Probabilistic Estimation of Wind Storm Losses in Germany from a Statistical-Dynamical Downscaling Approach

Kai Born

Patrick Ludwig

Melanie Karremann

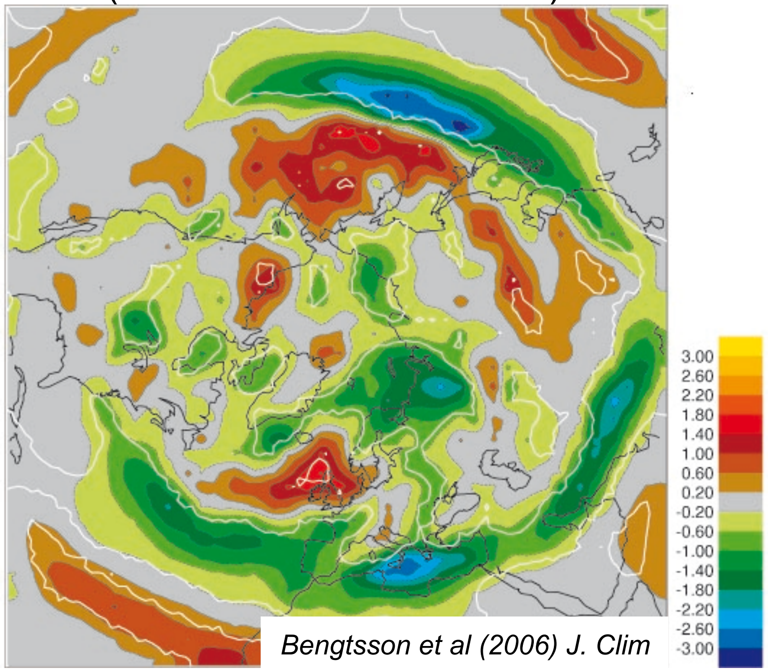
Joaquim G. Pinto

Institute for Geophysics and Meteorology, University of Cologne

kai.born@uni-koeln.de

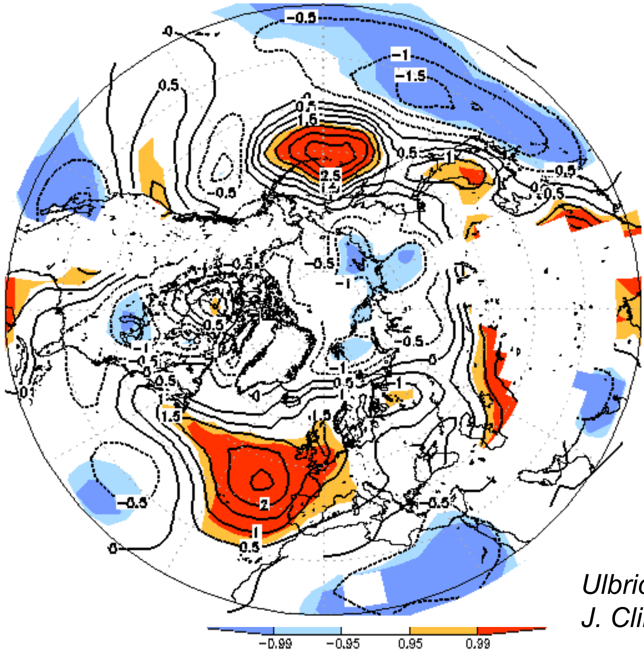
Motivation

cyclone track density
ECHAM5 A1B vs 20C
(2070-2100 vs 1960-2000)



Bengtsson et al (2006) J. Clim

MSLP storm track
IPCC 16 GCMs A1B vs 20C
(2080-2100 vs 1960-2000)

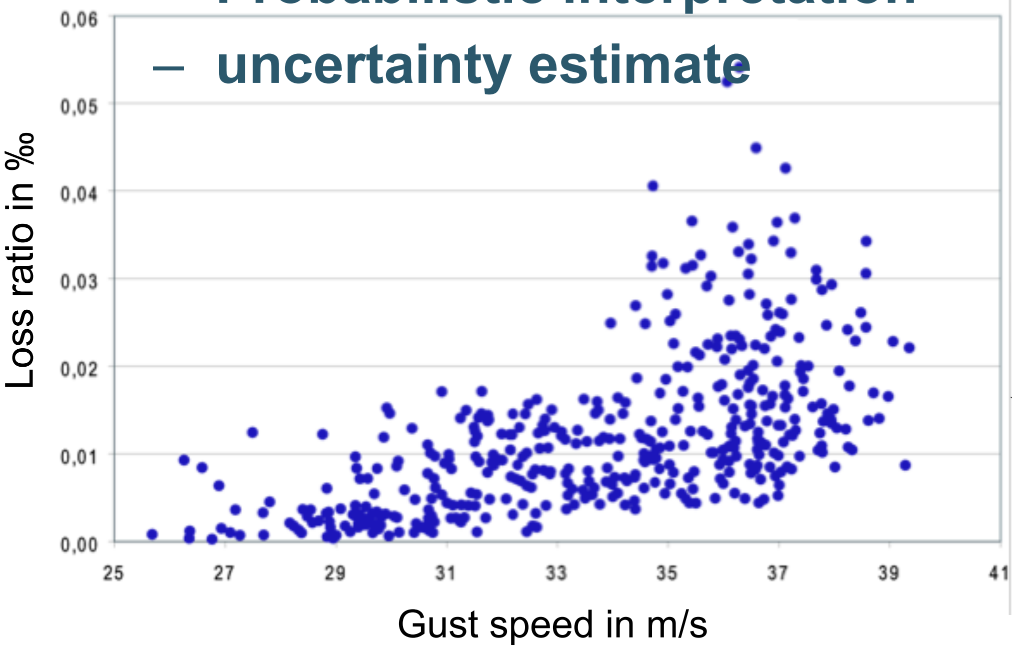


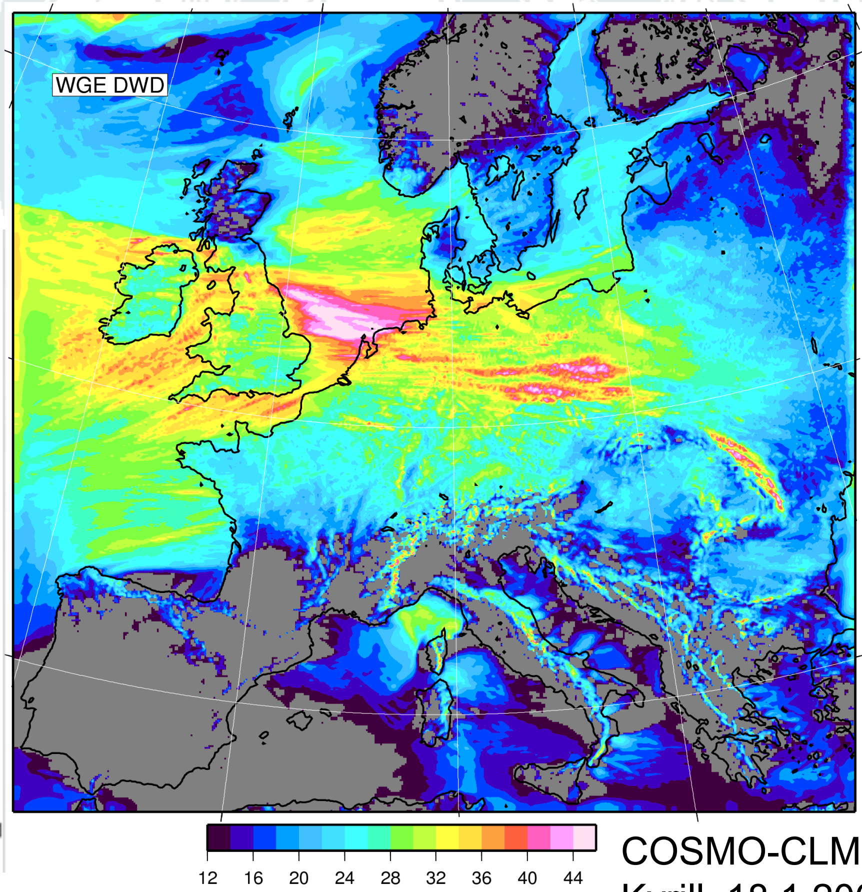
Ulbrich et al (2008) J. Clim

- Expected SE-expansion of the stormtrack over the Atl / GB towards Central Europe in future climate scenarios
- How does this translate to expected storm-related losses?
- Existing: different large scale studies (Pinto et al., Leckebusch et al., P. Della-Marta et al. …)
- Application of high-resolution modelling of storms?

Motivation

- High resolution modelling of storms easily done
  (Ensembles project, for loss estimation see e.g. Pinto et al., 2009, 2010, Rauthe et al. 2010, Donat et al. 2010, 2011…)
- But: are results reliable?
- Quasi-chaotic behaviour
- Demand:
  - **Probabilistic interpretation**
  - **uncertainty estimate**





COSMO-CLM 4.8
Kyrill, 18.1.2007

Motivation

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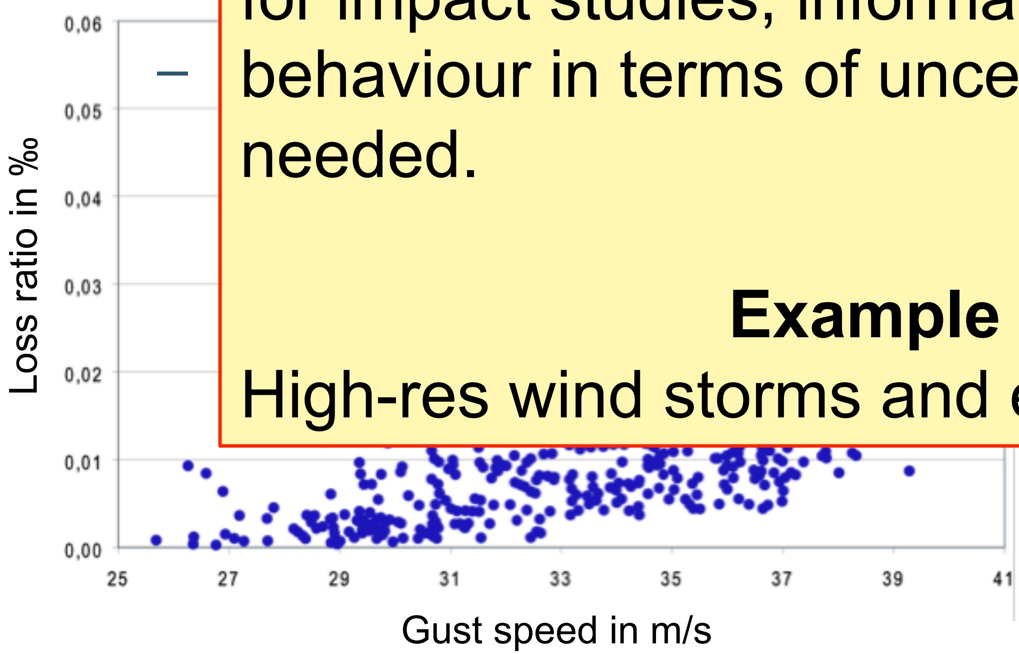
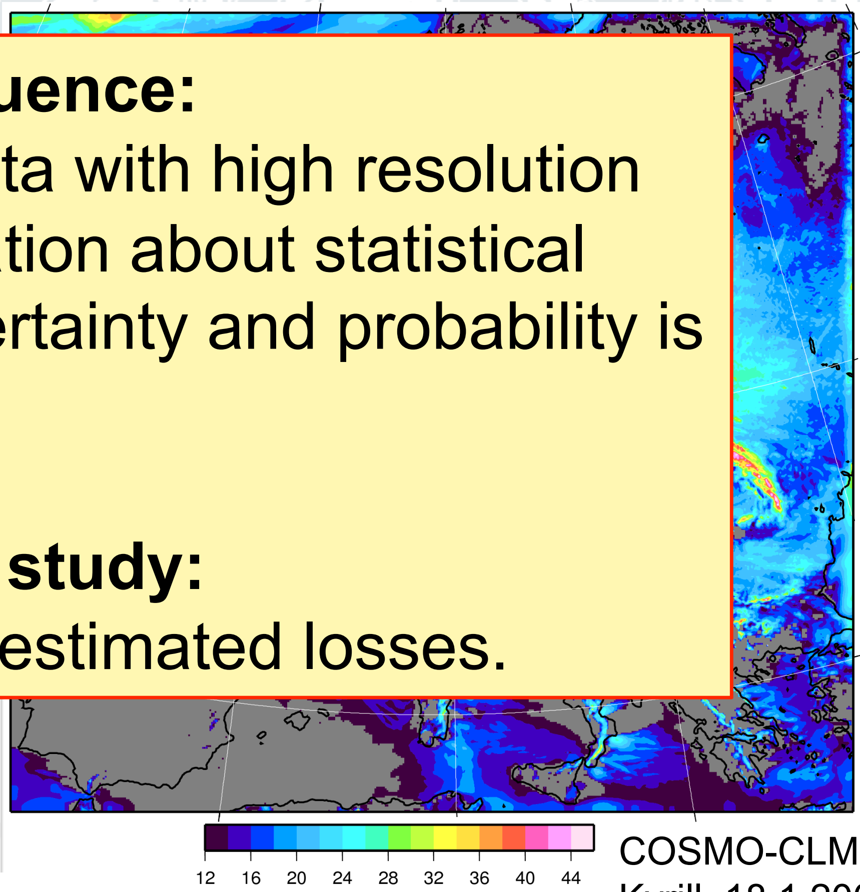


Consequence:
Using extreme weather data with high resolution for impact studies, information about statistical behaviour in terms of uncertainty and probability is needed.

Example study:
High-res wind storms and estimated losses.



COSMO-CLM 4.8
Kyrill, 18.1.2007

Content

Statistical-Dynamical Downscaling Approach

Given:

- Regionalized daily loss data (houses, private properties) for Germany from GDV
- NCEP and ERA 40 / Interim reanalyses
- ECHAM5 climate scenarios SRES A1B, B1 and A2
- The regional climate model COSMO-CLM (clm_4.1)

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Steps of SDD:

1. Weather-typing – frequencies p_i of weather types based on an climate variable ***V***
2. Dynamical downscaling – statistical distribution ***P(V)*** of climate parameter ***V*** per weather type
3. Connection between forcing parameter(s) ***V*** and indicator variable ***S(V)***
4. Re-combination – weighted sums of distributions provide long-term statistical distribution of indicator variable
5. Interpretation: averages, quantiles, return periods…

Probabilistic Aspects

Comparison between classical and probabilistic SDD

Steps	„Classic“ SDD	Probabilistic SDD
Variable	$\overline{V} = \frac{1}{\Delta T} \int_{\Delta T} V(\vec{x}, t) dt$	$P(V)$
Re-combination	$\overline{V} = \sum_{i=1}^{N} p_i \overline{V}_i$	$P(V) = \sum_{i=1}^{N} P(V \cap W_i) = \sum_{i=1}^{N} P(V \mid W_i) \cdot P(W_i)$
Impact Relation S(V)	(Logistic) Regression, MLR, GLM	Quantile Regression
Key Equation	$\overline{S} = \sum_{i=1}^{N} p_i S(\overline{V}_i)$	$P(S) = \int_V P(S \cap V) dV = \int_V P(S \mid V) \cdot \sum_{i=1}^{N} P(V \mid W_i) P(W_i) dV$

Probabilistic Aspects

Probabilistic impact view and the Bayes theorem: The key equation

$$\boxed{\text{Impact } S(V)}$$

$$\boxed{\text{Impact probability } P(S) = P(S \cap V)}$$

$$P(S) = \int_V \underbrace{P(S|V)}_{\text{Climate - Impact transfer relation}} \cdot \sum_{i=1}^{N} \underbrace{P(V|W_i)}_{\text{Climate parameter probability distribution for a WT } W_i} \underbrace{P(W_i)}_{\text{WT frequency}} dV$$

Climate - Impact transfer relation

Climate parameter probability distribution for a WT W_i

WT frequency

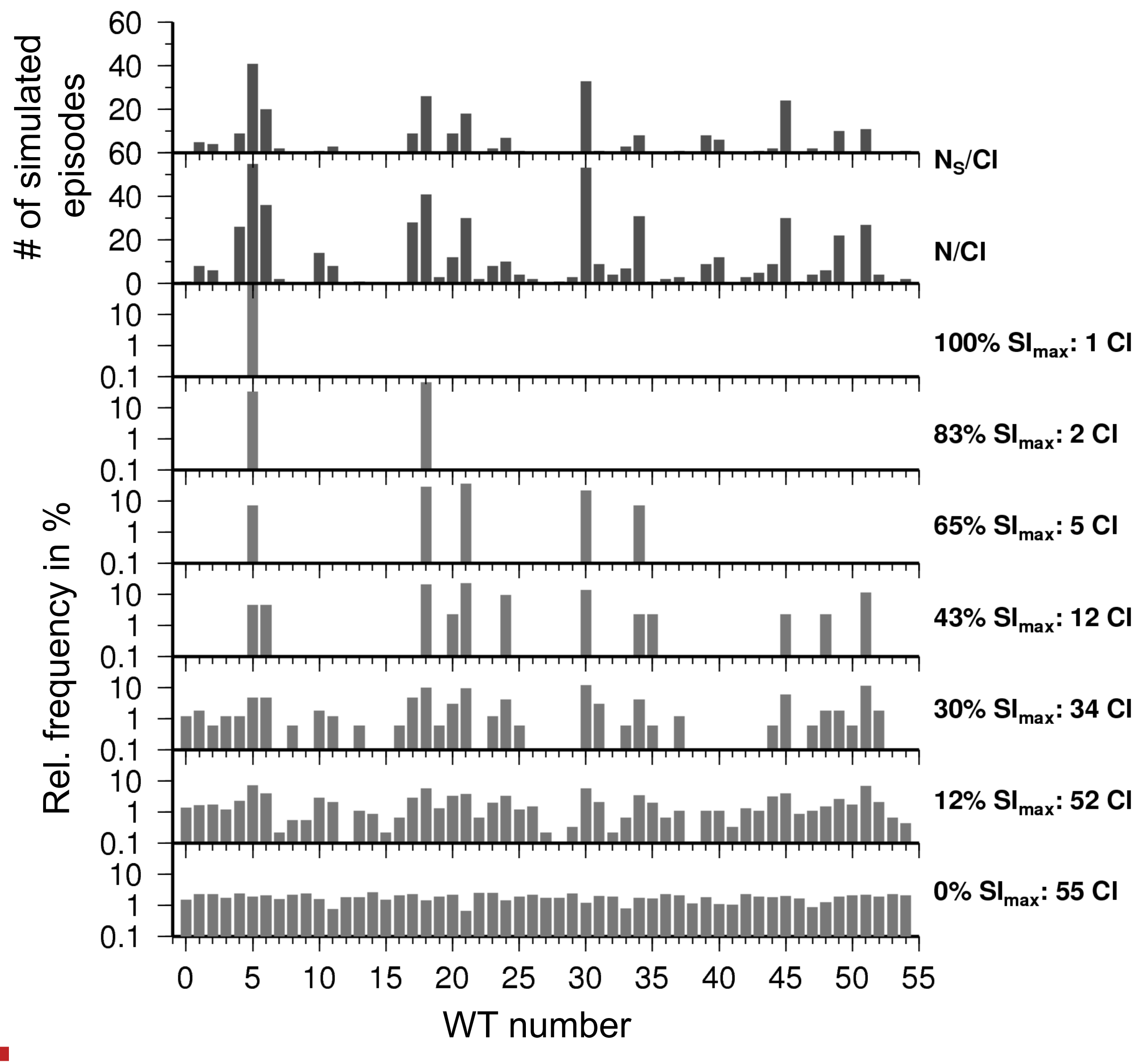
Steps of SDD – I. Storm related Weather Types

- Clustering of dynamical 3-day weather developments for winter (Oct-Mar) after Leckebusch et al. (2008)
  - Result: 55 storm-related weather types

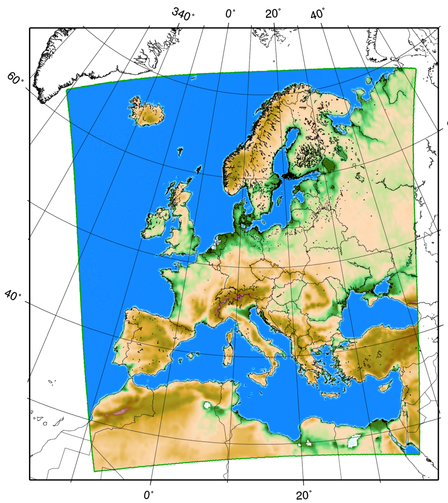
Right picture:

Bottom 7 rows: frequencies of WT occurrences, depending on loss intensity

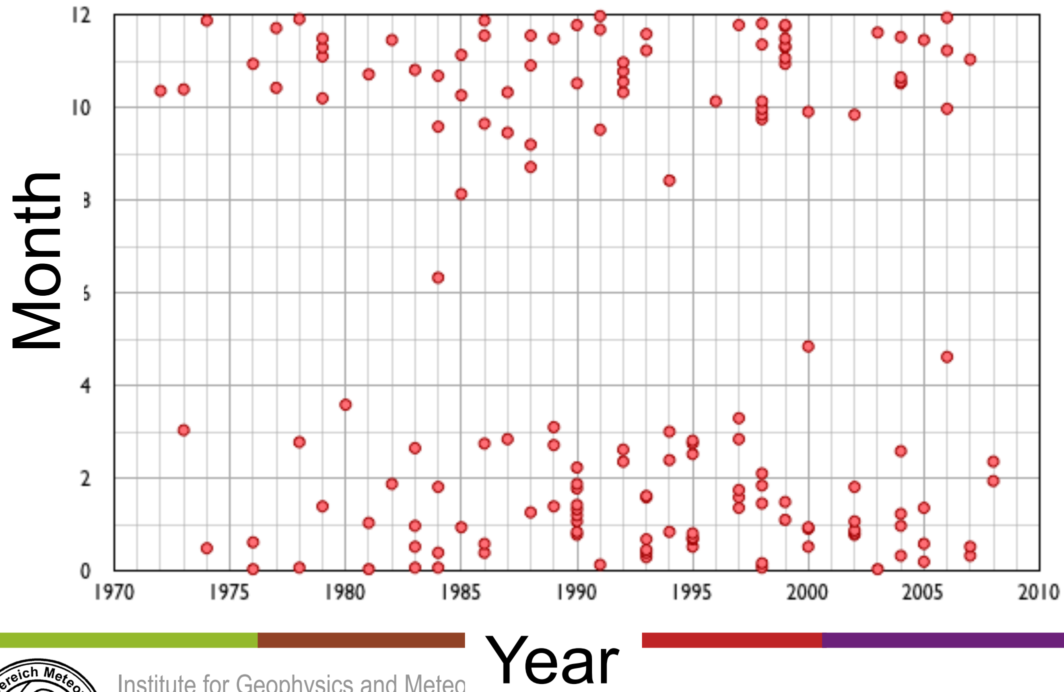
Top 2 rows: numbers of simulated episodes (bottom) and storms (top) per WT

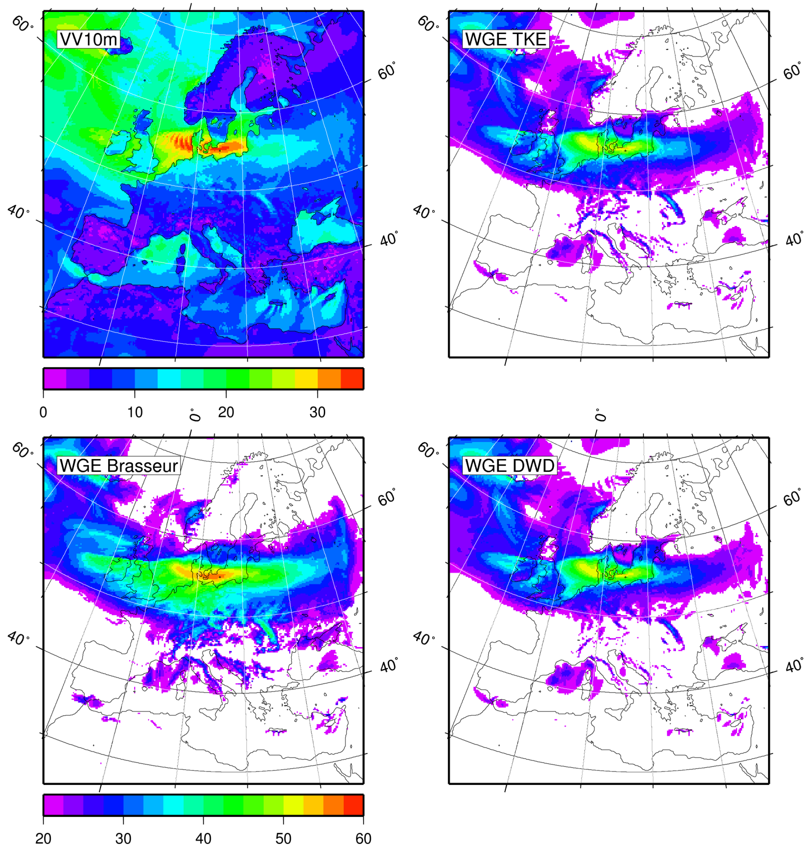


Steps of SDD – II. Dynamical Downscaling



- COSMO-CLM 4.1
- 158 CCLM historical storm simulations in Europe
- RCM with 0.165° grid res.
- Non-hydrostatic





Steps of SDD – III. Wind-Loss-Relation

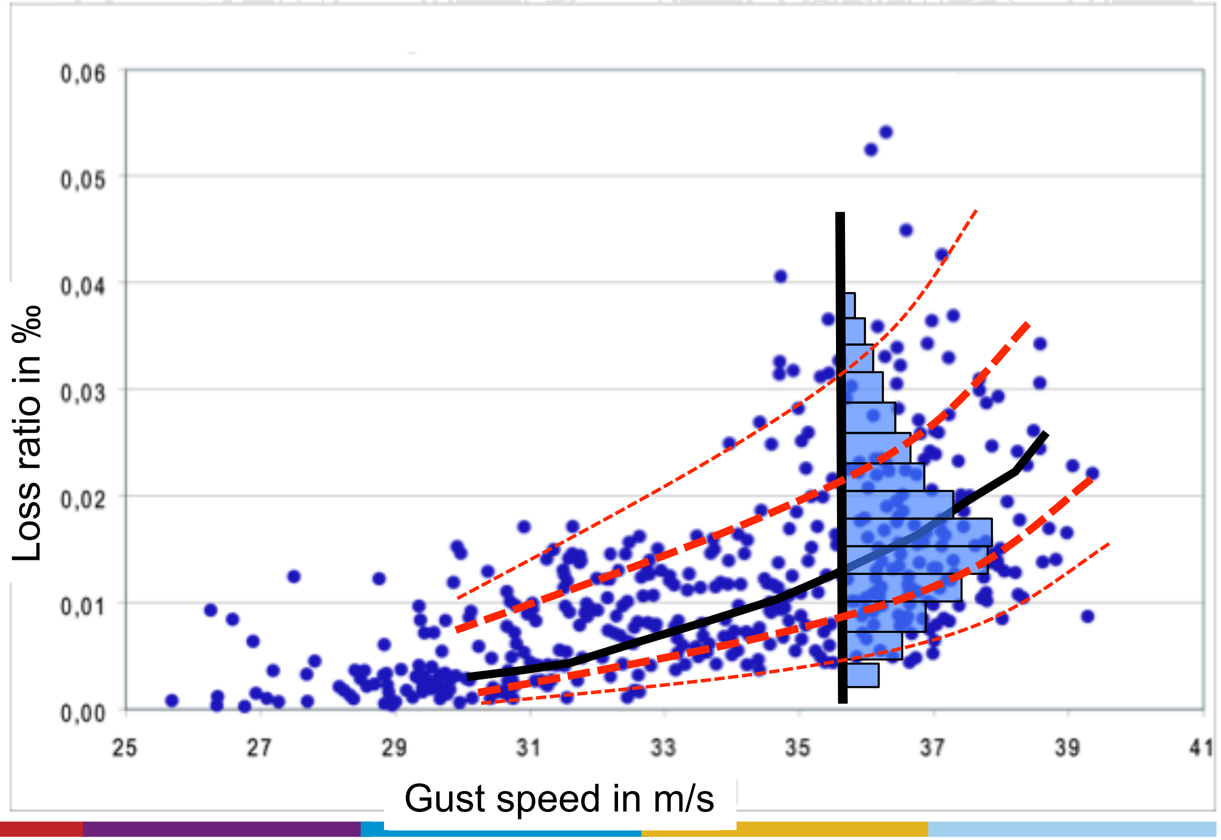
Method: Quantile regression model for losses as a function of wind gust

GDV: Loss S

CCLM: Wind Gust V

Quantile regression $S_n=F_n(V)$

Spatially distributed quantiles S_n / cluster



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Department Meteorology
Kai Born
20.10.2011

University of Cologne
Faculty of Mathematics and Natural Sciences

Steps of SDD – IV. Re-Combination

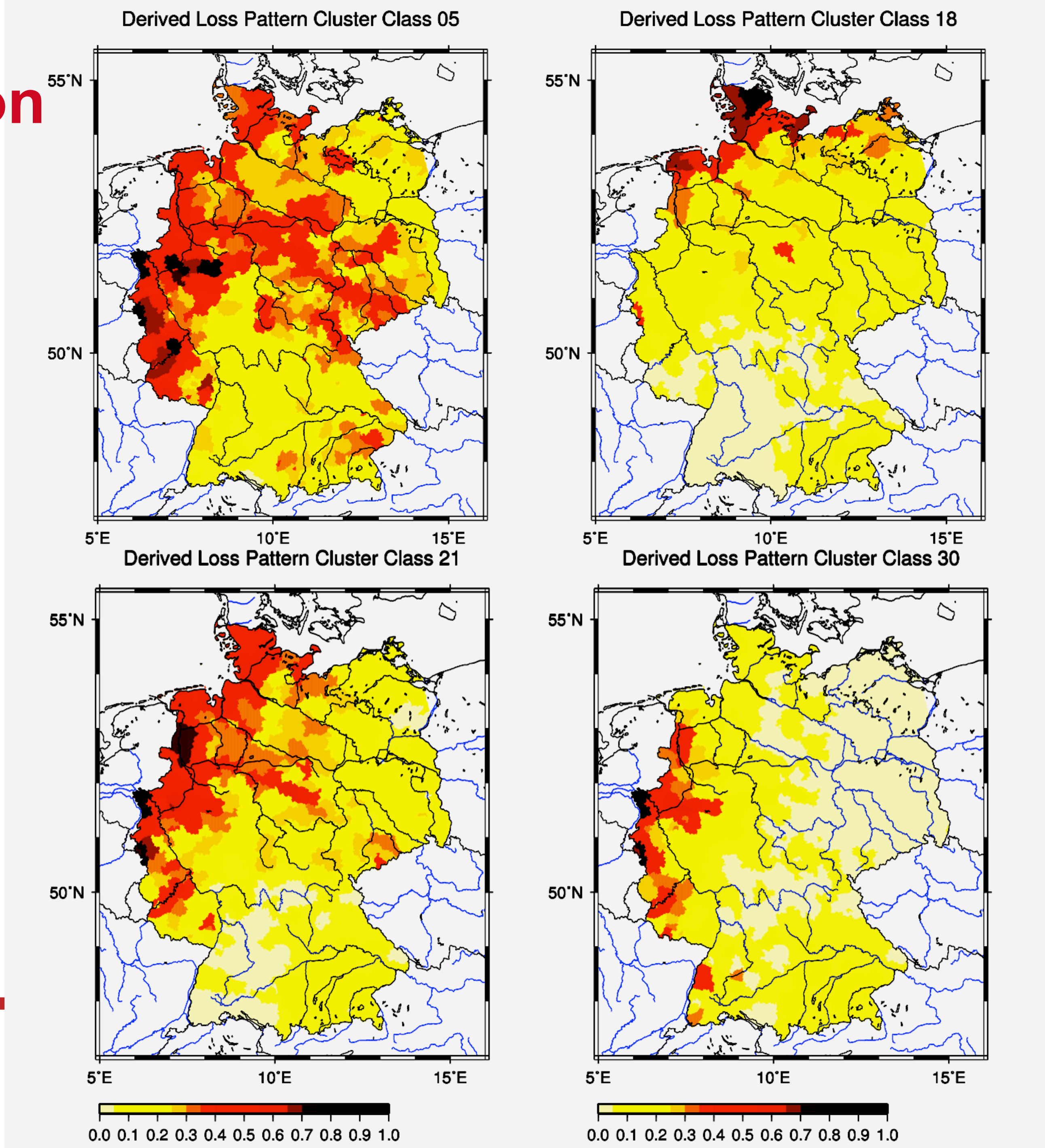
Estimated **medians** of normalized loss patterns for 4 storm-prone WT classes

Top left:
Kyrill, Wiebke, Emma

Top right:
Agnes / Barbara, Ingo

Bottom Left:
Vivian, Franz III, Per

Bottom right:
Lothar, Desiree, Silke

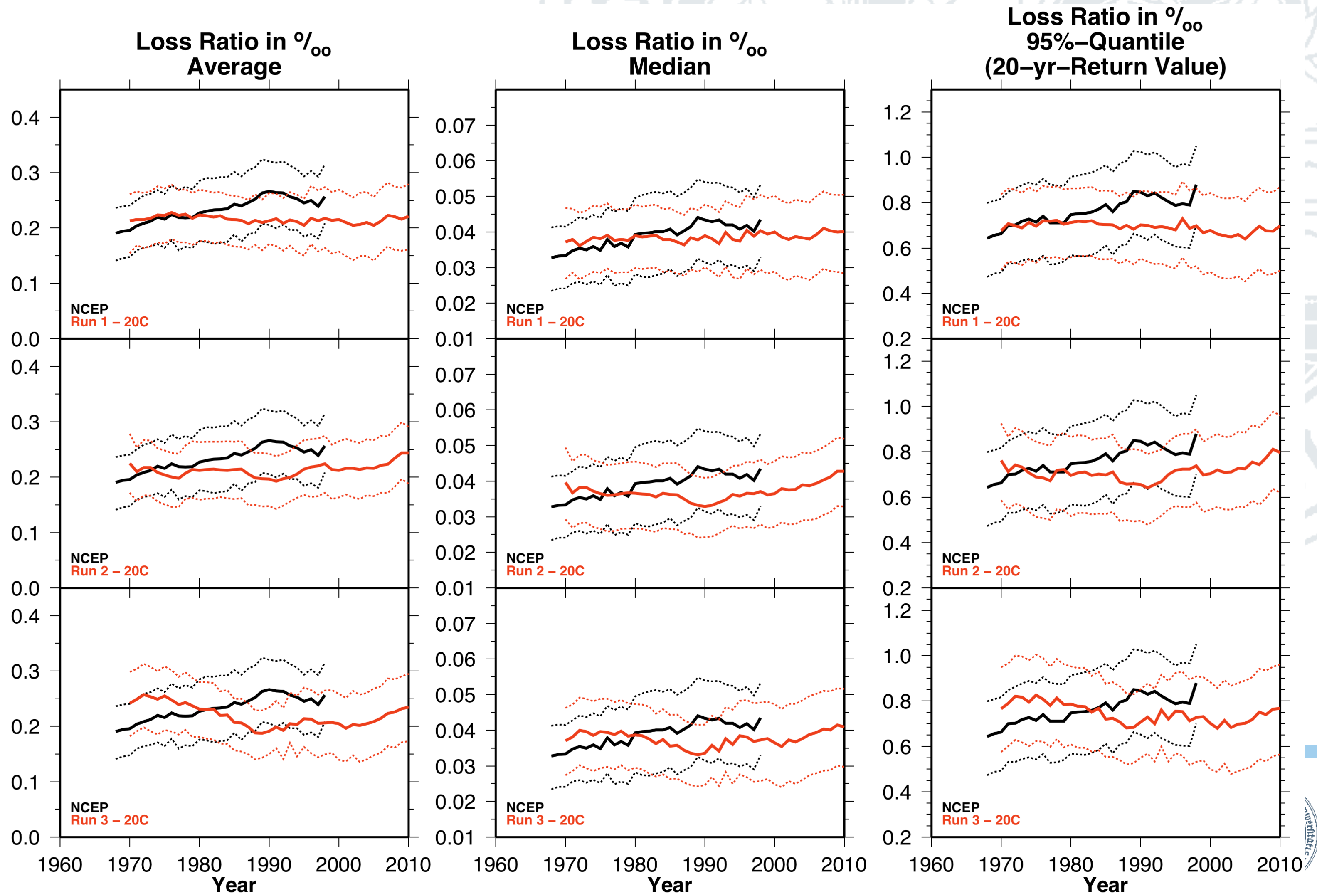


Discussion of Results

- Two types of graphics:
  - Filtered time series of loss expectation values, 50%- and 95%-quantiles
  - Return levels of loss expectation values from a generalized Pareto fit
- Validation: Historical series & 20C
- Future series

Discussion of Results – Historical vs. ECHAM 20C

- Changes in averages, medians (2-yr-return value) and 95% quantiles (20-yr-return value)
- Moving 21-yr window, 90%-uncertainty range from bootstrapping

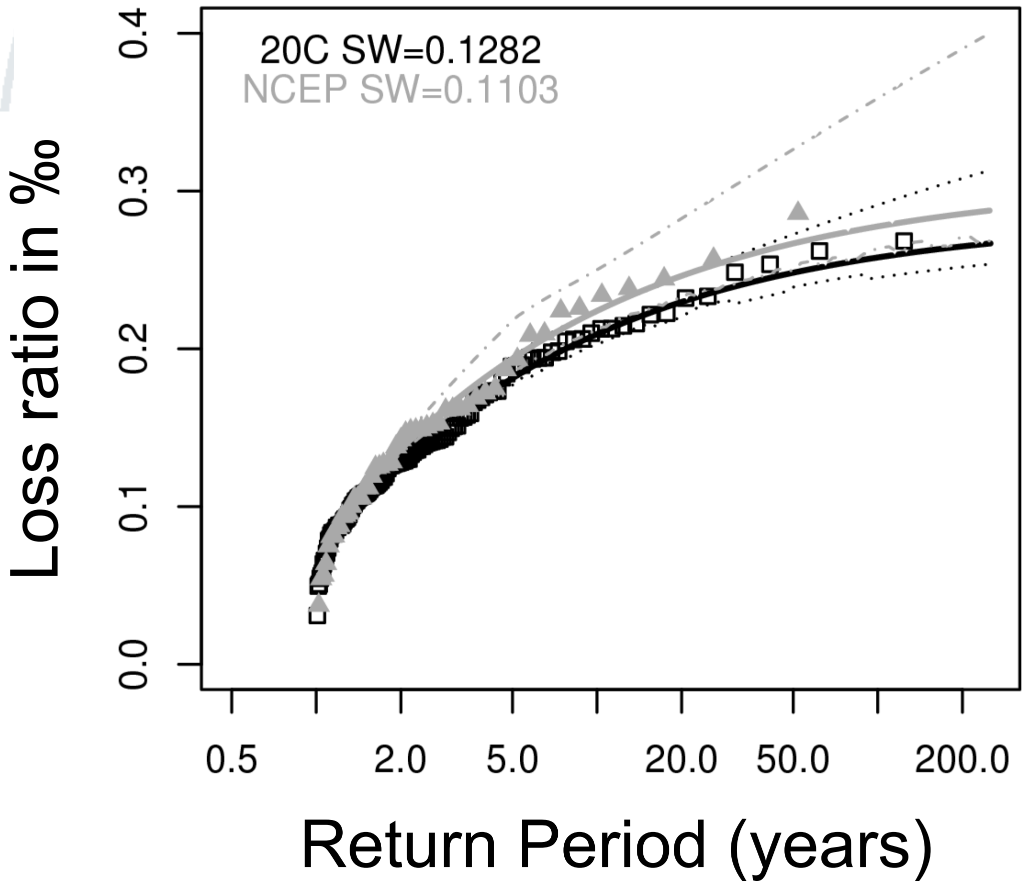


Discussion of Results – Historical vs. ECHAM 20C

Return periods of **average** annual loss frequencies by standard GPD fit,

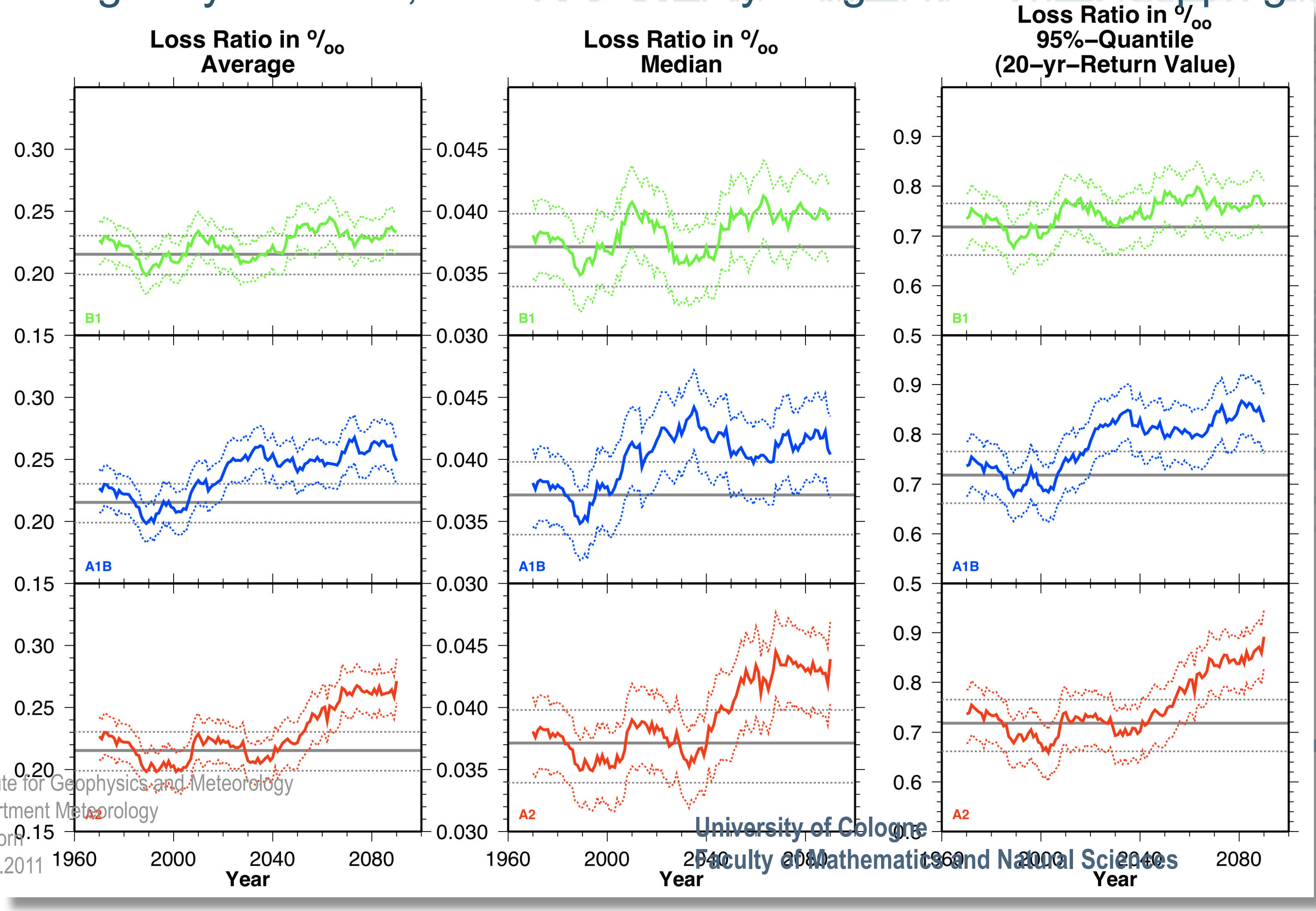
Black: pooled ensemble members of ECHAM5 scenarios for the 20C period (1960-2000)

Grey: loss estimation from NCEP reanalysis 1958-2008



Discussion of Results – Climate Scenarios ECHAM

- Changes in averages, medians (2-yr-return value) and 95% quantiles (20-yr-return value), three pooled ensemble members, black: ECHAM5 20C
- Moving 21-yr window, 90%-uncertainty range from bootstrapping



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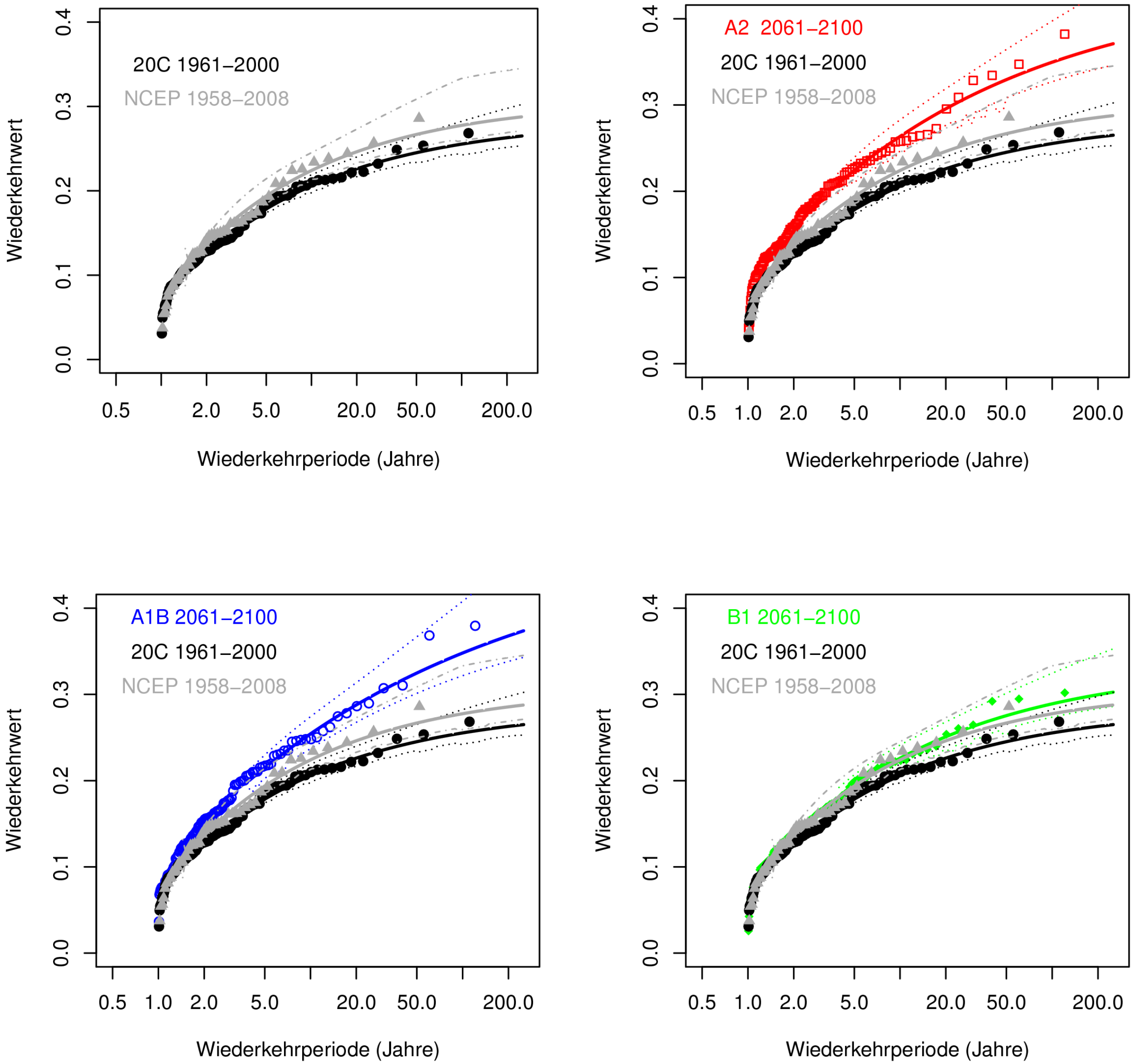
Discussion of Results – Climate Scenarios ECHAM

Return periods of **average** annual loss by standard GPD fit, pooled ensemble members of ECHAM5 scenarios A2, A1B and B1 for the period 2061-2100



Discussion of Results – Climate Scenarios ECHAM

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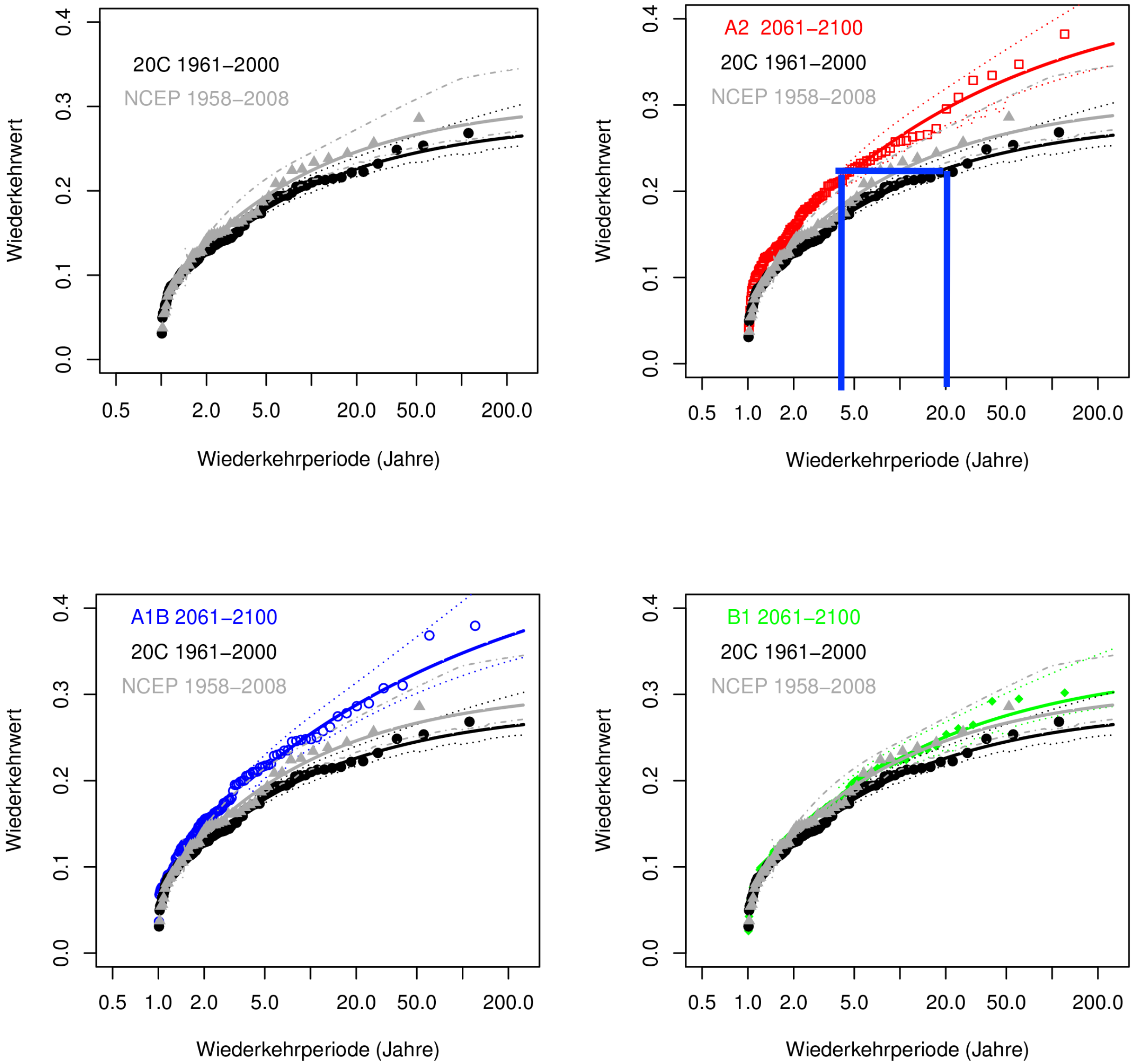
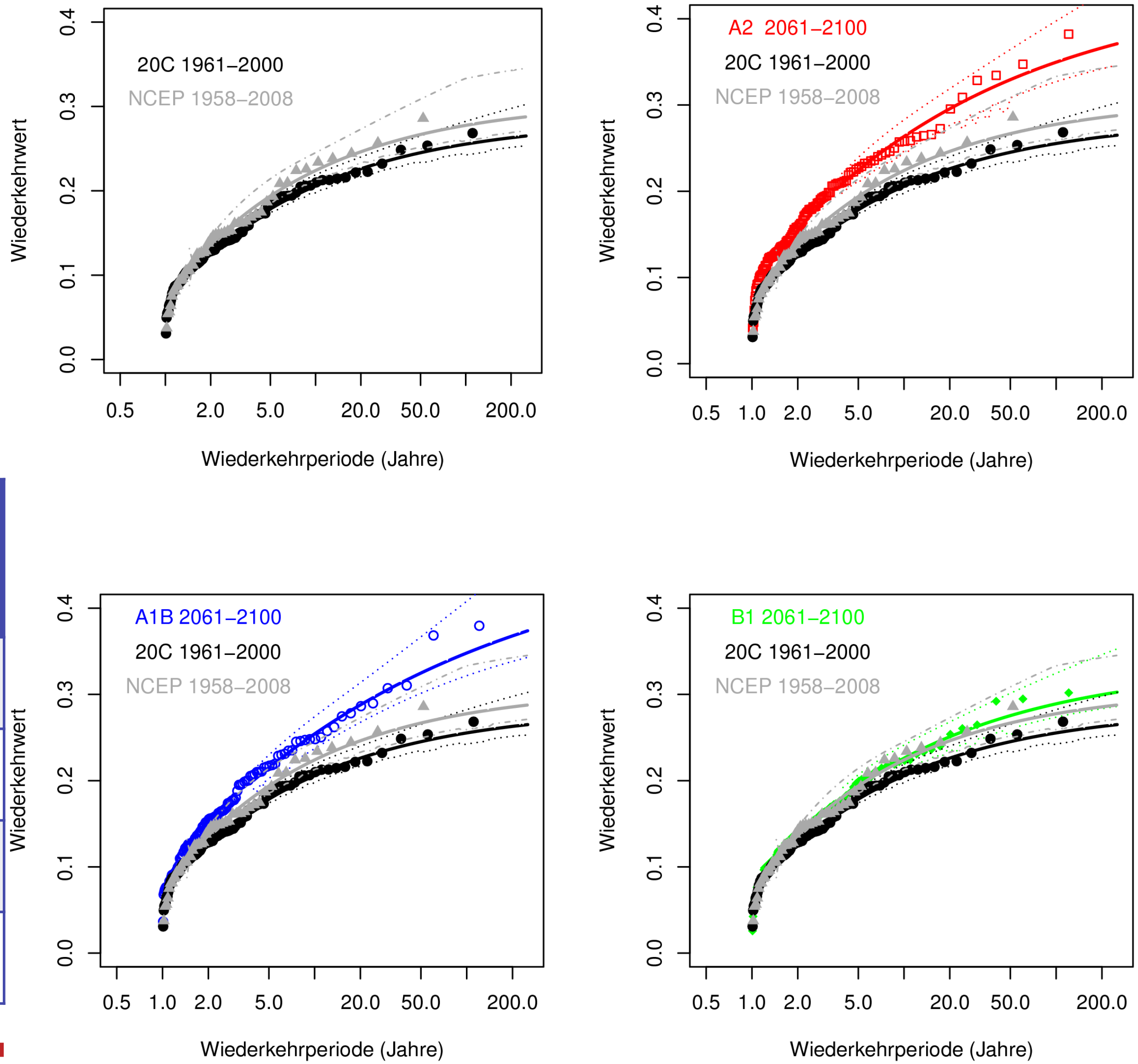


Discussion of Results – Climate Scenarios ECHAM

Return periods of **average** annual loss by standard GPD fit, pooled ensemble members of ECHAM5 scenarios A2, A1B and B1 for the period 2061-2100

Interpretation

RP 20C	A2	A1B	B1
10 a	3.8	4.3	6.4
20 a	5.1	6.0	10.0
50 a	7.1	8.4	16.7
100 a	8.5	10.1	22.8



Conclusions

- Probabilistic extension of statistical-dynamical downscaling approach allows uncertainty estimates of climate change impact
- Application on wind-storm related insurance losses show a significant increase in losses of both average and extreme storms, but with slightly stronger intensification of severe events in ECHAM5 future climate scenarios
- Climate signal in terms of natural variability significant, in terms of wind-loss-relation uncertainty possibly hidden
- Underestimated decadal variability in ECHAM5 scenarios?

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Acknowledgement: The Association of German Insurances (GDV) provided insurance data and funded the project in which this study was undertaken

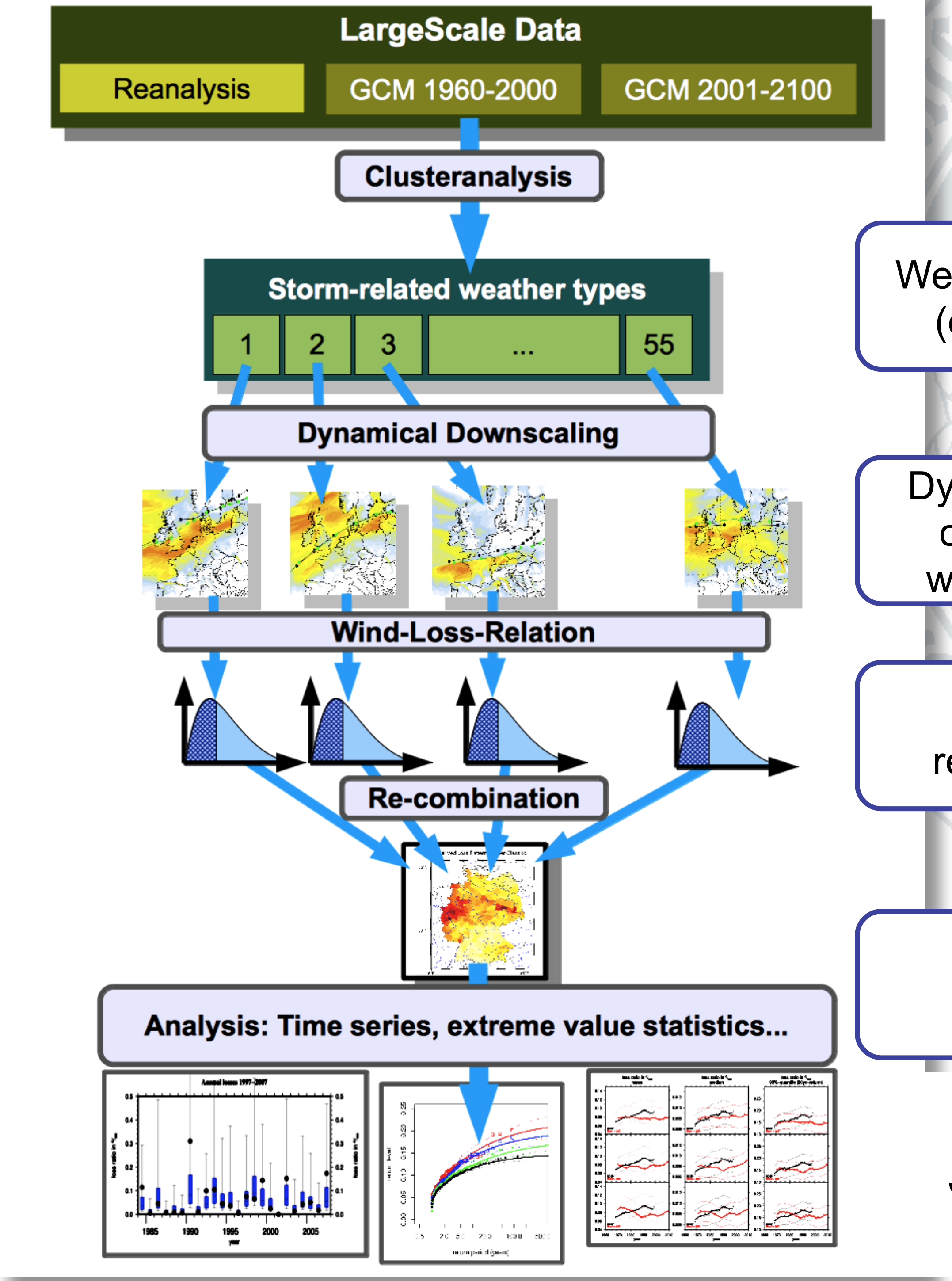
Alternative Slides

as supplemental material

Statistical-Dynamical Downscaling Approach

- Combination of dynamic downscaling (GCM -> RCM), and statistics (relevant weather-types)
- Aims at statistical characteristics of longer periods
- Potential of probabilistic extension

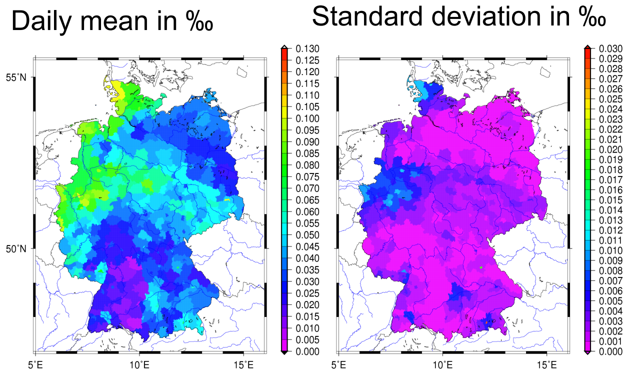
Statistical-Dynamical Downscaling Approach



Weather type episodes W_i (cluster classification)	Frequencies p_i
Dynamic Downscaling of climate variable V for weather type episodes	Regional patterns V_i
Recombination of regionalized episodes	$\overline{V} = \sum_{i=1}^{N} p_i \overline{V}_i$
Impact relation, Interpretation	$\overline{S} = \sum_{i=1}^{N} p_i S(\overline{V}_i)$

V = climate parameter,
S(*V*) = relation climate parameter - impact indicator

Steps of SDD



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Steps:

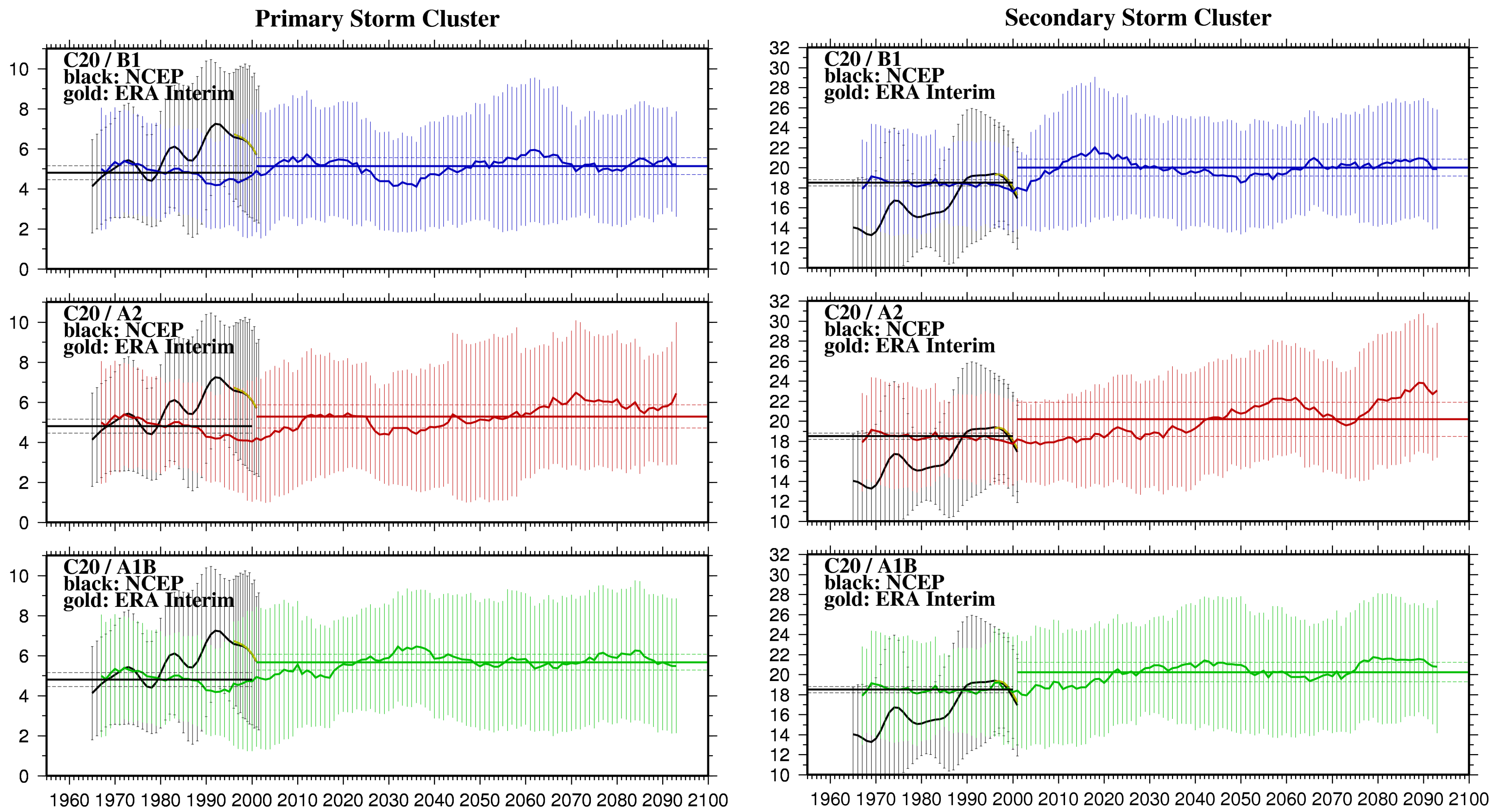
1. Storm related WT classification for historical and scenario periods
2. Dynamical Downscaling using COSMO-CLM fro WT episodes
3. Probabilistic Wind-Loss relation assessment
4. Recombination
5. Interpretation

Probabilistic Aspects

- Probabilistic interpretation for assessing uncertainties
- Decadal variability - variability in frequencies of WT occurrence
- Impact uncertainty – uncertainty in the climate-impact relation *S(V)*

Steps of SDD – I. Storm related Weather Types

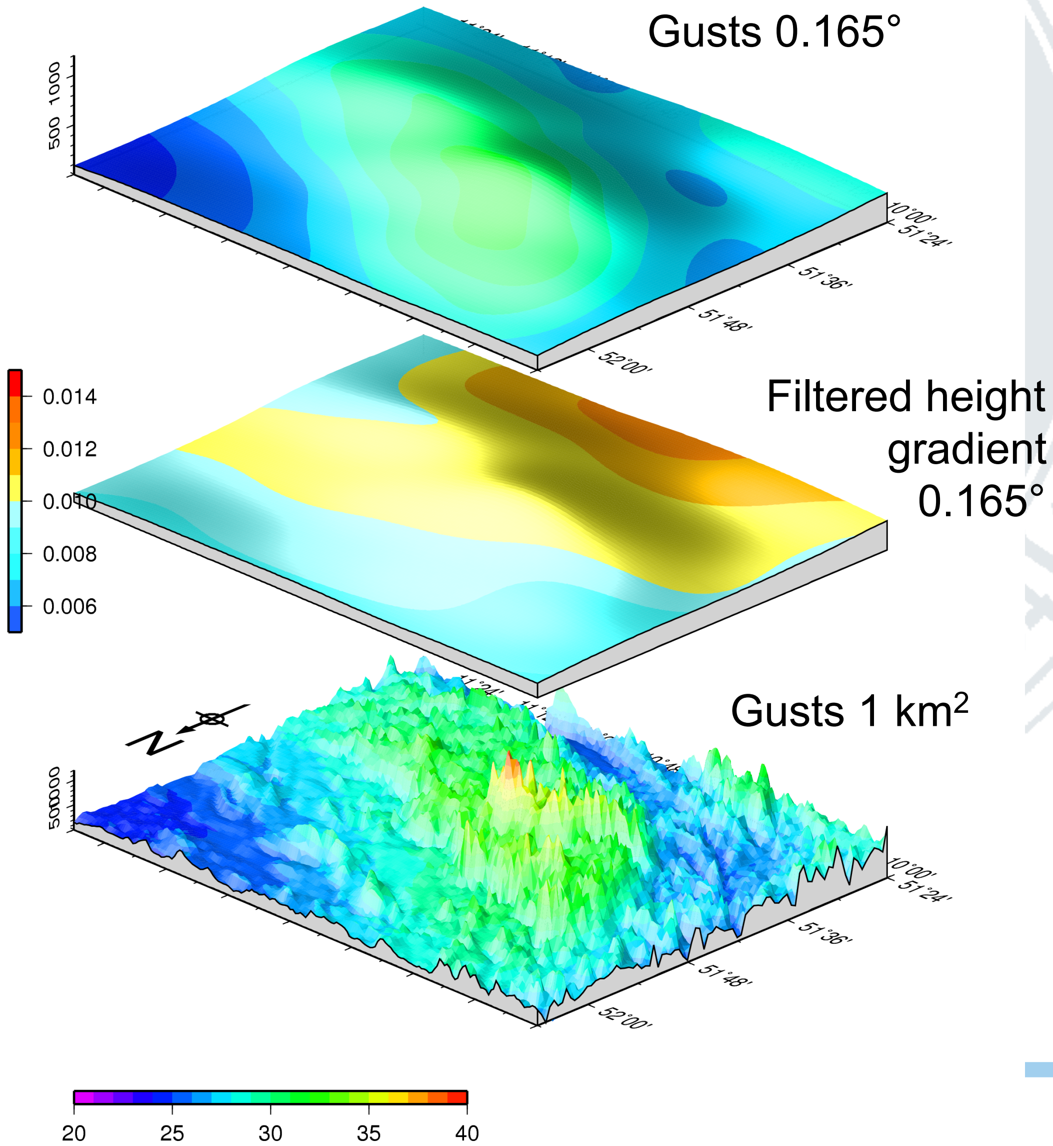
Temporal development of grouped WT frequencies



Steps of SDD – II. Dynamical Downscaling

Postprocessing:

- „intelligent“ interpolation to 1 km^2 grid
- Aggregate **wind gust distributions** in districts



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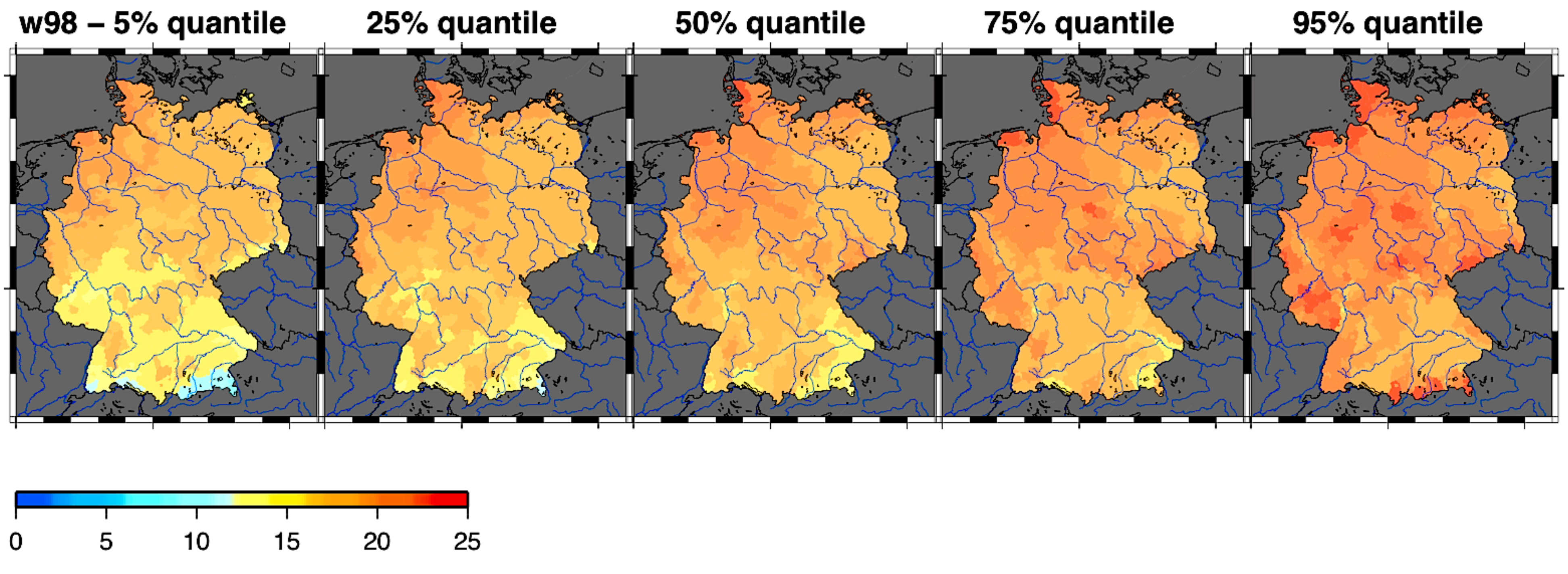
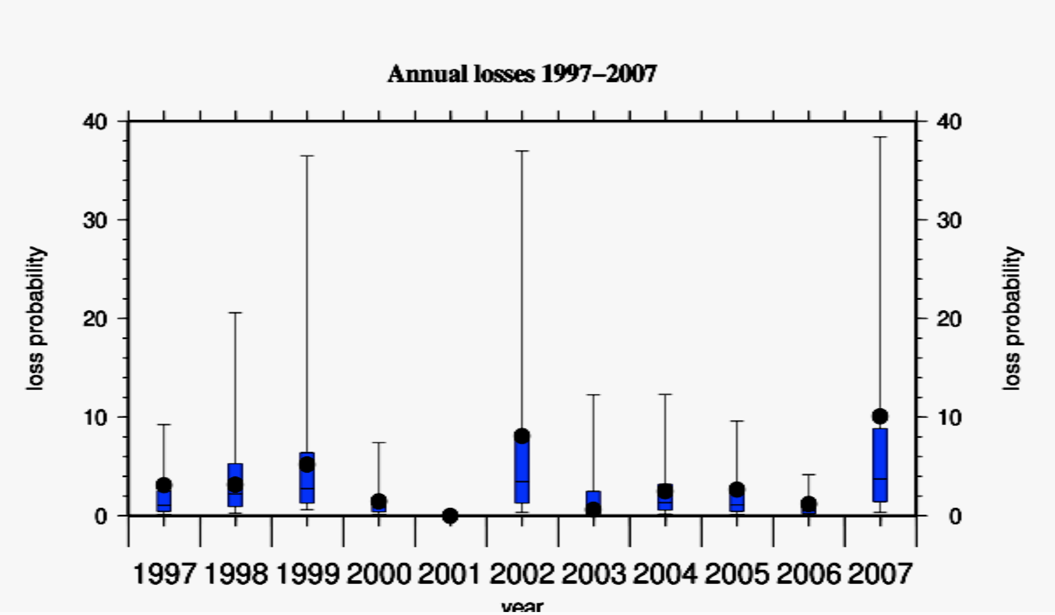
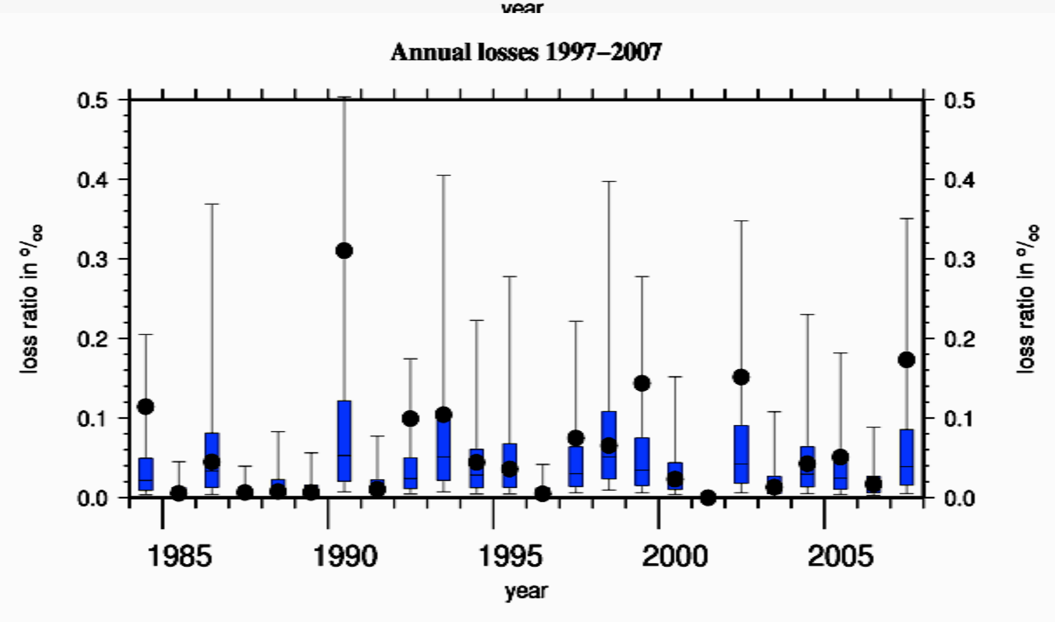


Discussion of Results - Validation





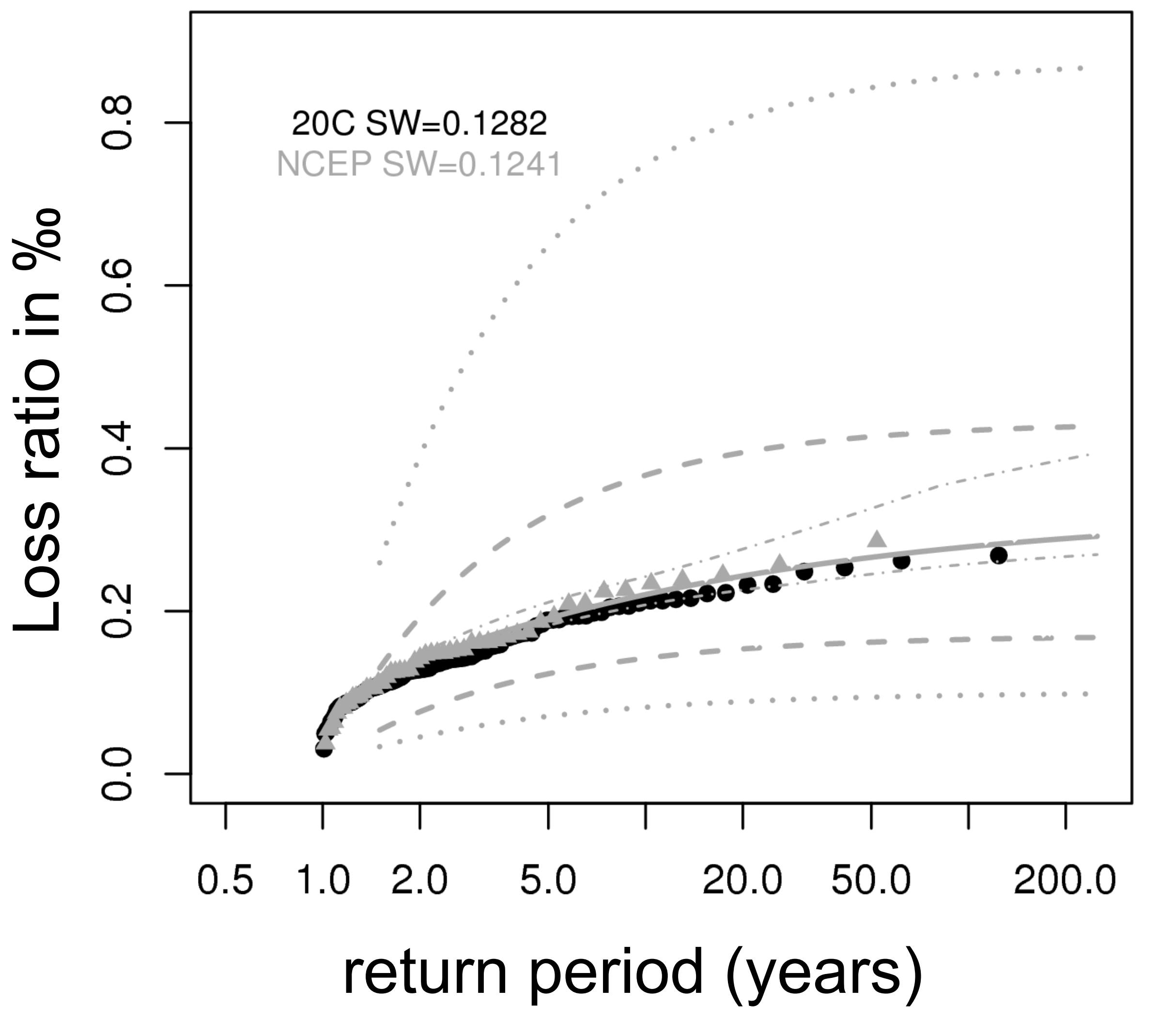
Loss frequencies 1997-2007

Black dots: observed
Blue bars and whiskers: estimated

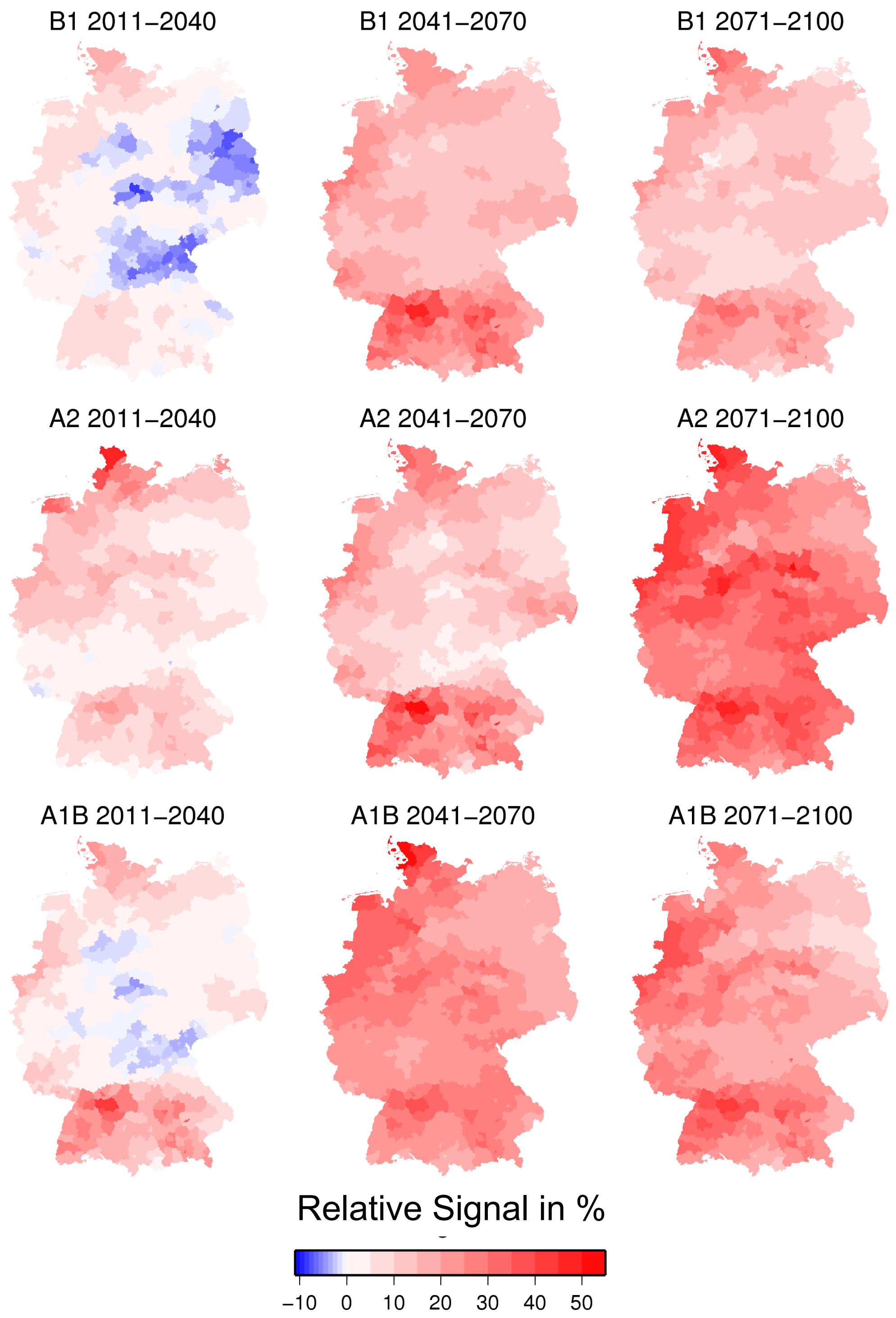
Loss ratios 1984-2008

Discussion of Results – Something about Uncertainty

- Approach to estimate different sources of uncertainty:
  - Wind-loss relation
  - Dynamic realization
  - GPD parameter estimation



Results and Interpretation: Relative regional losses in ECHAM5 climate scenarios



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