precip >= 1**

1971-2000



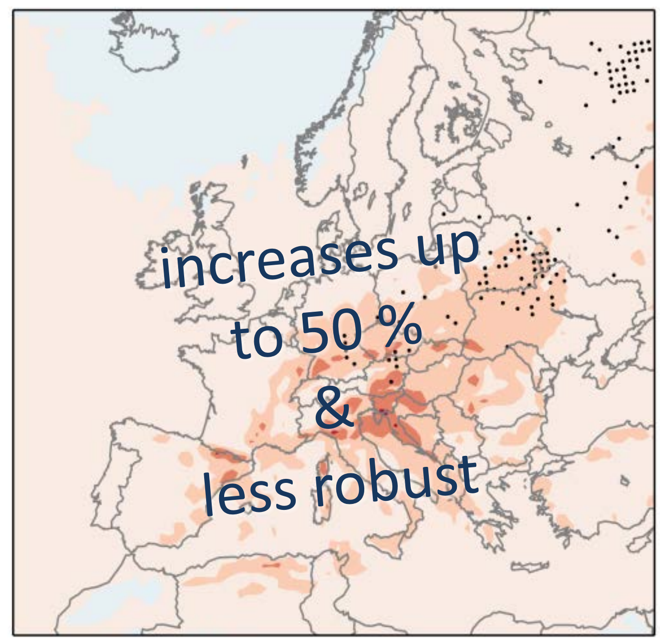
change until 2071-2100

RCP 8.5



Black dots:
Mean change
> 2 x
standard
deviation

RCP 4.5

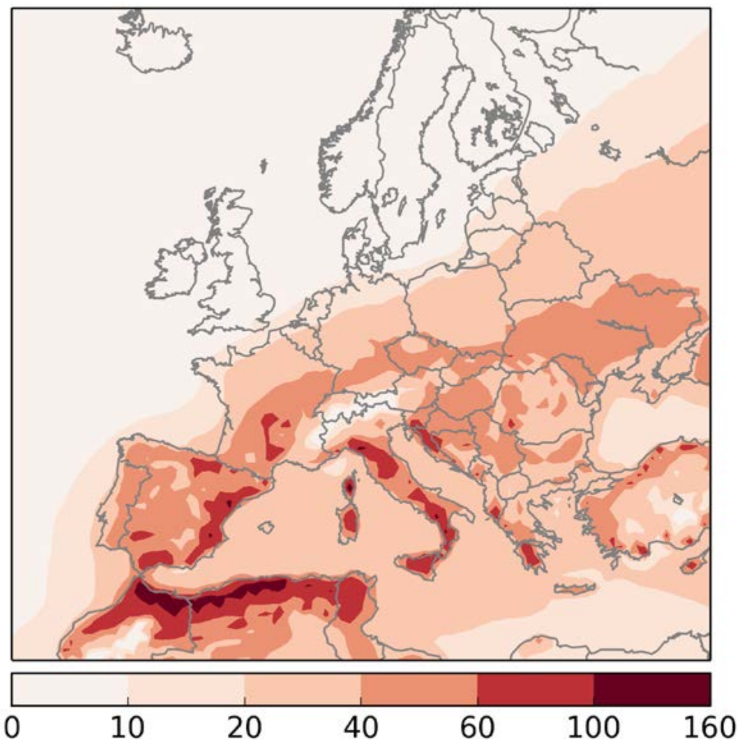


Instability

severe environment:

1. **unstable** **LI <= -2**
2. strongly sheared
3. precipitating

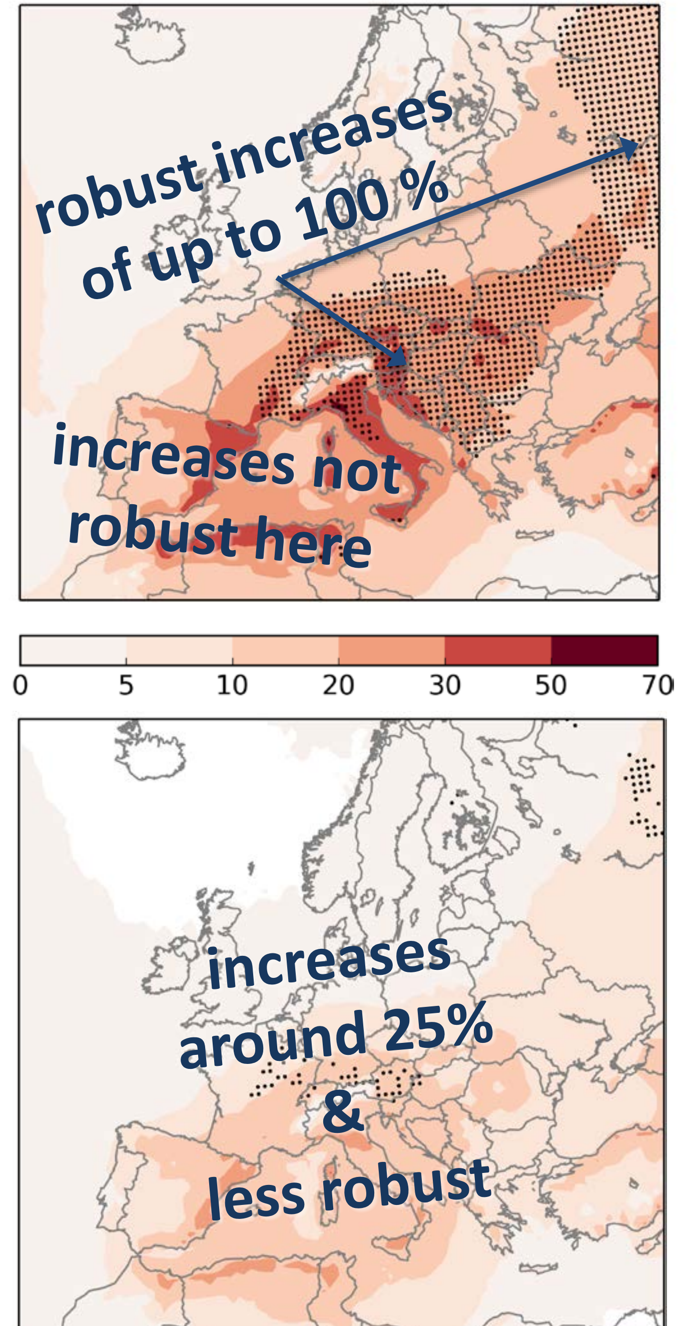
1971-2000



annual number of 6-hourly periods

change until 2071-2100

RCP 8.5



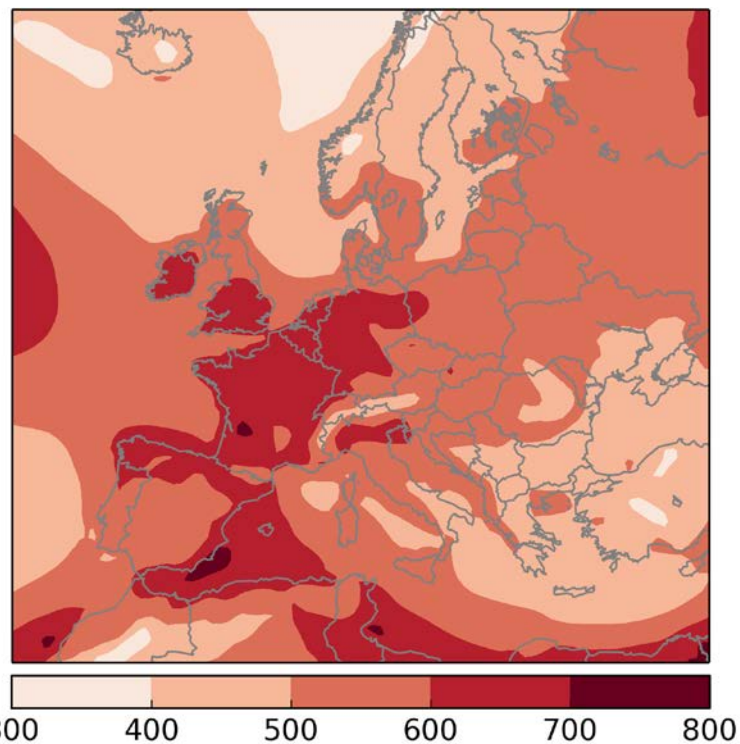
RCP 4.5

Shear

severe environment:

1. unstable
2. **strongly sheared** **DLS >= 15**
3. precipitating

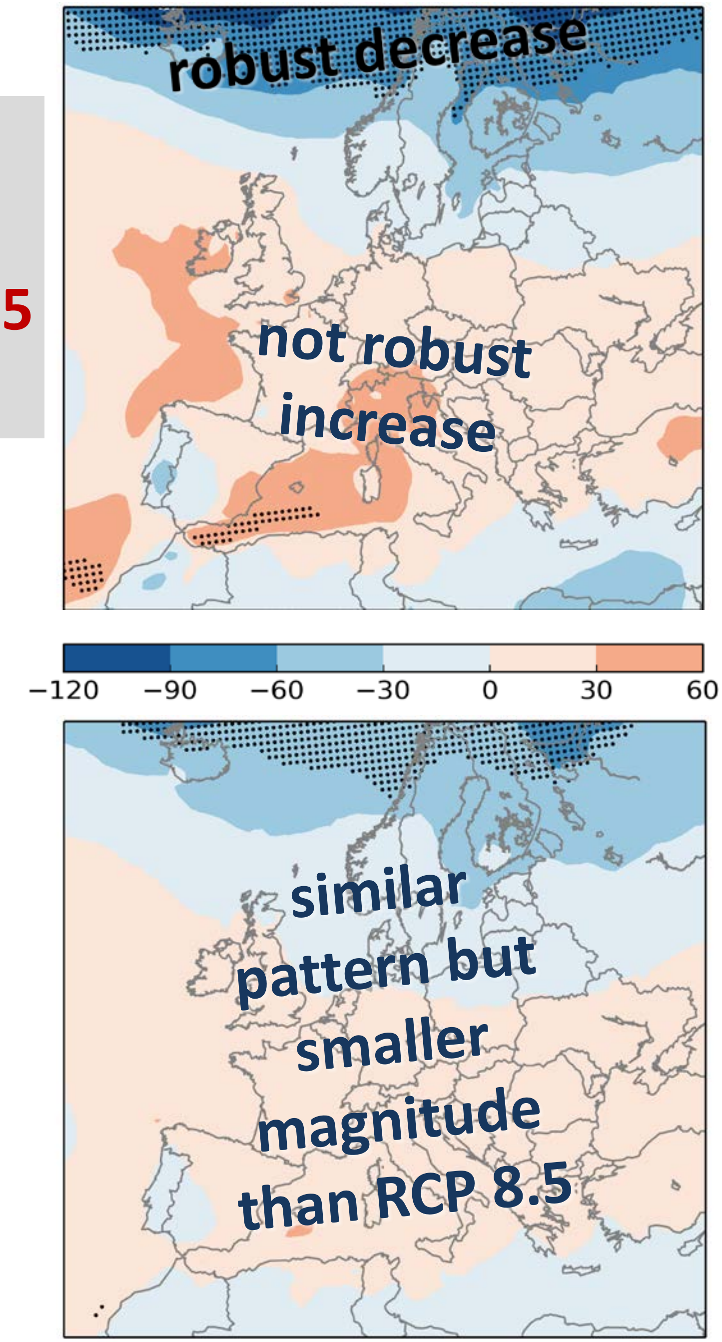
1971-2000



annual number of 6-hourly periods

change until 2071-2100

RCP 8.5



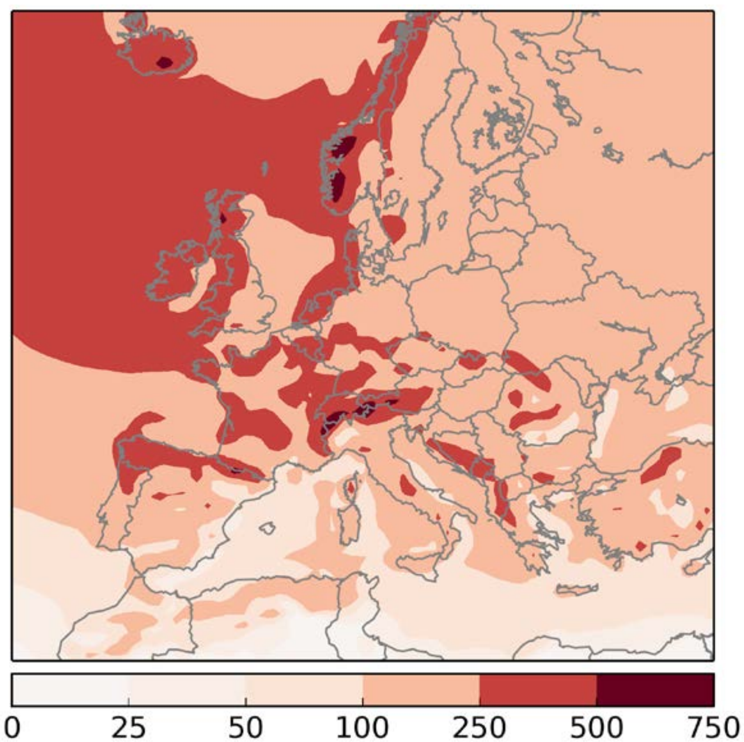
RCP 4.5

Precipitation

severe environment:

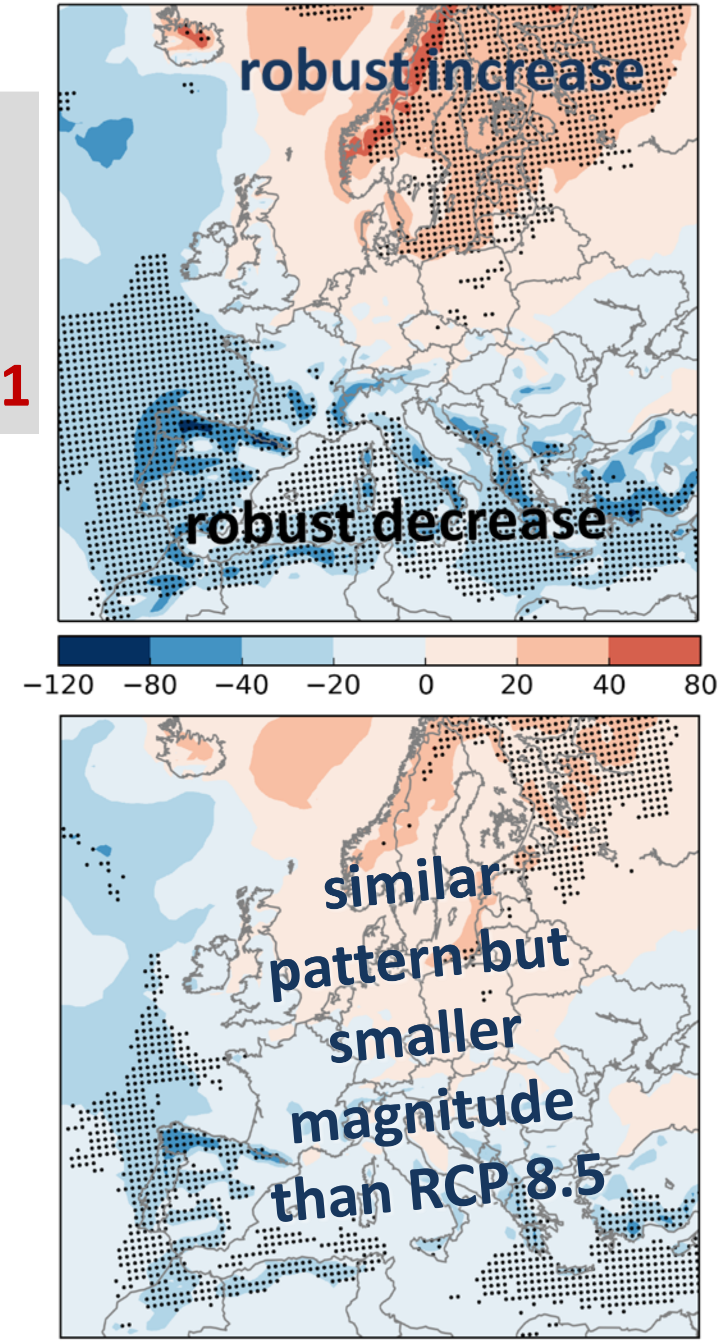
1. unstable
2. strongly sheared
3. **precipitating** **Precip >= 1**

1971-2000



annual number of 6-hourly periods

change until 2071-2100

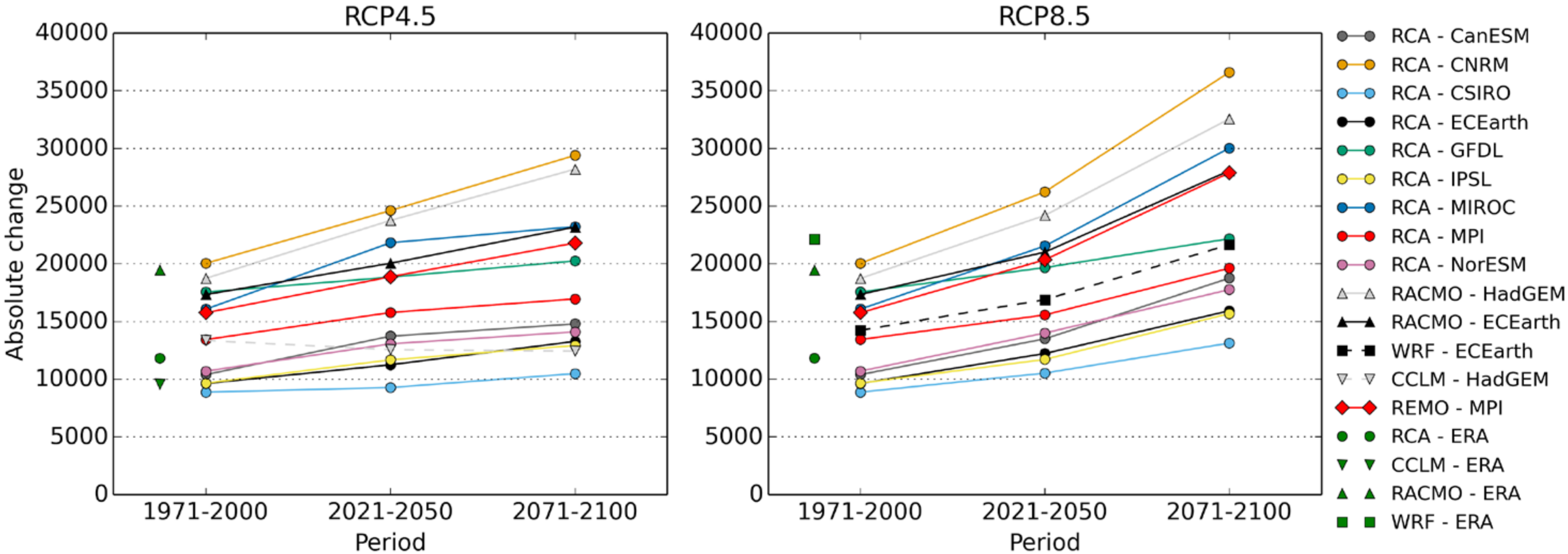


RCP 8.5

RCP 4.5

Model divergence

Mean annual number of severe environments in individual models



Models mostly agree on the direction of change

Large spread already for the historical period, increasing in the future

Source of spread (uncertainty): **Instability**

Limitations of results

- The 0.44° models fail to capture local maxima around the mountains (e.g. Alps)
- We are not modelling a number of hail events, but only “favourable situations for severe storms”

Additive Regression Convective Hazard Model (ARCHaMo)

Anja T. Rädler

- Estimates the probability of hail:
  P (hail) = P (storm) x P (hail|storm)

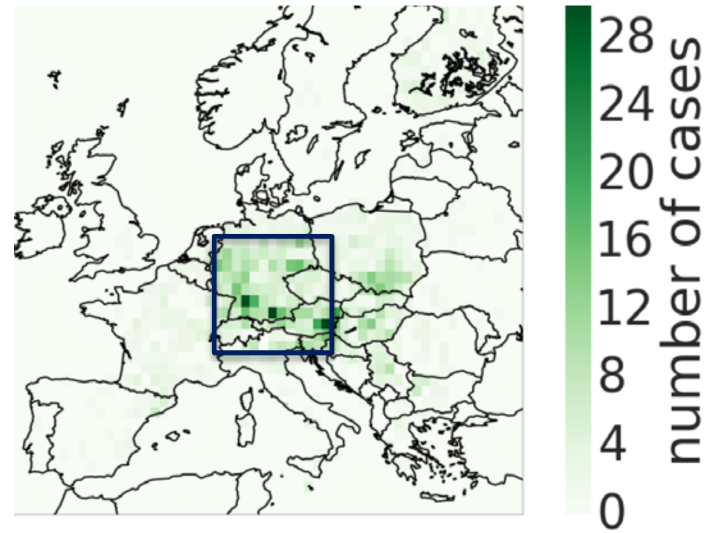
- These probabilities are estimated by predictors derived from reanalysis data

- The P functions are estimated by an additive logistic regression using severe weather observations

Project ARCS
FONA
Research for Sustainable Development
BMBF
Federal Ministry of Education and Research

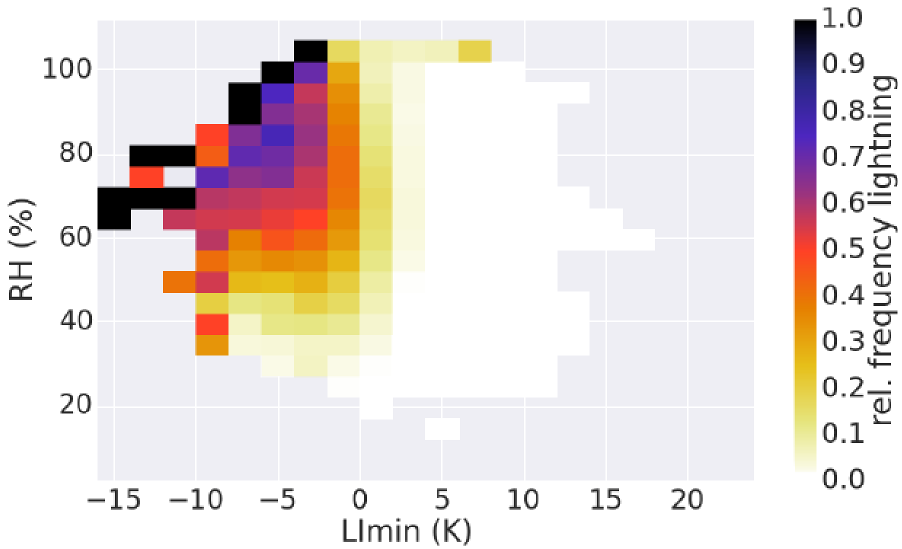
ESSL
European Severe Storms Laboratory

Logistic model ARCHaMo

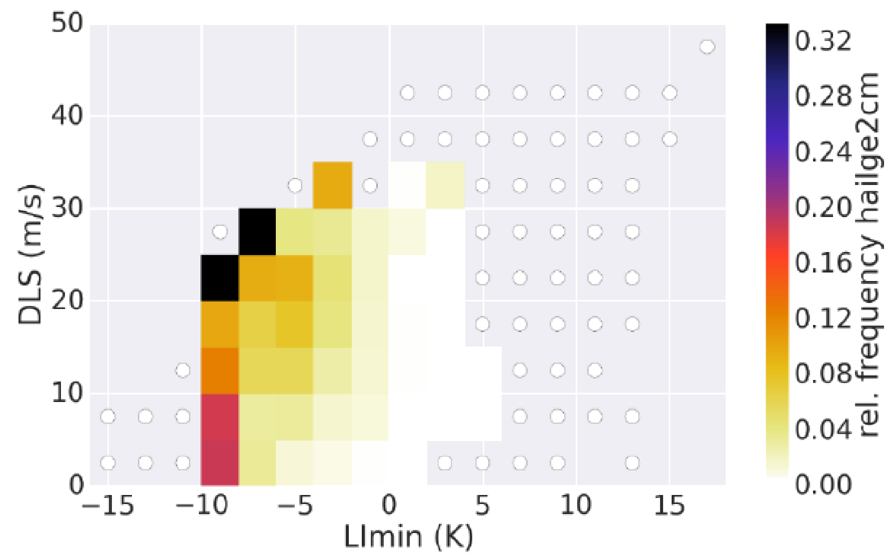


Observed relative frequencies as a function of ERA-Interim predictors

Lightning



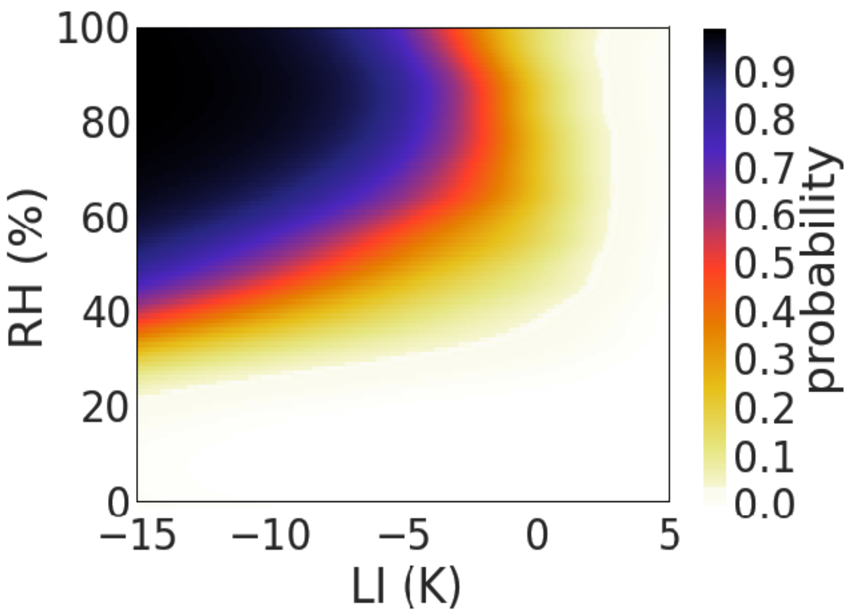
Hail ≥ 2 *cm*



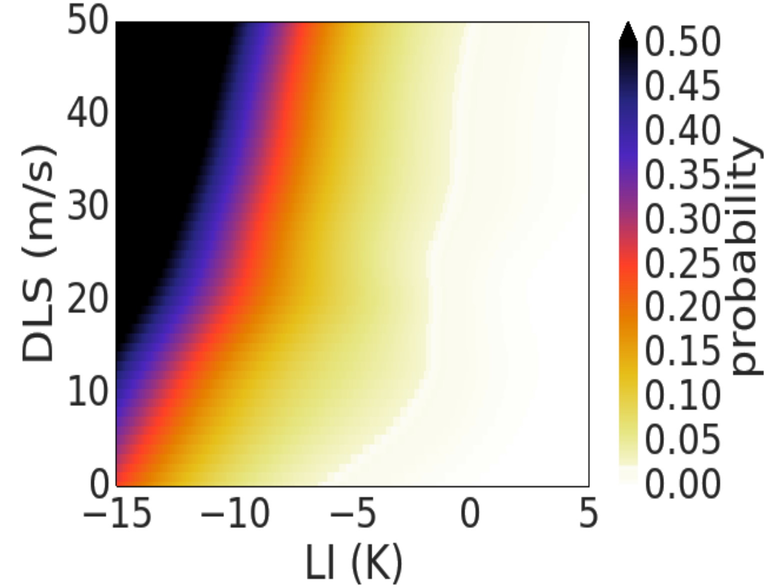
Logistic model ARCHaMo

Observed relative frequencies as a function of ERA-Interim predictors

P(lightning)

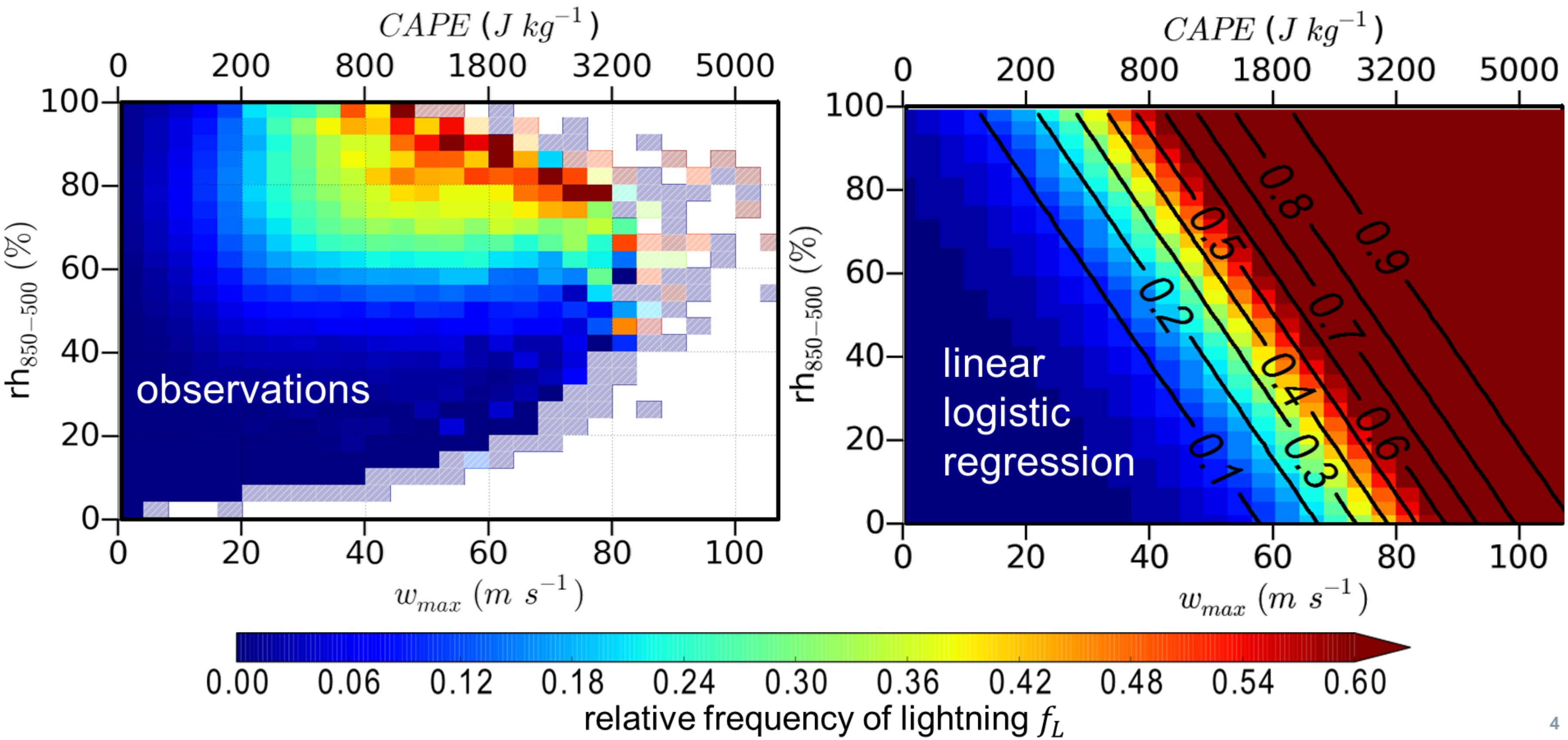


P(hail ≥ 2 cm | lightning)



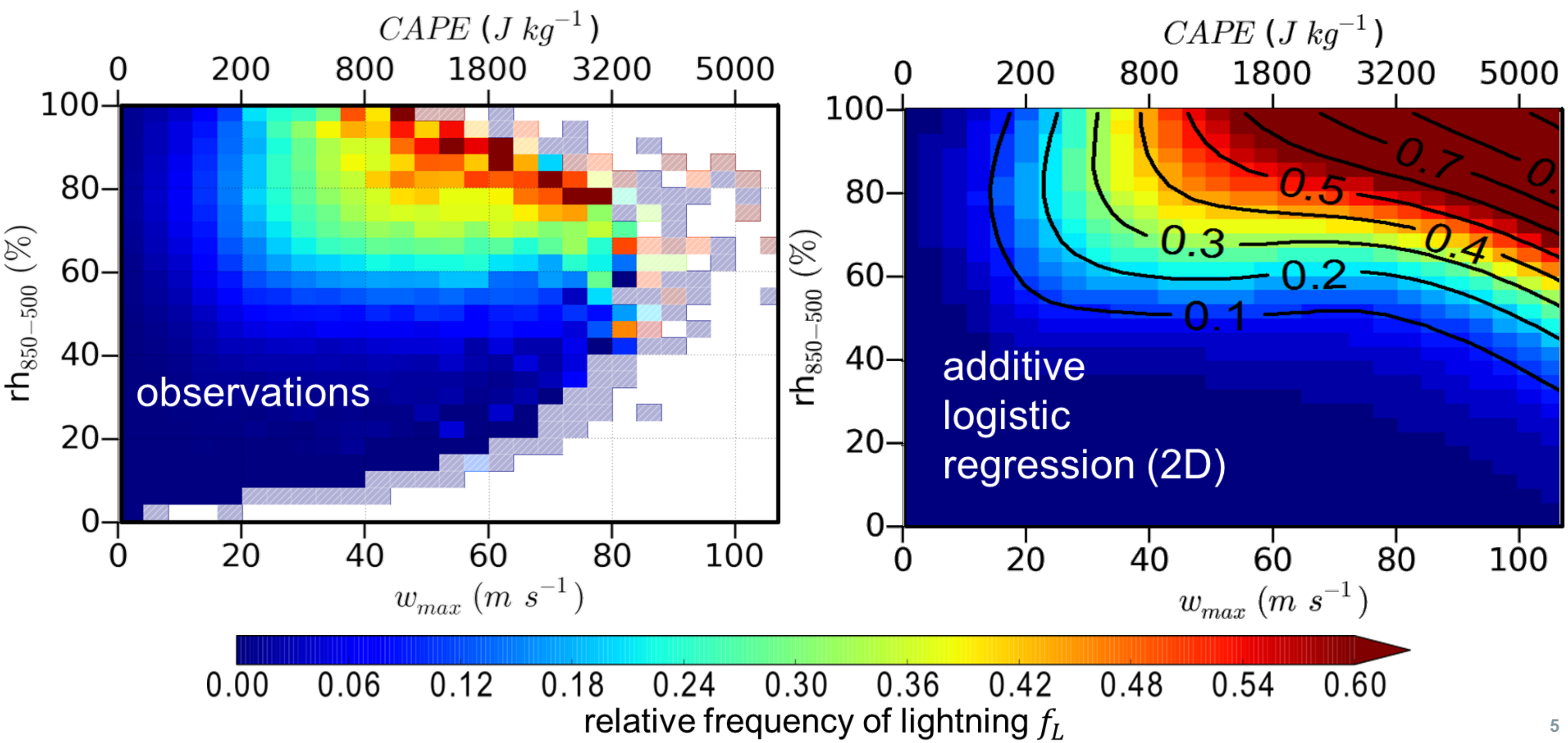
Logistic model ARCHaMo

Fit to the observations:
Linear model vs. additive model



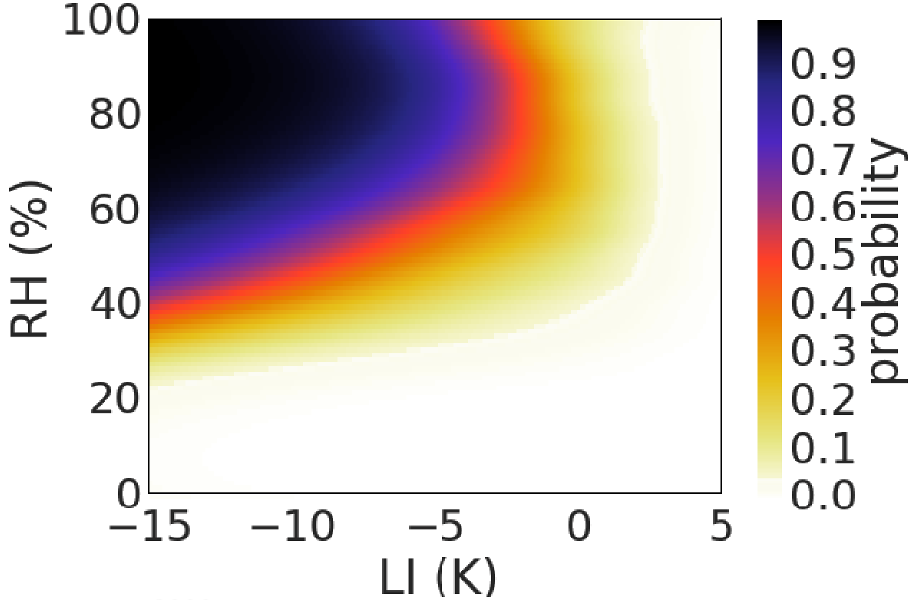
Logistic model ARCHaMo

Fit to the observations:
Linear model vs. additive model

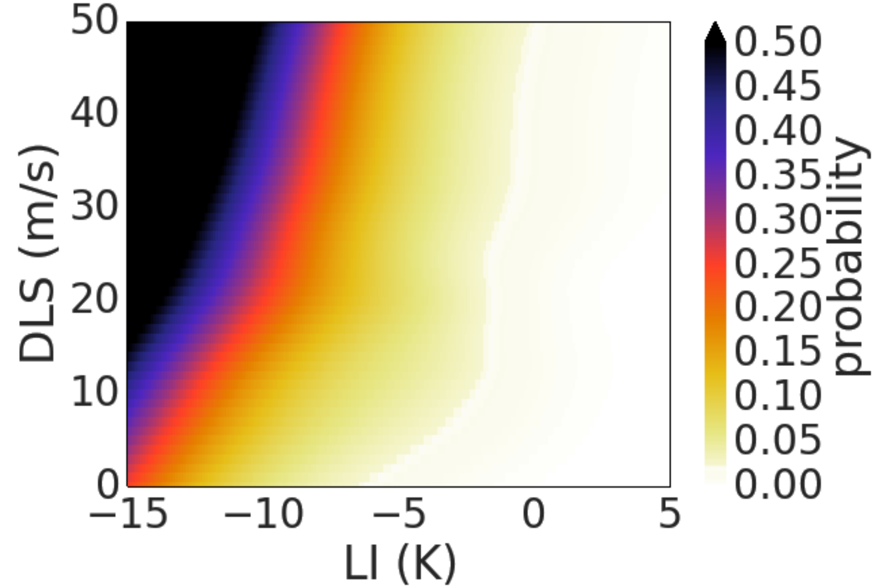


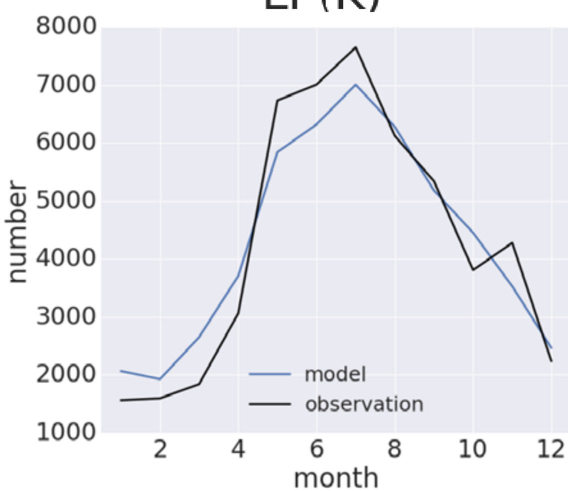
Annual cycles

P(lightning)

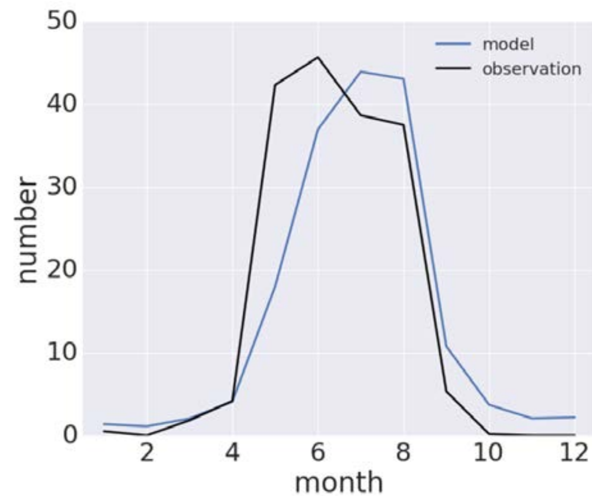


$P(\text{hail} \geq 2\ cm\,|\,\text{lightning})$





(a) Lightning



(b) Hail ≥ 2 cm

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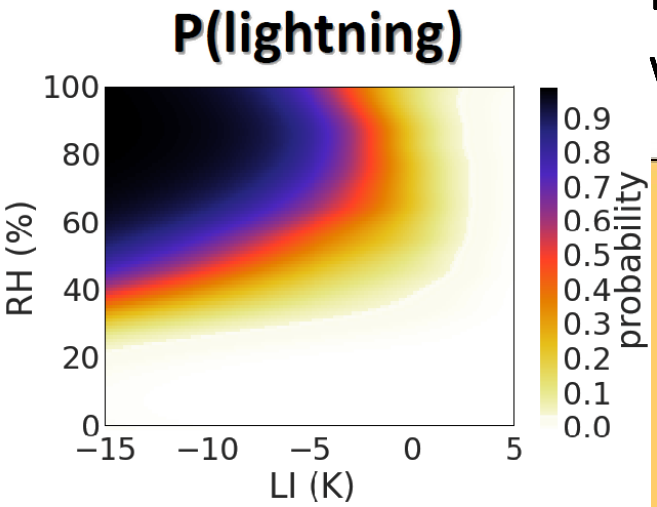
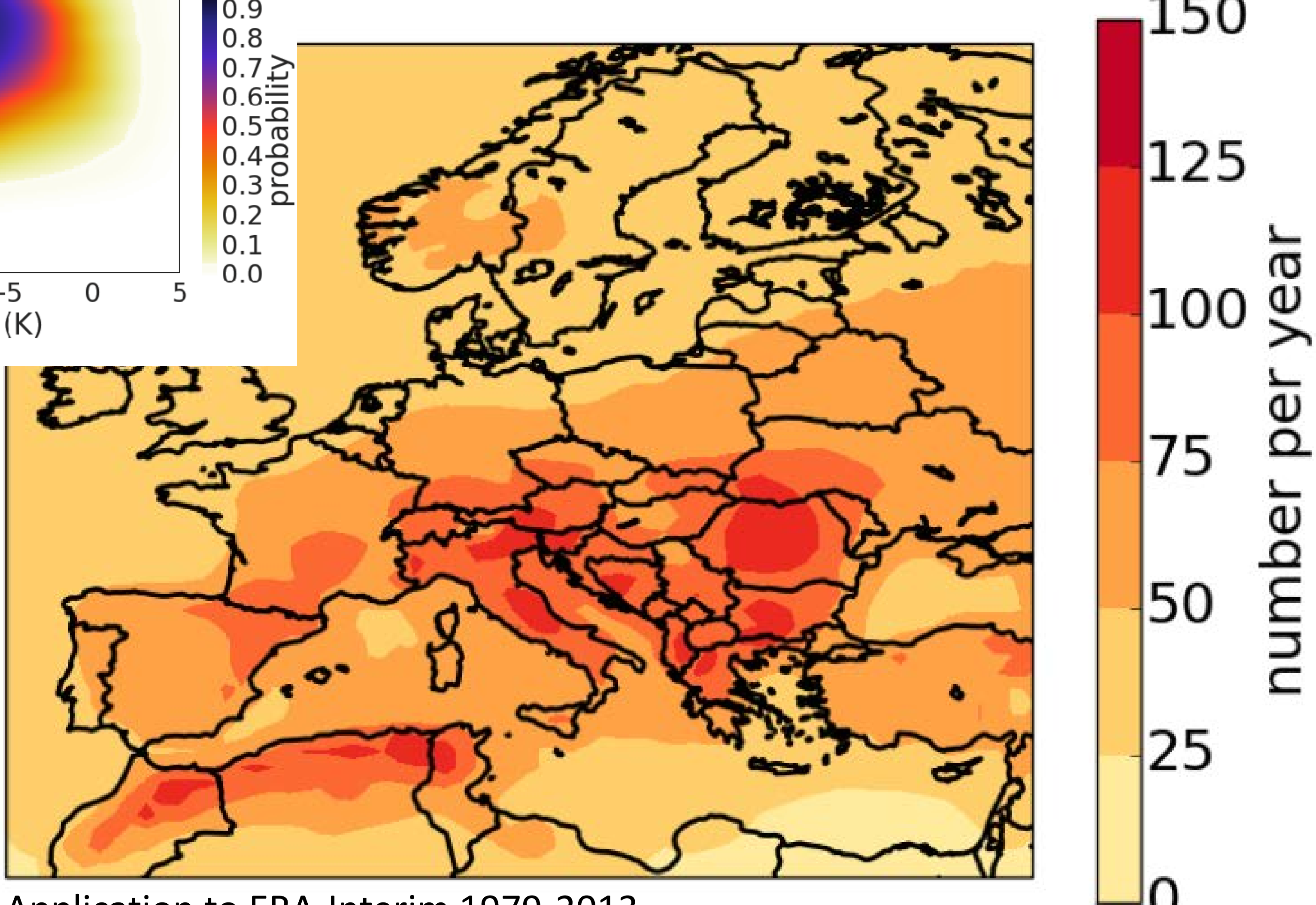
Modelled lightning



Expected annual number of 6-hourly periods with lightning (within ~70 km of a point)



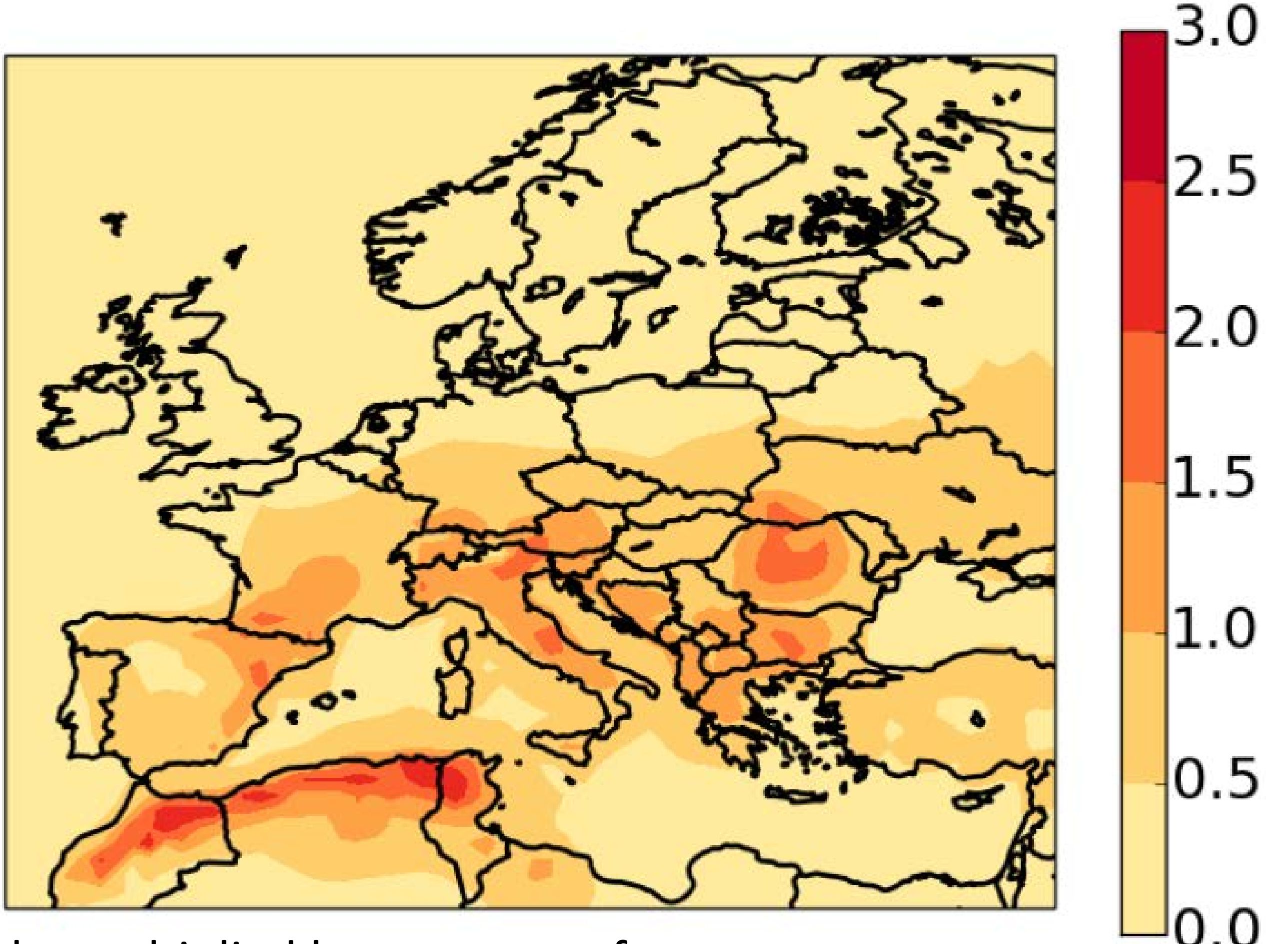
Application to ERA-Interim 1979-2013

Modelled hail

P(hail)

Expected annual number of 6-hourly periods with hail of 2cm or larger (within ~70 km of a point)

Application to ERA-Interim 1979-2013

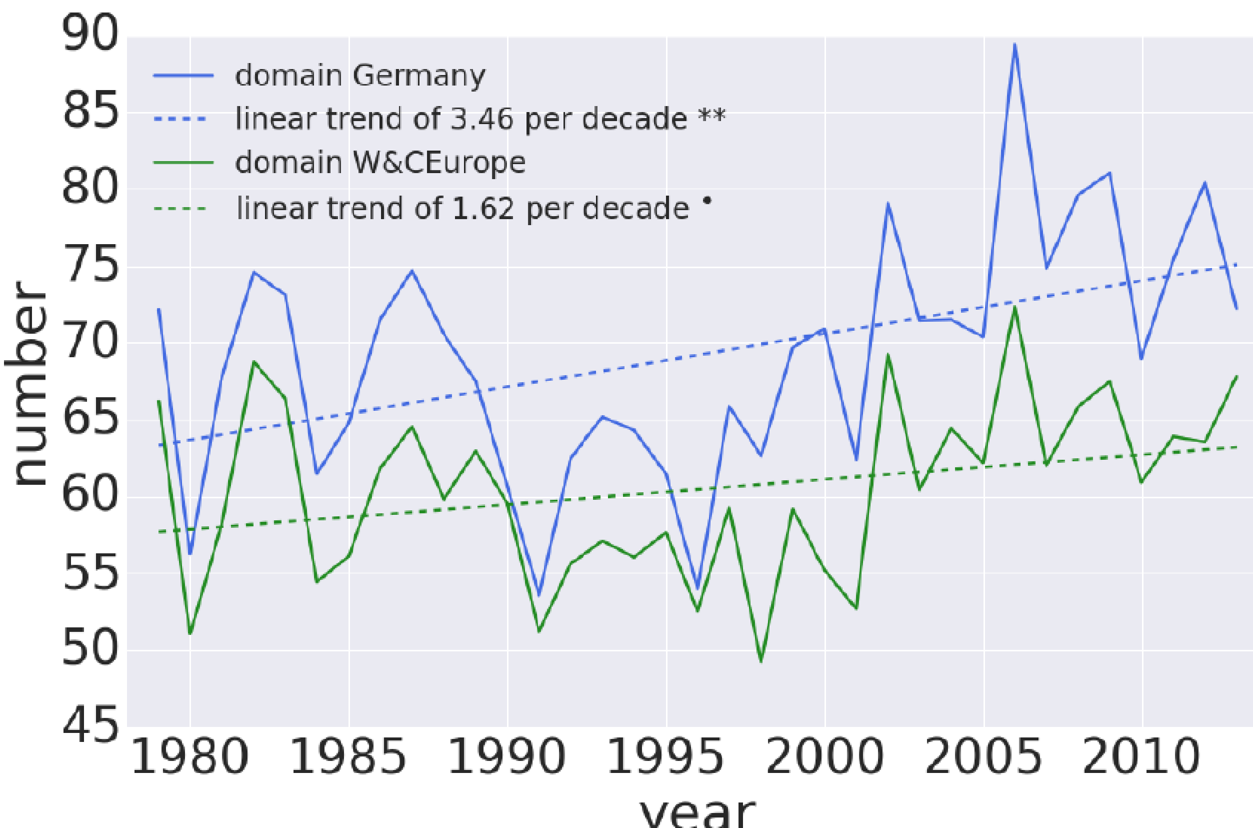


Numbers need to be multiplied by a constant factor to account for underreporting in the calibration data set

Trends in the past

Trend of lightning

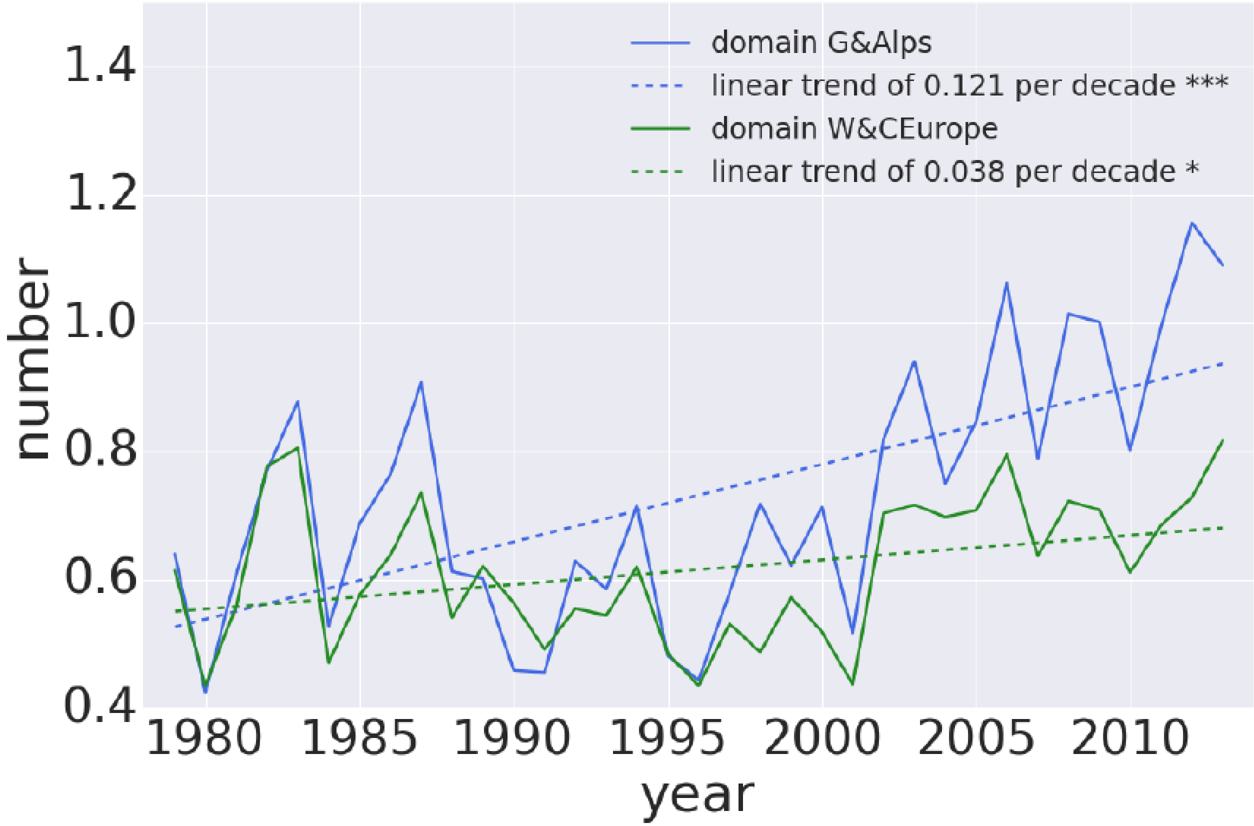
Annual number of 6-hourly periods with lightning (within ~70 km of a point)



Trends in the past

Trend of large hail

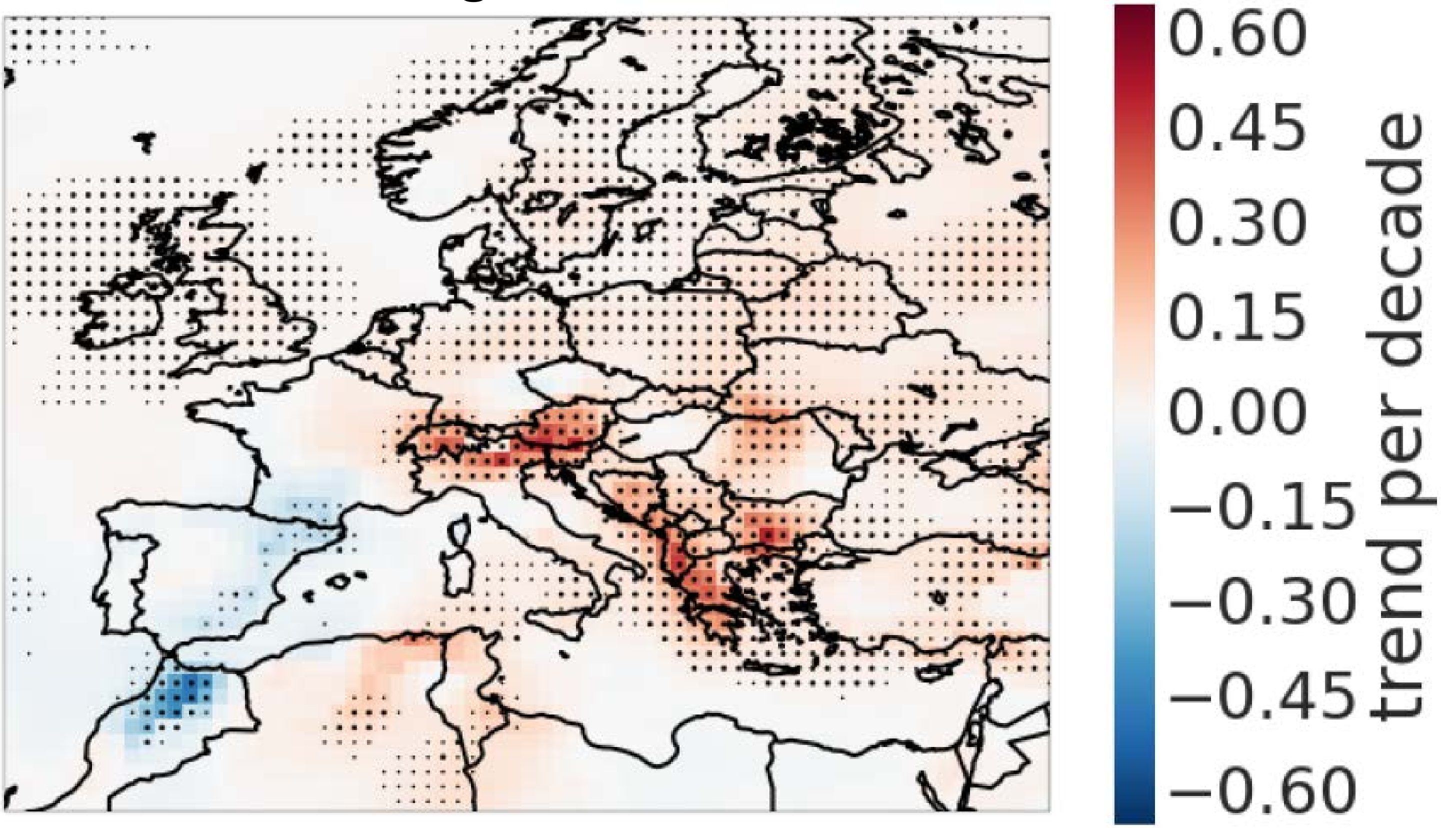
Annual number of 6-hourly periods with hail of 2 cm or larger (within ~70 km of a point)



Trends in the past

Trend of large hail
(1979 – 2013)

Annual number of 6-hourly periods with hail of 2 cm or larger (within ~70 km of a point)



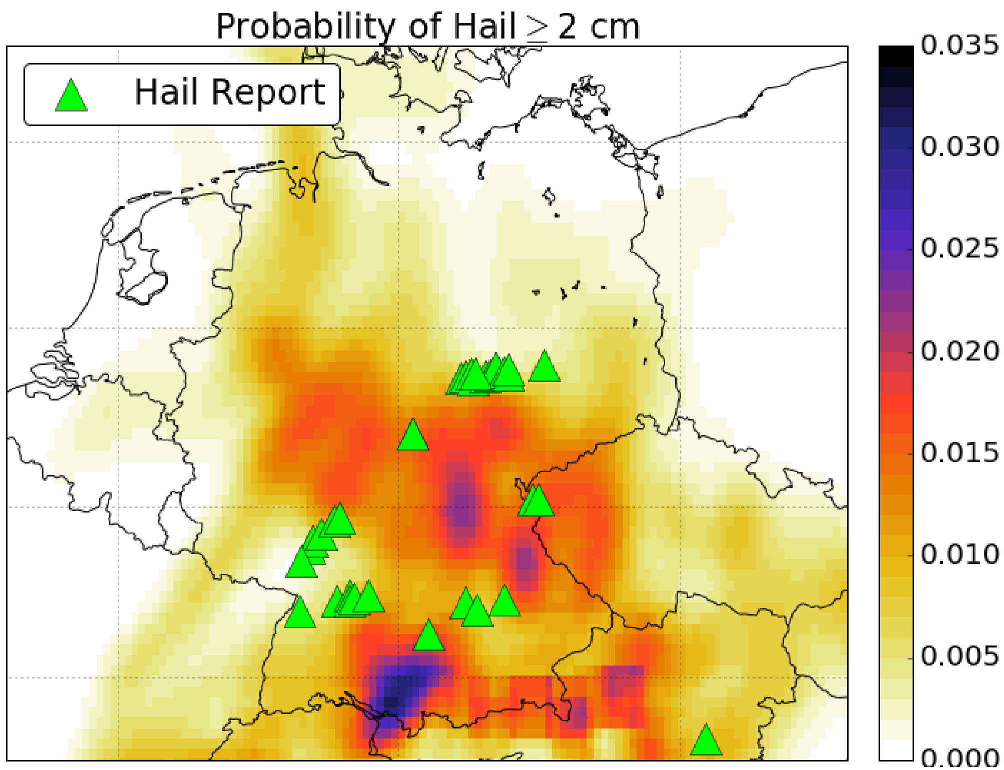
Forecasting applications

Lars Tijssen

Developed for
German Weather Service

ARCHaMo model can also be applied to numerical weather forecasts

07 July 2015 18Z



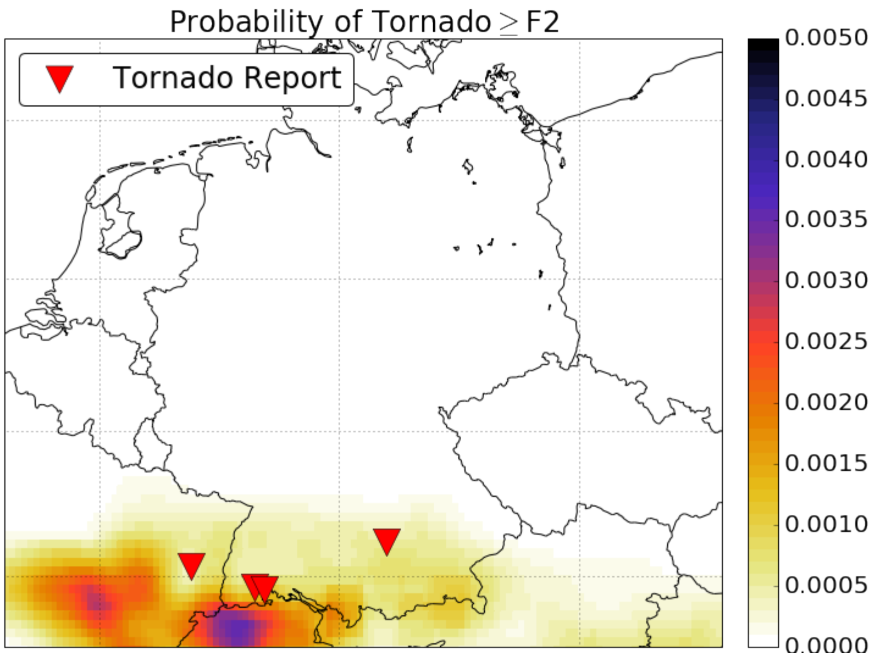
ECMWF + 30 hour forecast
ESWD reports between -3 and +3 hours

Forecasting applications

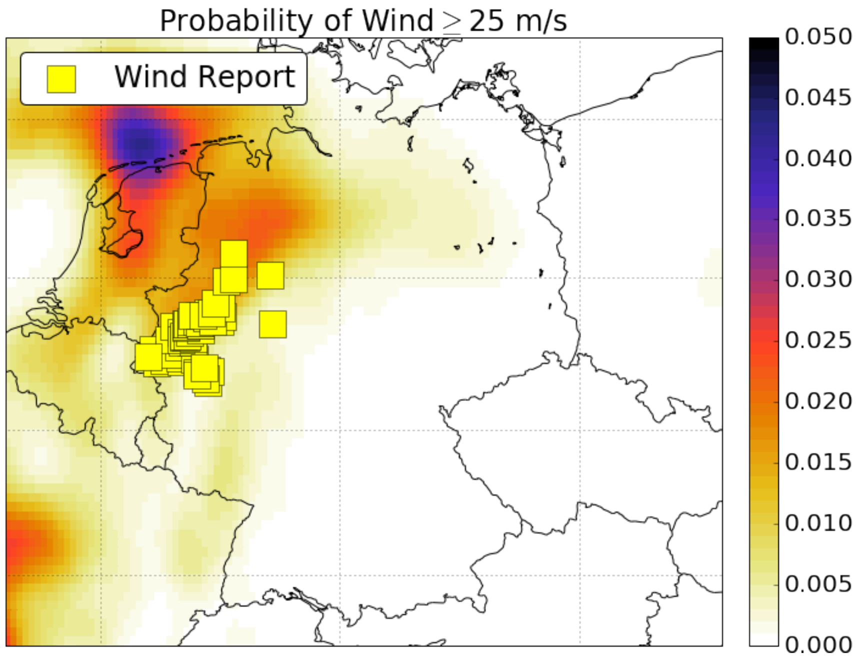
From: Lars Tijssen and Anja Rädler

... and to other convective hazards

13 May 2015 18Z



09 June 2014 18Z

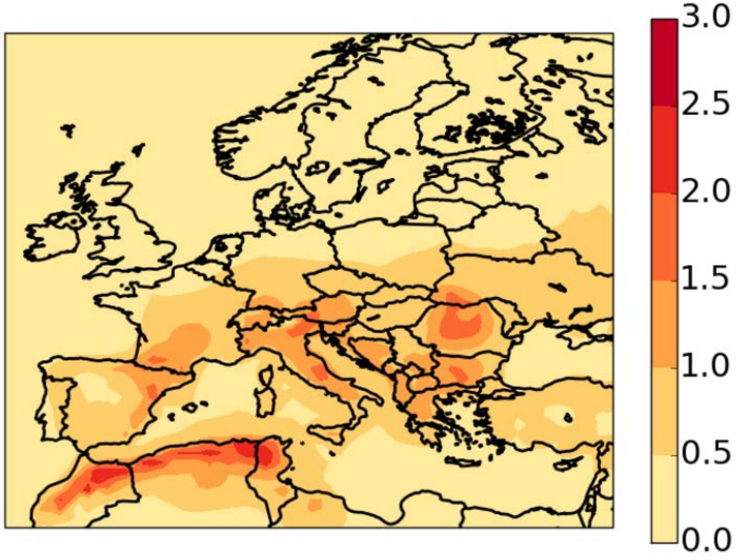


Answers

Questions:

1. How is the hail hazard distributed according to the present climatology?

-> general picture:
details depend on
reanalysis data set



2. Will climate change affect hail probability? How?

-> increases are likely across much of Europe,
in particular central Europe, end of century, in RCP8.5

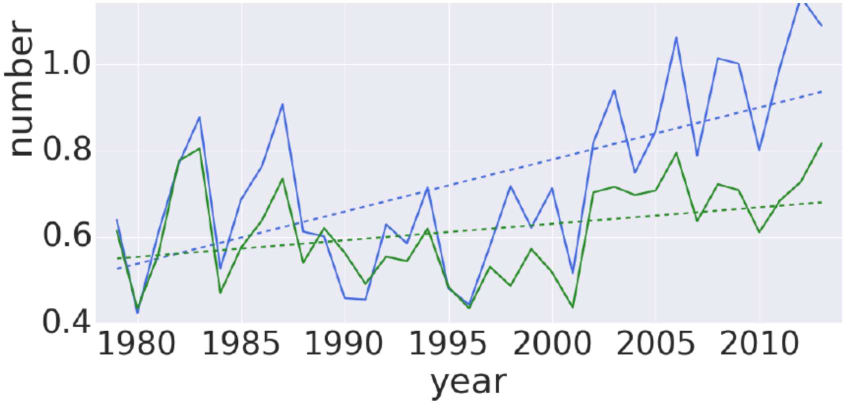
-> quantitative results using ARCHaMo coming up

Answers

3. Is climate change already having a measurable effect?

   -> increase since 1979, consistent with climate change predictions

   we cannot say for sure how much is due to climate change



4. Can we improve hail probability forecasts for the next days or weeks using numerical models?

   -> we have started to explore this: the first results are hopeful

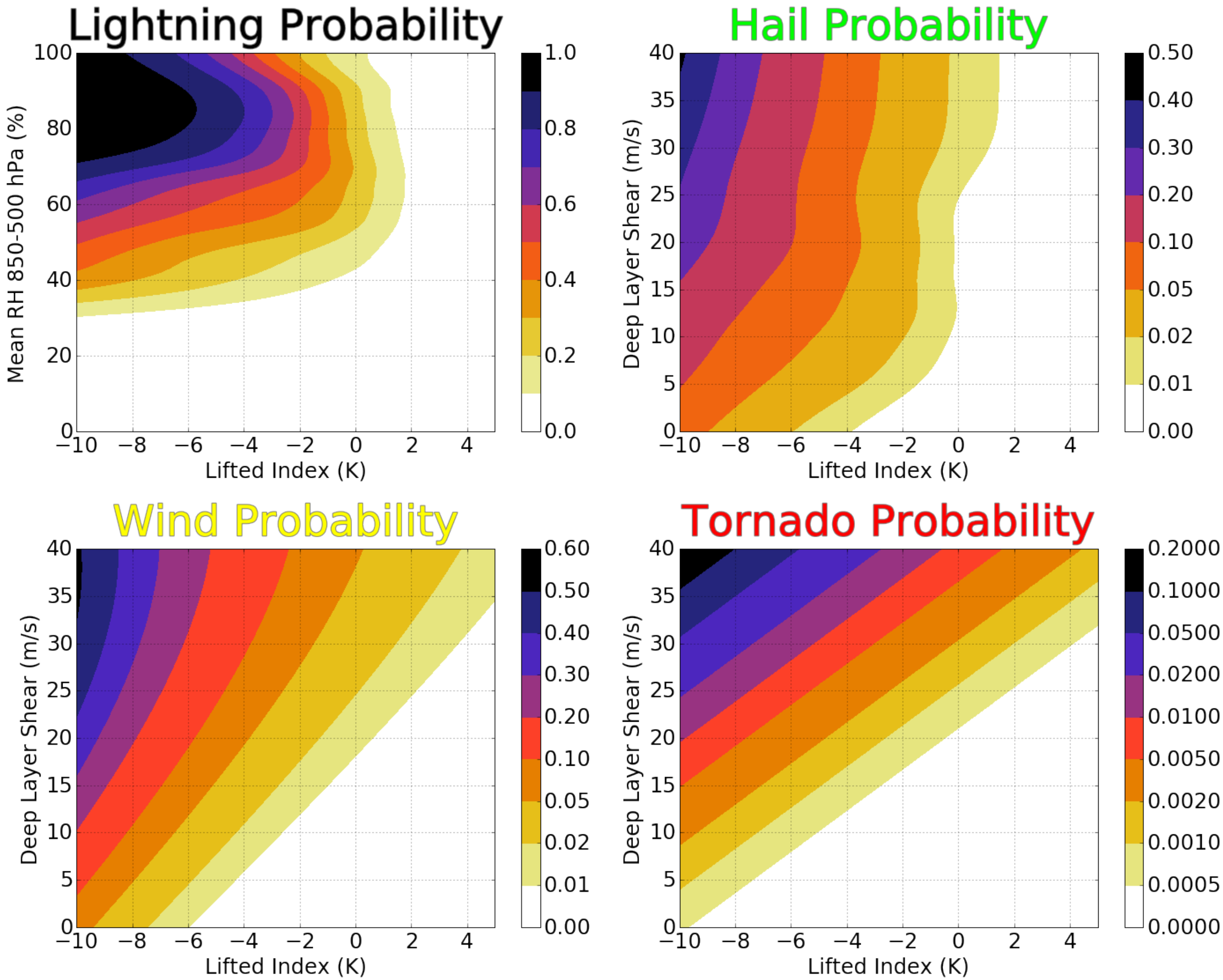
Limitations to be addressed

- The ARCHaMo model is a basic framework, that can be refined by using more predictors
- We are now applying it to EuroCordex model projections
- Need to go beyond probabilities to smaller scales, and also model the impact
- We are working to apply and calibrate the model using data from the USA
- More data needed in Europe!

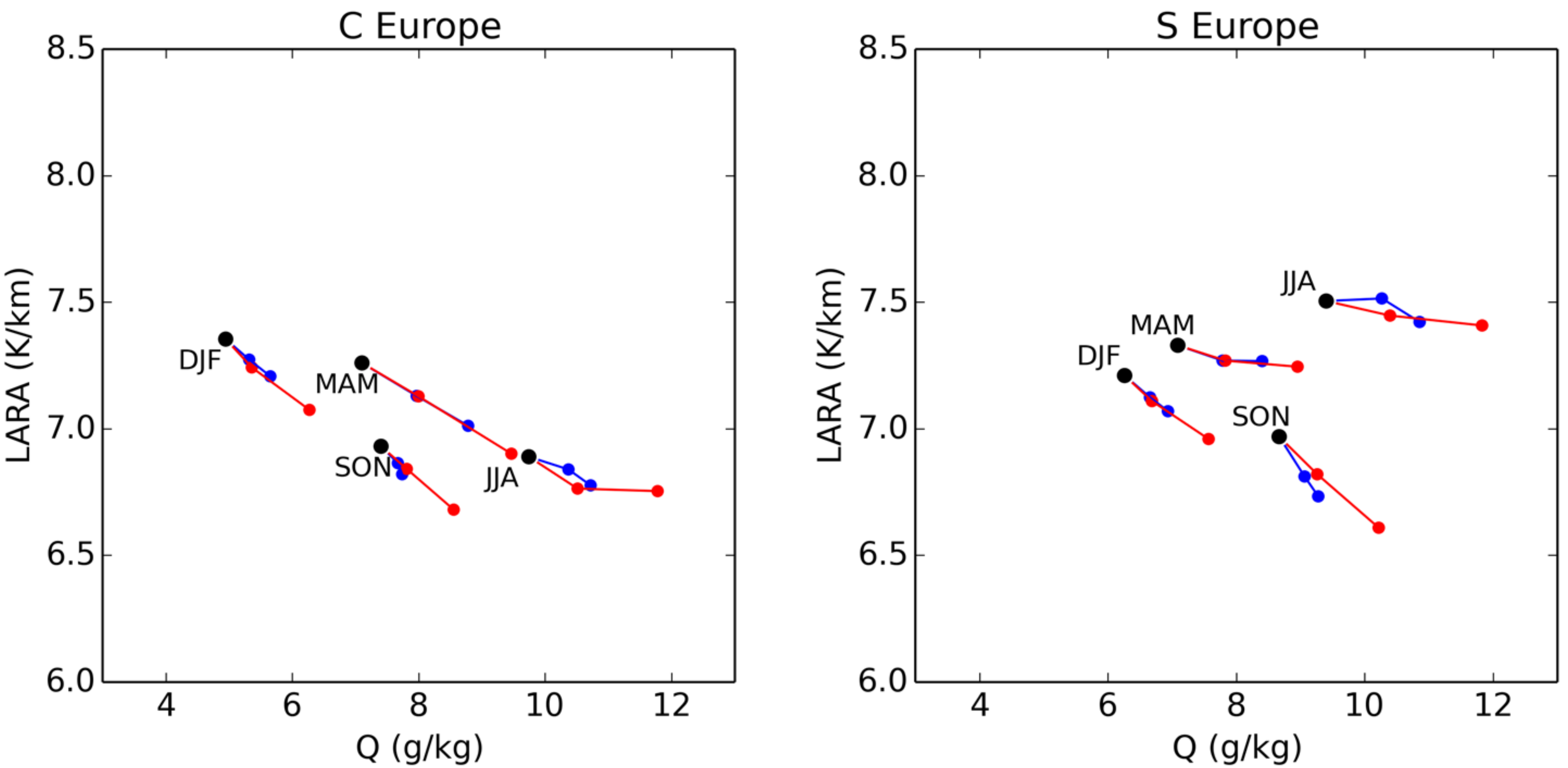
Data availability over Europe is a problem

Help ESSL collect more data by using:

Bonus slides


Lightning Probability
Mean RH 850-500 hPa (%)
Lifted Index (K)
0.0 0.2 0.4 0.6 0.8 1.0
Hail Probability
Deep Layer Shear (m/s)
Lifted Index (K)
0.00 0.01 0.02 0.05 0.10 0.20 0.30 0.40 0.50
Wind Probability
Deep Layer Shear (m/s)
Lifted Index (K)
0.00 0.01 0.02 0.05 0.10 0.20 0.30 0.40 0.50 0.60
Tornado Probability
Deep Layer Shear (m/s)
Lifted Index (K)
0.0000 0.0005 0.0010 0.0020 0.0050 0.0100 0.0200 0.0500 0.1000 0.2000

Seasons LARA vs Q925



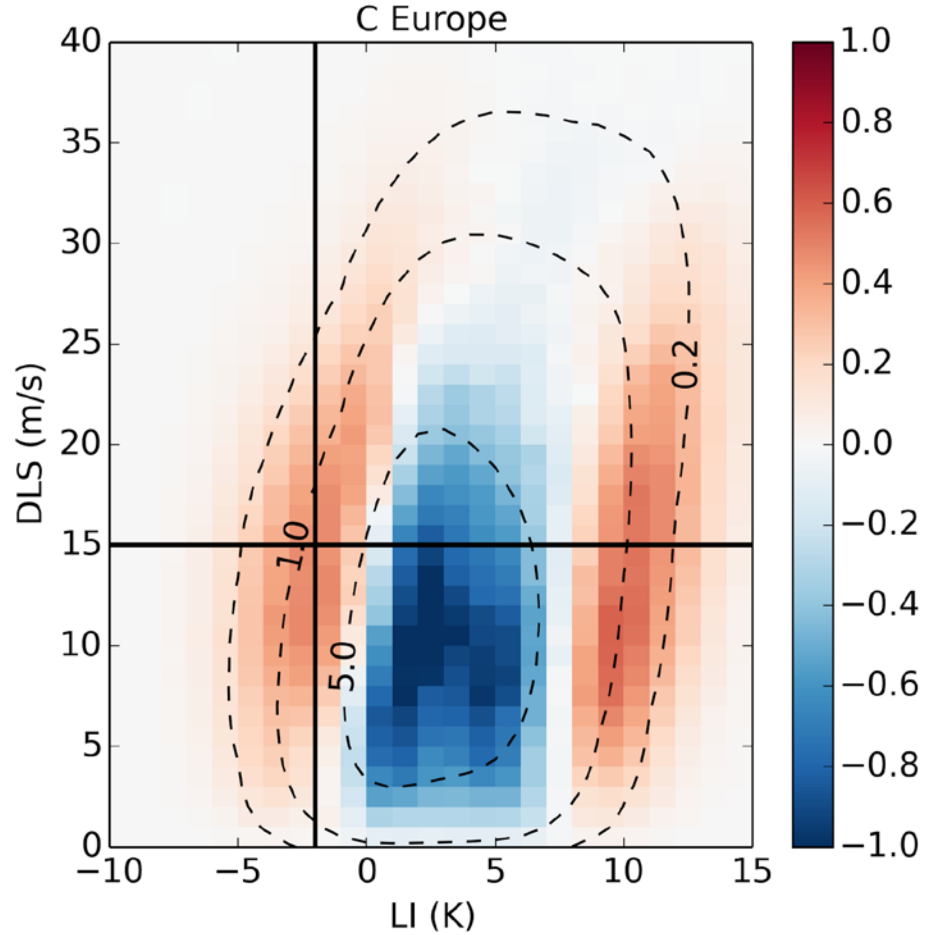
Changes in LI and DLS parameter space

Increase in unstable environments regardless of vertical wind shear

Increase in extremely stable environments

Decrease in weakly stable environments

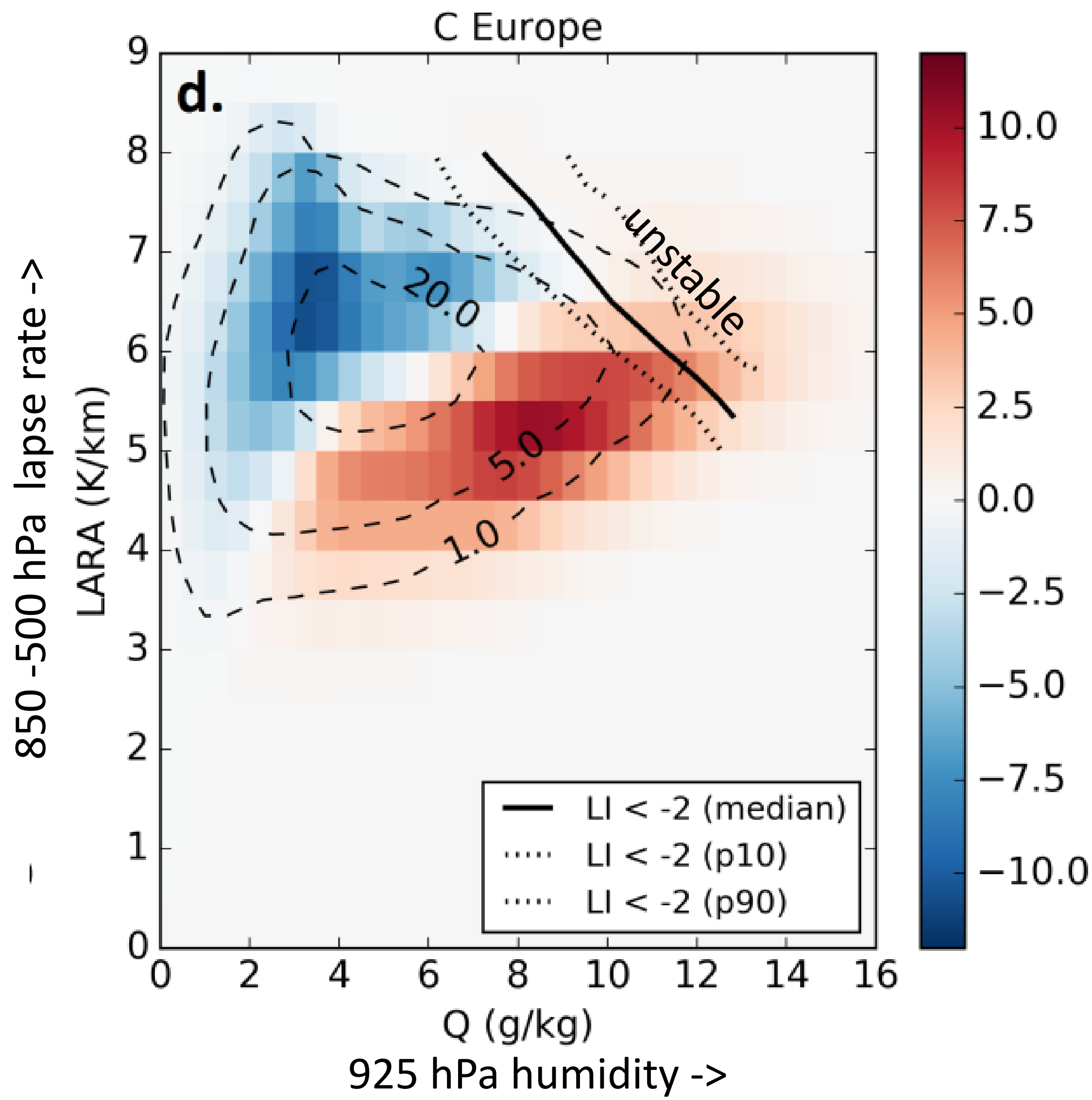
Annual mean number of environments in 1 K and 1 m/s grid



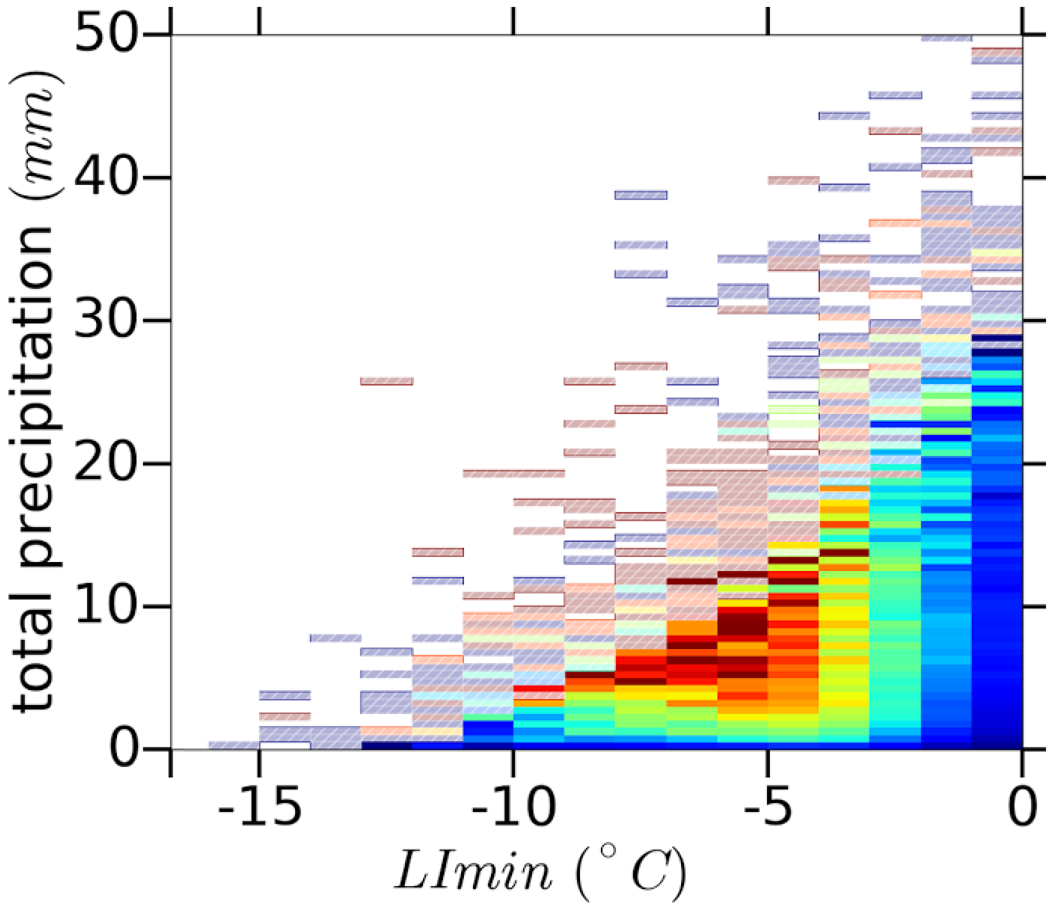
reasons for increased instability

dashed: present climate frequency

colors: changes between present and 2071-2100 rcp8.5



Precipitation vs LI model



Model spread individual parameters