From high-resolution global climate modelling to precipitation downscaling

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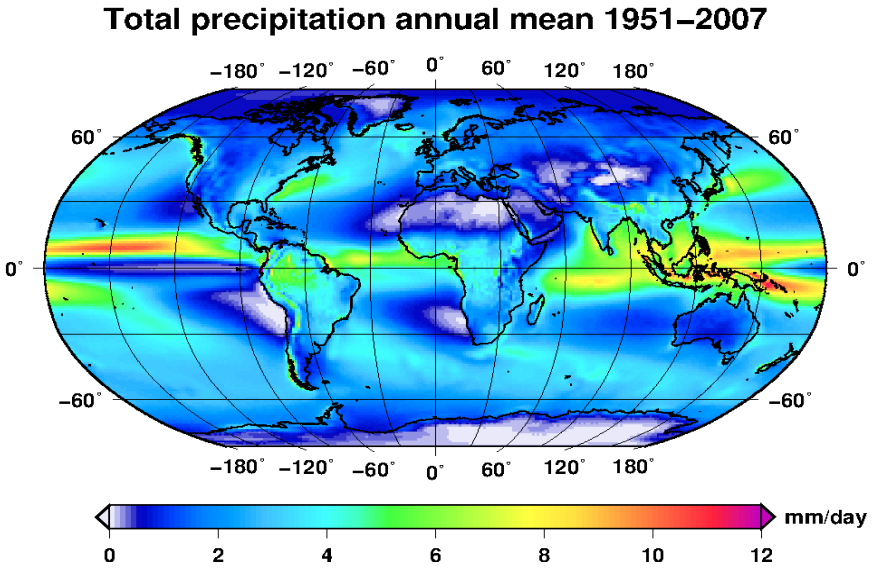
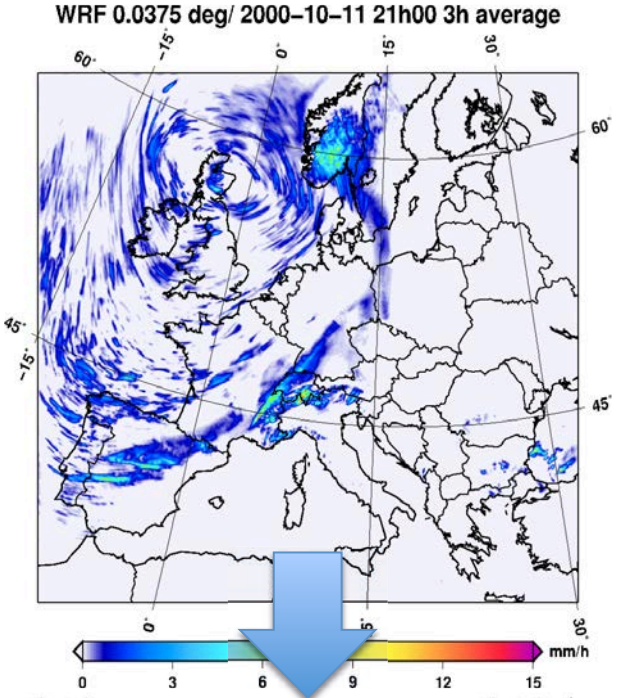
Global climate model



Regional climate model



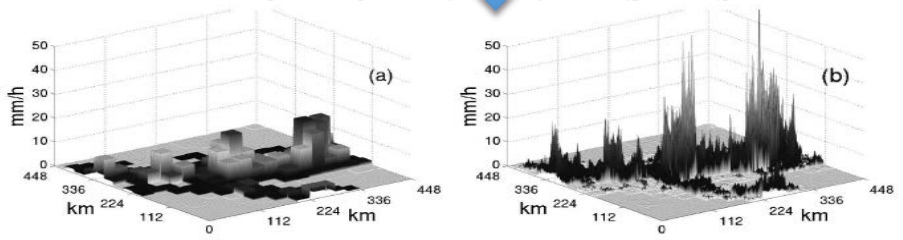


FIG. 10. (a) A snapshot of the forecasted rain field obtained from the LAM forecast and (b) one example of a downscaled field obtained by application of the RainFARM. The vertical scale indicates precipitation intensity (mm h^{-1}) and it is the same for the two fields.

Impact on eco-hydrological processes

Statistical/stochastic downscaling

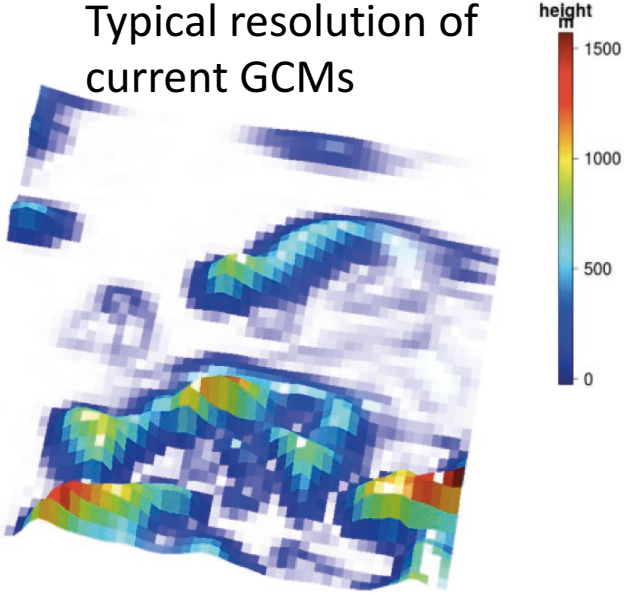
THE ROLE OF HORIZONTAL RESOLUTION FOR GLOBAL CLIMATE MODELS

- The current-generation of relatively low-resolution climate models:
  - Underestimate the number of observed storms
  - Simulate poorly midlatitude atmospheric blocking
  - Systematic errors which impact on weather regimes, regional variability

- High resolution climate models show improved representation of
  - the global water cycle (Demory et al. 2014)
  - Interannual variability of tropical cyclone counts (Strachan et al. 2013)
  - Large scale circulation (jet streams)
  - Euro-Atlantic Blocking (Jung et al., 2012)
  - Madden-Julian oscillation (Peatman et al., 2015)
  - Heat waves, droughts (Van Haren et al., 2015)

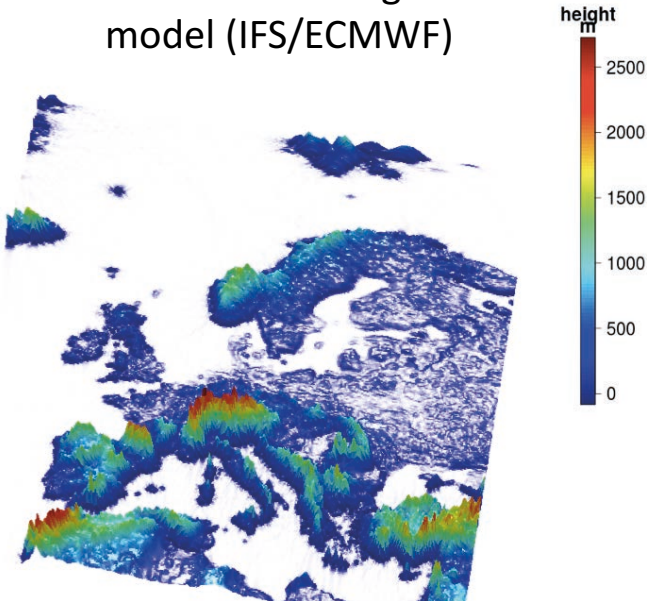
80-125 Km

Typical resolution of current GCMs



16 Km

Operational resolution of a state-of-the-art global weather model (IFS/ECMWF)



IMPROVEMENTS IN THE REPRESENTATION OF THE GLOBAL HYDROLOGICAL CYCLE WITH HIGHER RESOLUTION

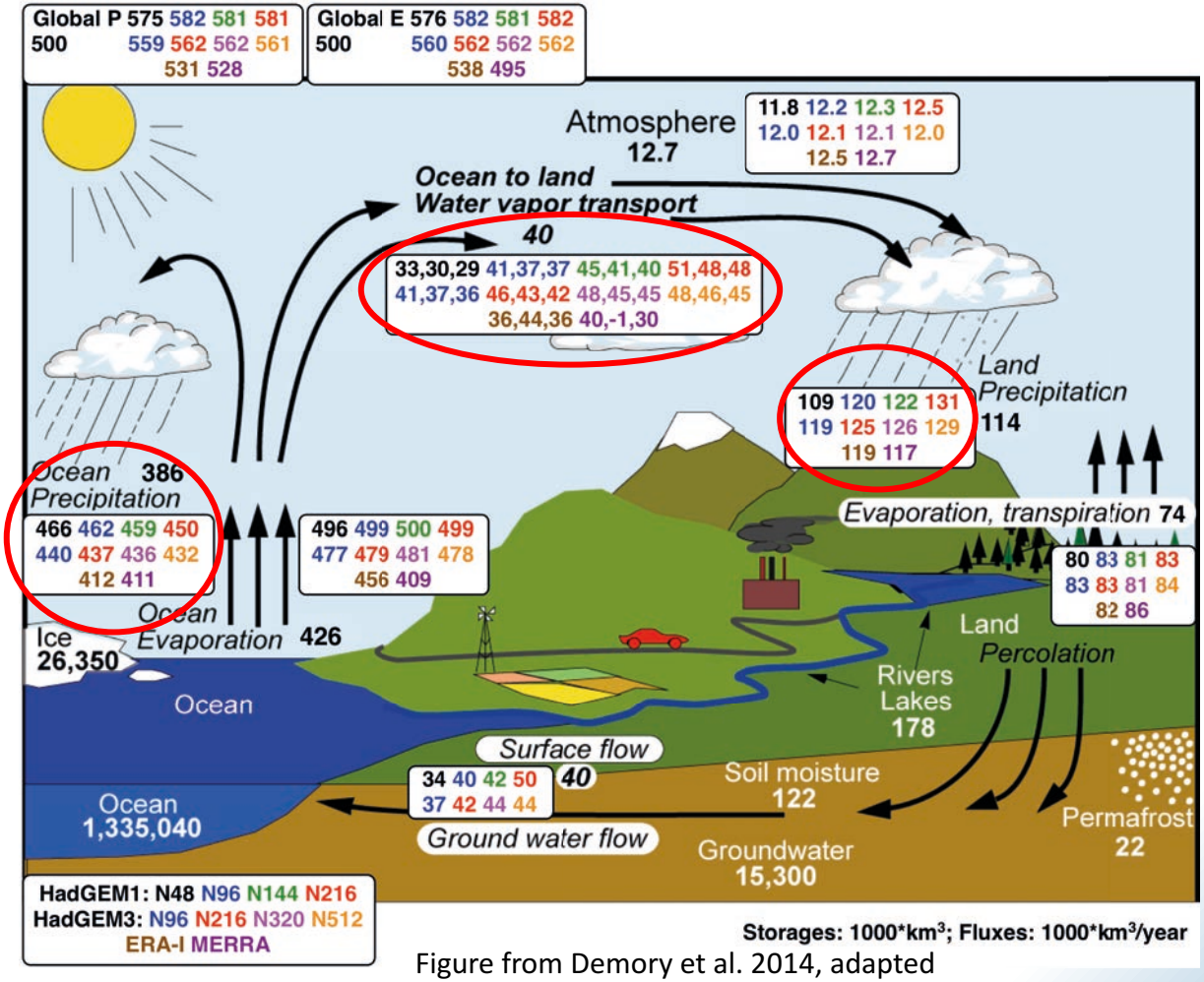


Figure from Demory et al. 2014, adapted from Trenberth et al, 2007, 2011

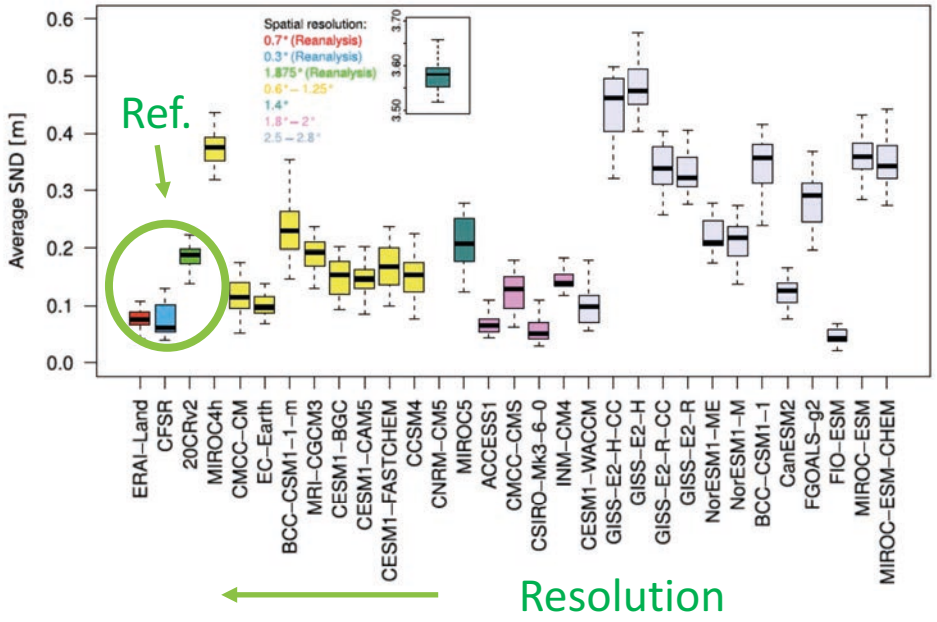
- Classic GCMs too dependent on physical parameterisation because of unresolved atmospheric processess
- Role of resolved sea→land transport larger at high resolution
- Changes in moisture recycling, transport and moisture convergence over land → convergence only below 60km in resolution

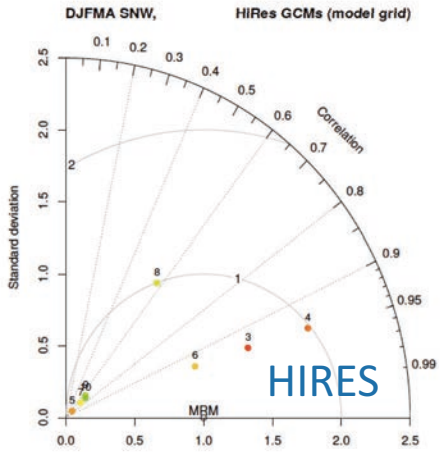
Demory et al., Clim. Dyn., 2014

Equivalent resolution at 50N:
270 km 135 km 90 km
60 km 40 km 25 km

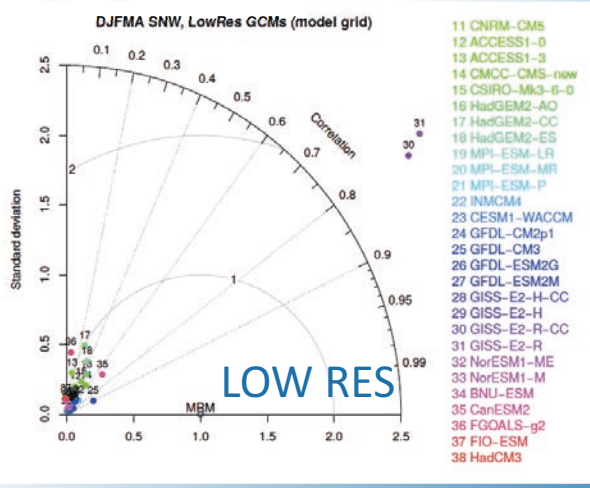
SNOW DEPTH AND SNOW-WATER EQUIVALENT IN HIGH-RESOLUTION MODELS

Average snow depth in the Himalayan region for CMIP5 models





Snow-water equivalent in the Alps

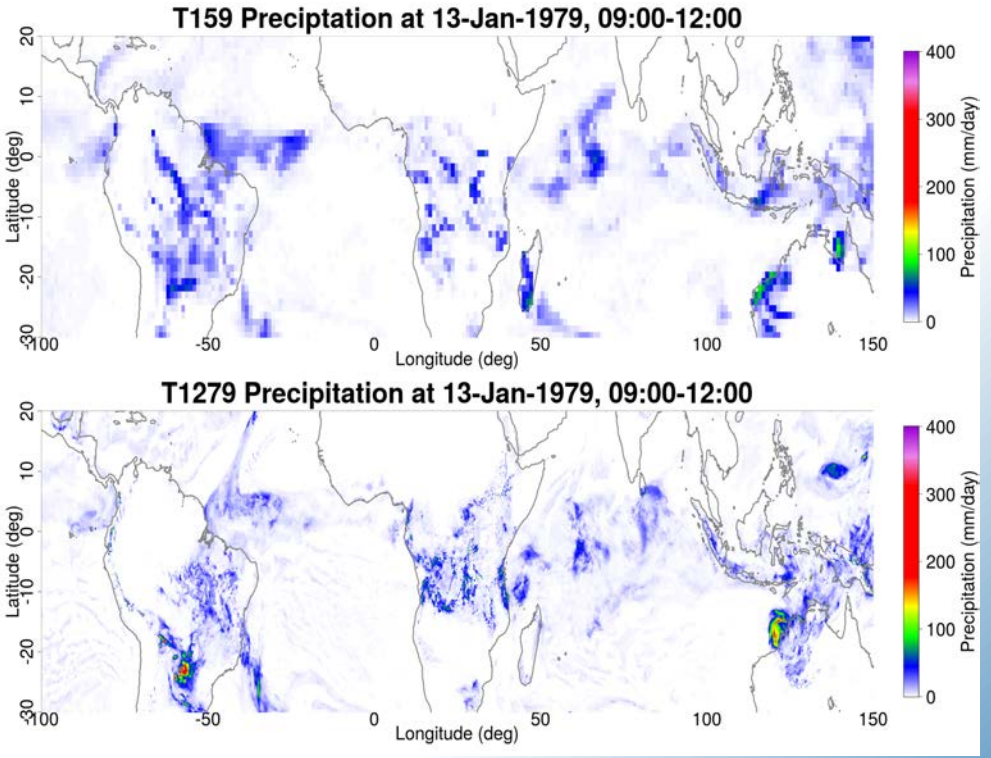


Terzago et al. 2014, Snowpack Changes in the Hindu Kush–Karakoram–Himalaya from CMIP5 Global Climate Models, *Journal of Hydrometeorology, 15 (6), 2293-2313*

Terzago et al. 2017, Snow water equivalent in the Alps as seen by gridded datasets, CMIP5 and CORDEX climate models, *The Cryosphere, sub judice*

HIGH-RESOLUTION CLIMATE MODELING

- Impact of small-scale processes on large-scale atmospheric motion → Importance of representing small scale processes.
- **High-resolution global climate modeling** has the potential to improve significantly the representation of climate variability, circulation regimes, extremes and transport.
- ***BUT*** high-resolution is computationally expensive, particularly in fully coupled models and the same model parameterizations may not be suitable

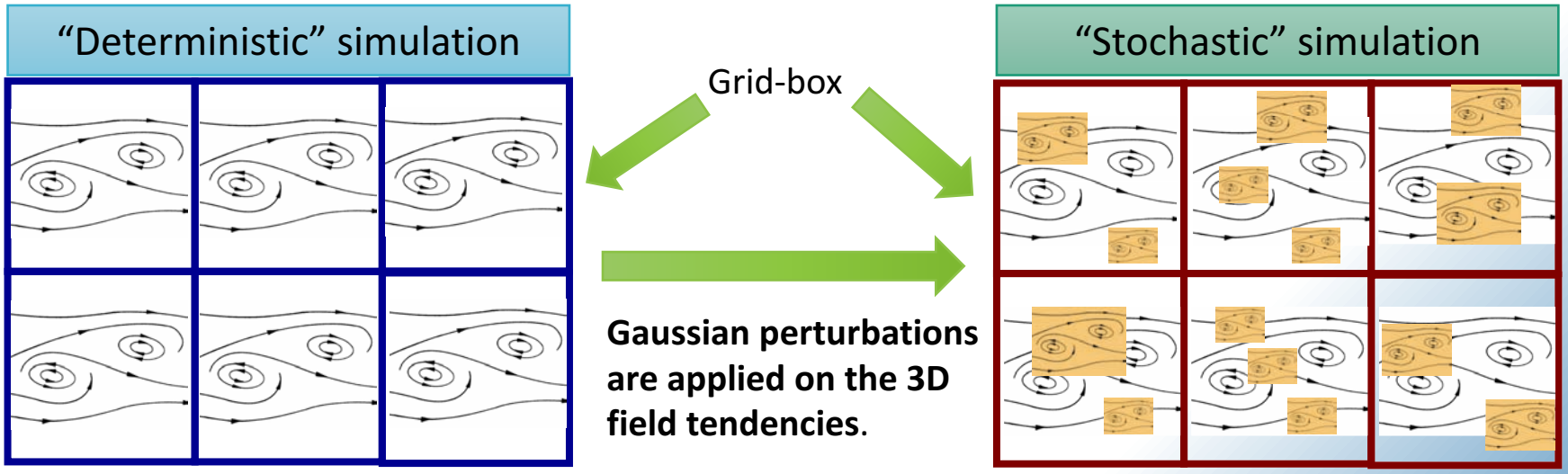


16 km

STOCHASTIC PHYSICS PARAMETERIZATIONS

Instead of explicitly resolving small-scale processes by increasing the resolution of climate models, a **computationally cheaper** alternative is to **use stochastic parameterization schemes** (Palmer 2012).

A stochastic scheme includes a **statistical representation of the small scales**, and hence is able to represent the impact of such small-scale processes on the resolved scale.



There is mounting evidence that stochastic parameterizations are beneficial for climate variability in GCM simulations (Dawson et al, 2012):

- Better representation of flow regimes
- Reduction of systematic biases

Climate SPHINX (Stochastic Physics High Resolution Experiments) is a supercomputing **PRACE** project (2015-2016) investigating **high-resolution** climate simulations and the role of **stochastic parameterizations**

CLIMATE SPHINX

Stochastic **P**hysics **HI**gh resolutio**N** e**X**periments

- **20 million of core hours** on **Supermuc** @ LRZ Computing Center, Garching, Germany + **10 million** core hours on **Marconi** @ CINECA, Italy
- About **150 TB** of post-processed data available
- More than 110 ensemble members at resolutions from 125 to 16km available.

Model: EC-EARTH 3

global climate model with additional tuning.

See:

Davini P., von Hardenberg J., Corti S., Christensen H., Juricke S., Subramanian A., Watson P., Weisheimer A., Palmer T. N., Climate SPHINX: evaluating the impact of resolution and stochastic physics parameterisations in climate simulations, *Geosci. Model Dev.*, in press, doi:10.5194/gmd-2016-115

ISAC · UNIVERSITY OF OXFORD · lrz · CINECA · EUDAT

EXPERIMENTS & RESOLUTIONS

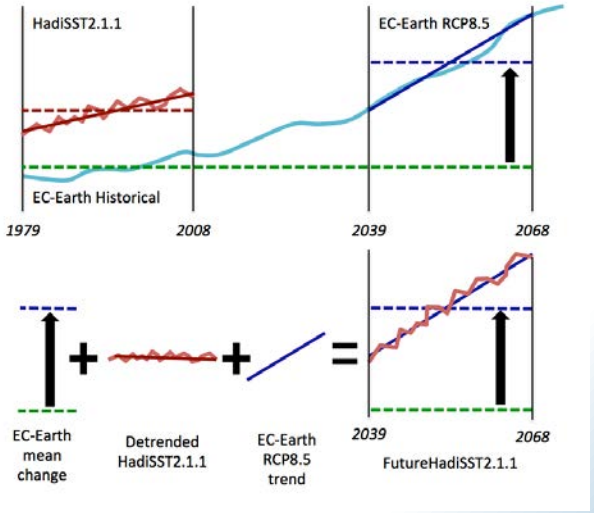
CLIMATE SPHINX

Atmospheric-only:
5 horizontal resolutions

Present day
1979-2008

Future Scenario
2039-2068 RCP85

Coupled: T255L91
1850-2100, historical + RCP8.5

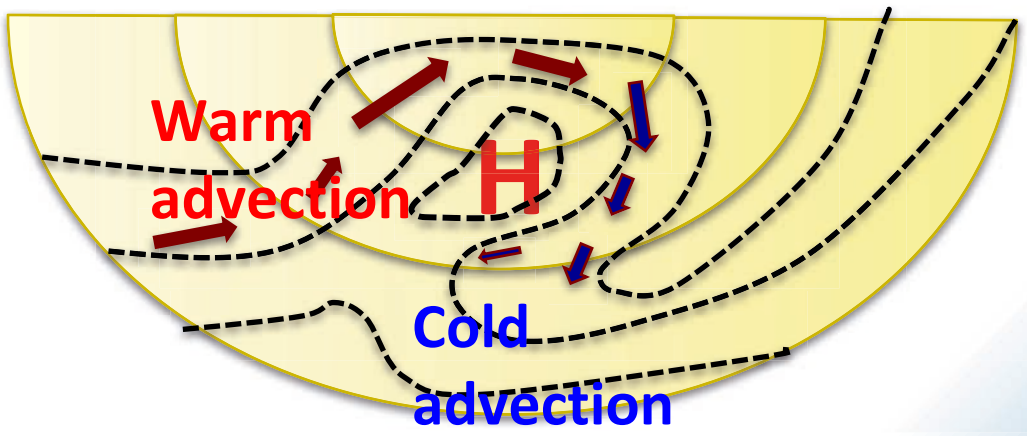


- **More than 110 simulations**
- **About 5000 model years of simulation**

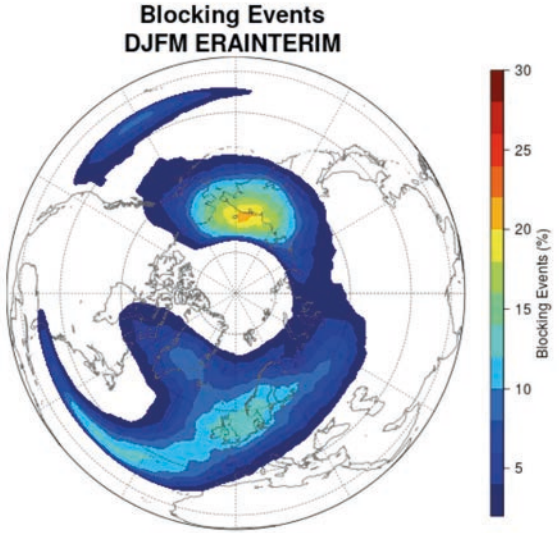
T159L91 (125km): 10+10 ensemble members
T255L91 (80km): 10+10
T511L91 (40km): 5+5
T799L91 (25km): 3+3
T1279L91 (16km): 1+1

ATMOSPHERIC BLOCKING

- Atmospheric blocking describes a mid-latitude weather pattern where a **quasi-stationary high-pressure system modifies the westerly flow**, “blocking” (or at least diverting) the eastward movement of the migratory cyclones **(Rex, 1950).**



- Blocking affects leading to **cold spells in winter (when it is more frequent) and heat waves in summer**.



- Evaluation of winter (DJFM) **atmospheric blocking** using the 2D index extension of Tibaldi and Molteni (Davini et al 2012) in the present day (30 years).

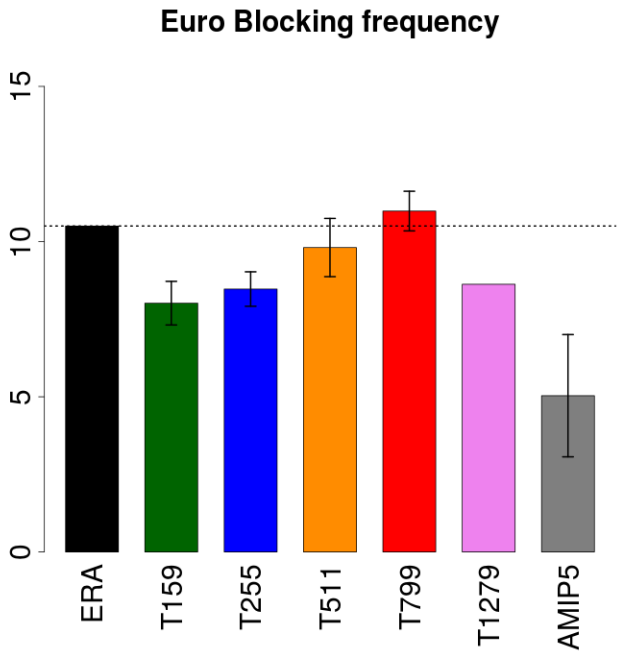
- Blocking over the **Pacific** and the **Atlantic**, at the exit of the jet stream.

- **Long-standing issue in GCMs**, large negative bias over Europe even in CMIP5 models.

RESULTS: BLOCKING

Improvements in atmospheric blocking with increasing resolution.

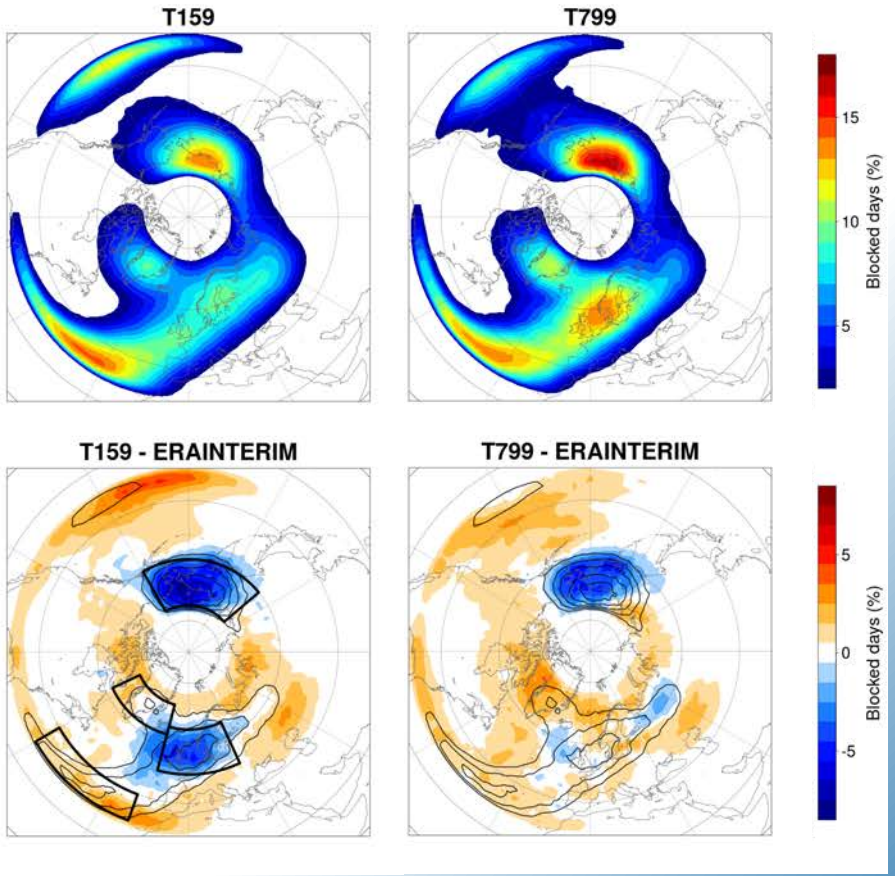
Way better than any CMIP5 models



Winter (DJFM) , Present Day

125 km resolution

40 km resolution

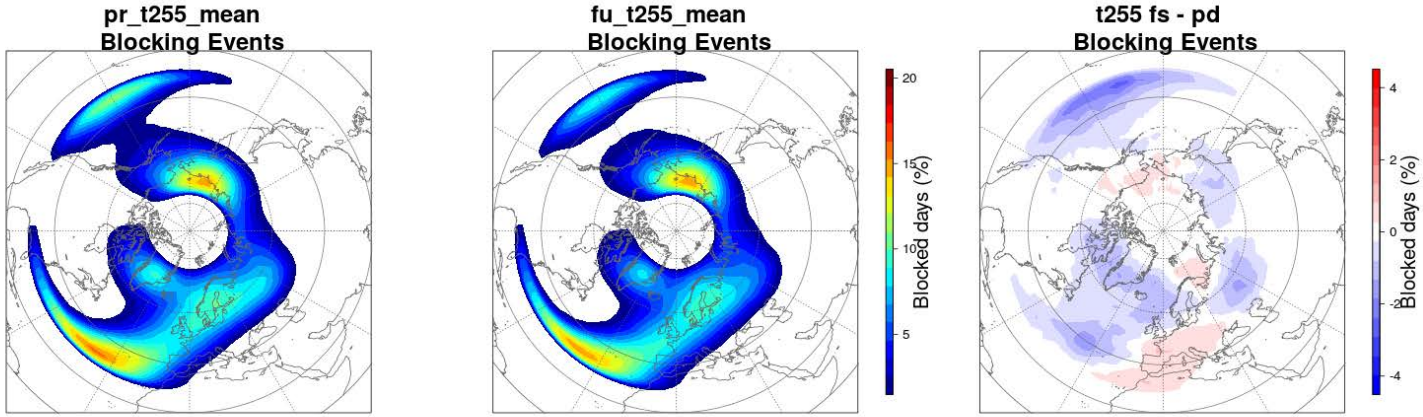


RESULTS: BLOCKING

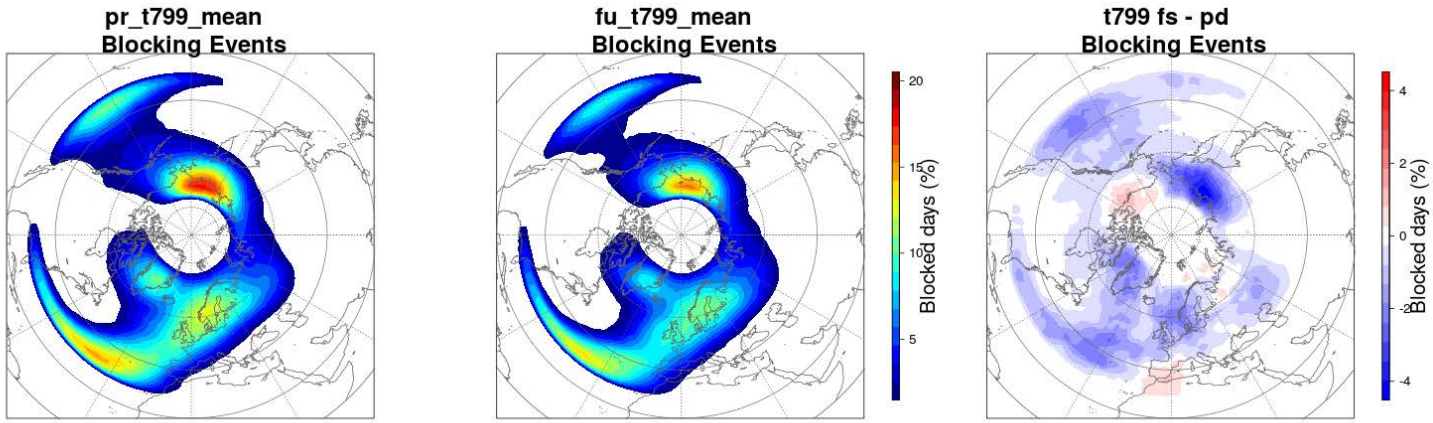
Resolving the present day blocking allows us provide possibly more reliable predictions for the future climate

Winter (DJFM) , Future change

80 km resolution

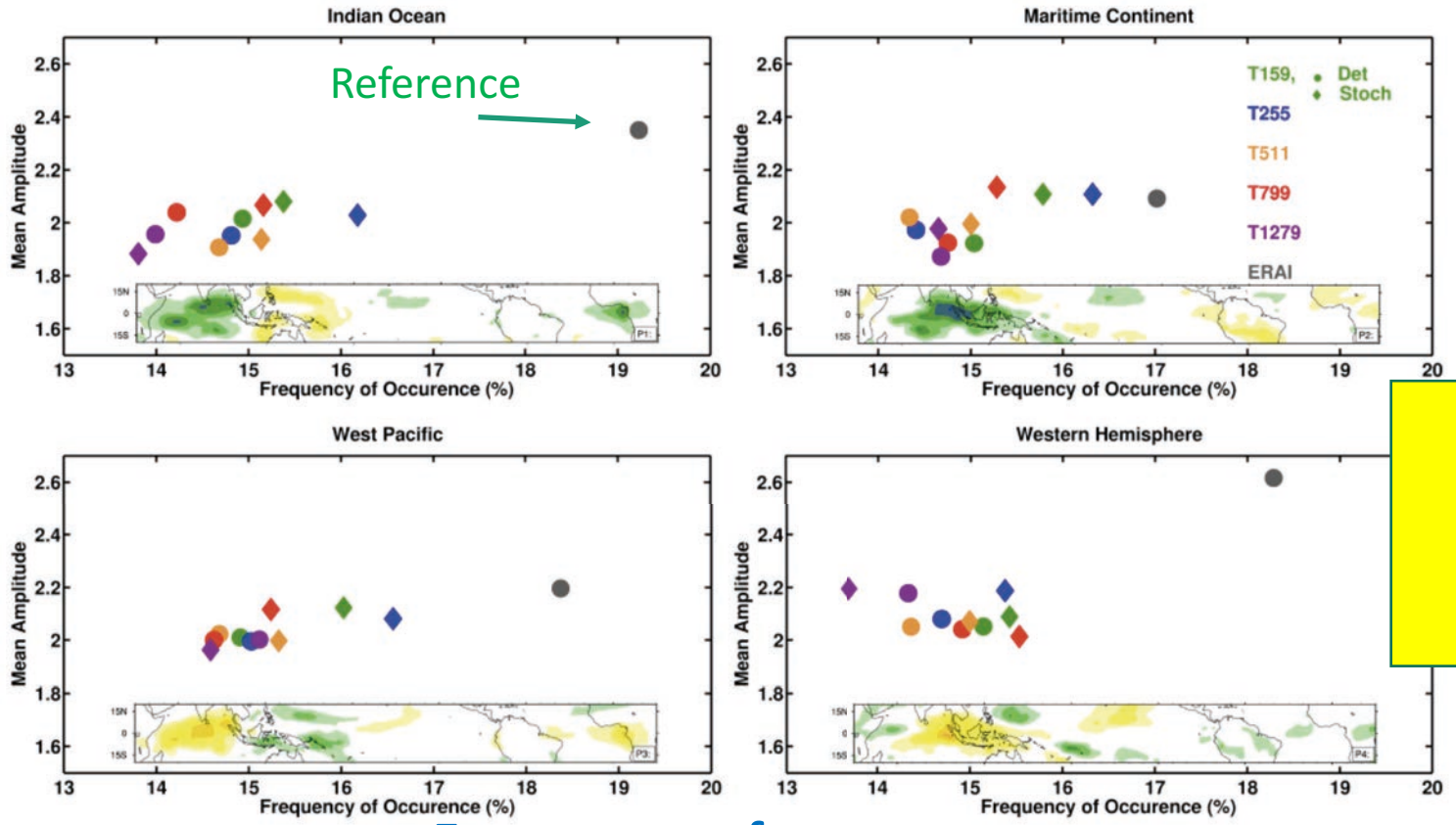


25 km resolution



MADDEN-JULIAN OSCILLATION

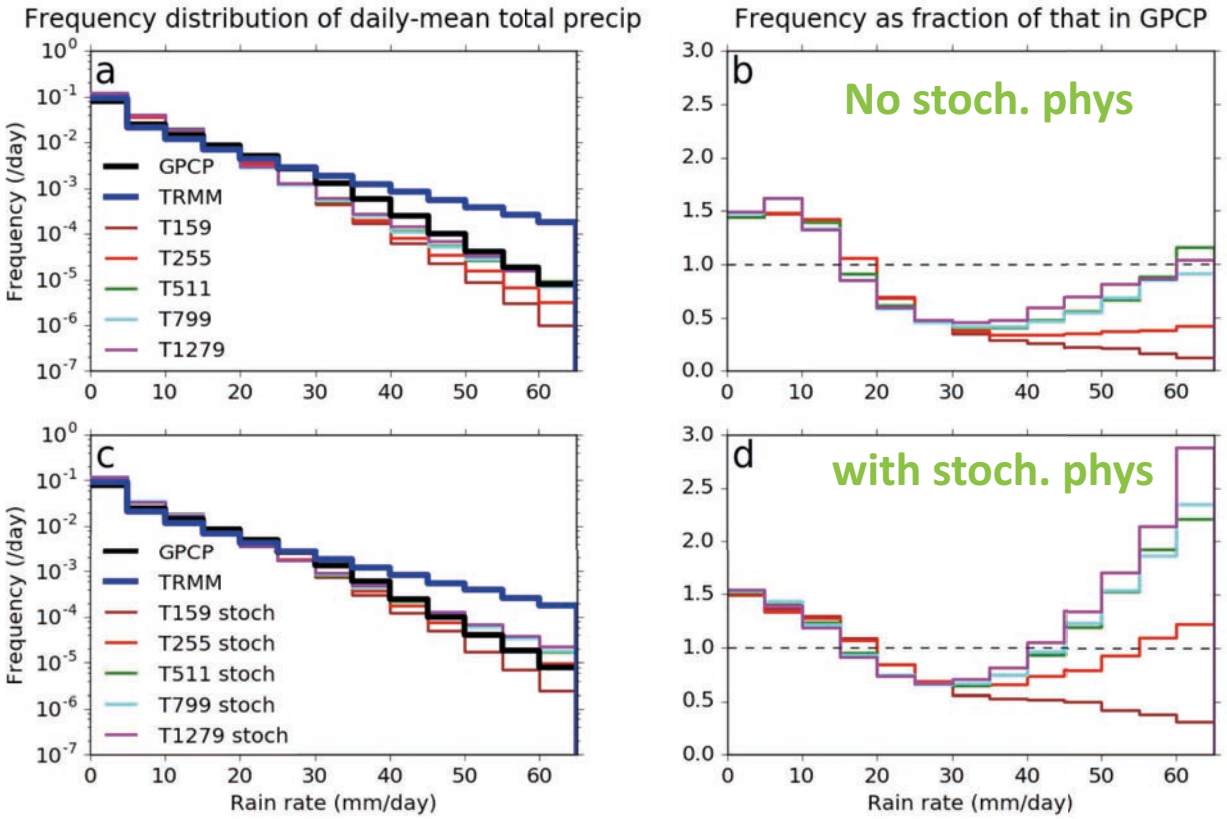
- The **Madden-Julian Oscillation** (MJO) is the dominant mode of variability in the tropical region on sub-seasonal timescales (30-90 days). Eastward travelling pattern in Indian Ocean and Pacific.
- It is a challenge for the current generation of global climate and weather models to represent the dynamics and thermodynamics of the MJO realistically



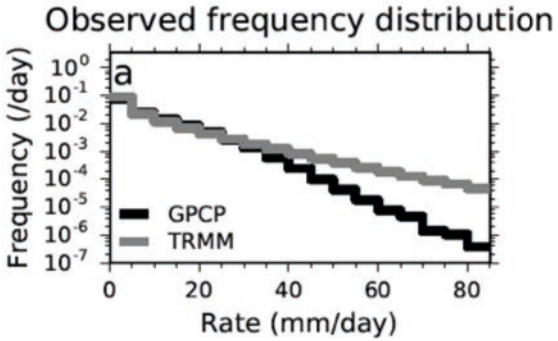
Benefit only from stochastics physics

TROPICAL PRECIPITATION

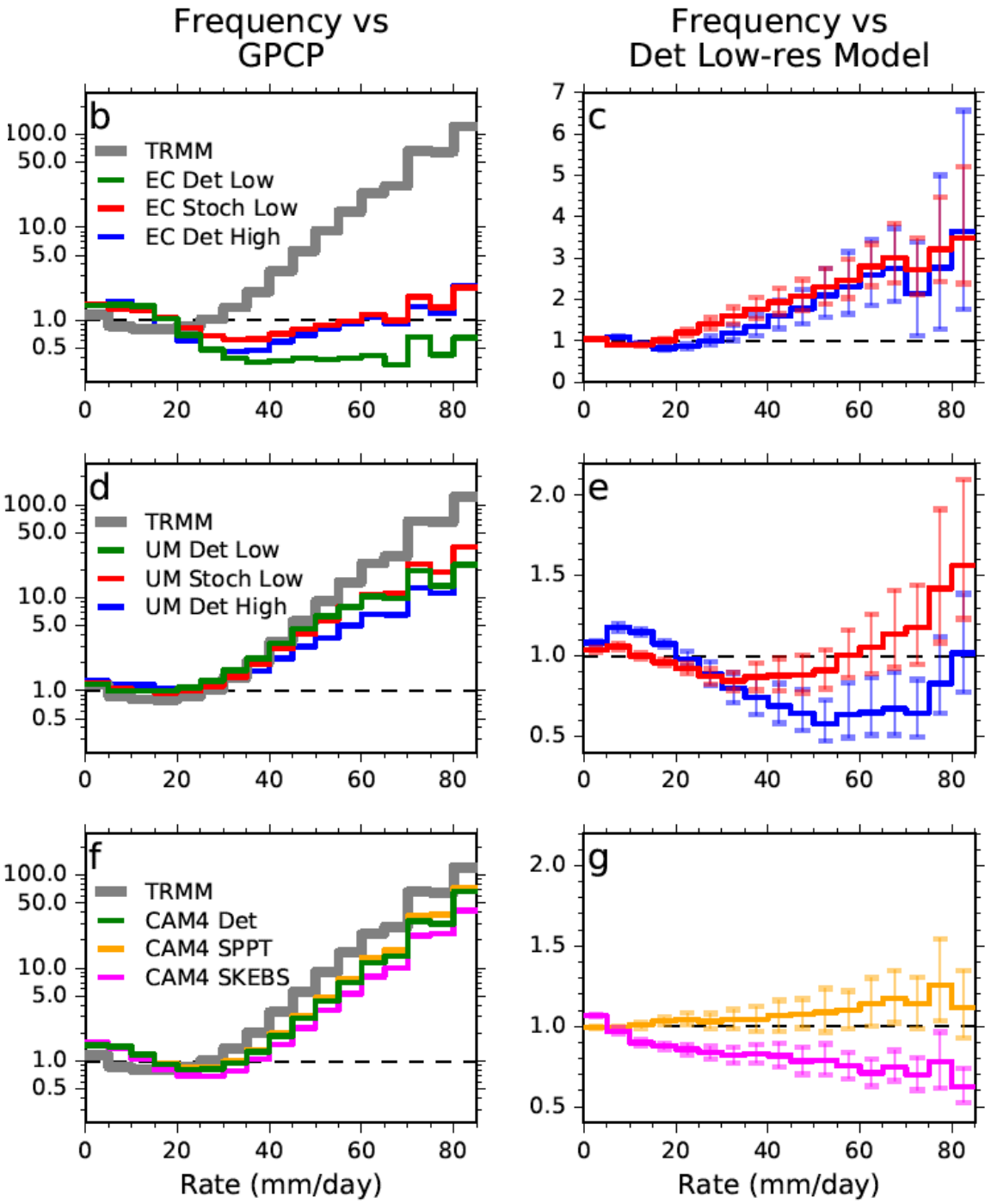
- One aspect of the **tropical variability** of particular interest is the **occurrence of heavy precipitation events**, which can result in flooding or reduce crop yields (IPCC, 2014).
- Estimated through the **frequency distribution of daily-mean precipitation rates** averaged over 2.5°x2.5° grid boxes **between 10°S-10°N** over the period 1998-2008



- In general, **underestimation of extreme rainfall events**
- **Increasing resolution leads to reduced bias**: however applying **stochastic parameterization improves the variability of low resolution models** (T159-T255).



Watson, P.A.G., Berner, J., Corti S., Davini, P., von Hardenberg, J., Sanchez, C. Weisheimer, A., Palmer T. (2017):
The impact of stochastic physics on tropical rainfall variabilitu on daily timescales in global weather and climate models, JGR-Atmospheres, sub judice



Projects working on improving the current generation of models and on high-resolution

- **CRESCENDO H2020 Project (2015-2020)**
  - Improve the process realism and future projection reliability of European **Earth-System Models**,.

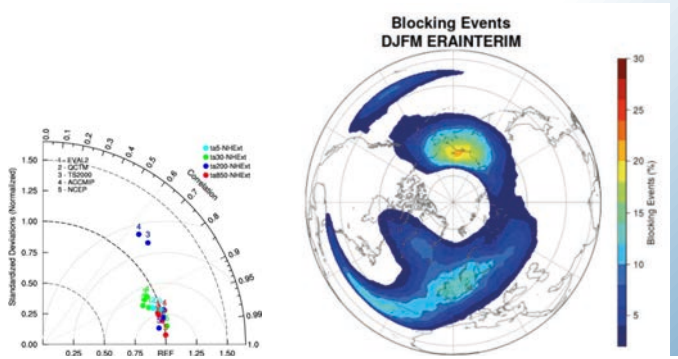
- **PRIMAVERA H2020 Project (2015-2020)**
  - Develop a new generation of well-evaluated **high-resolution global climate models**

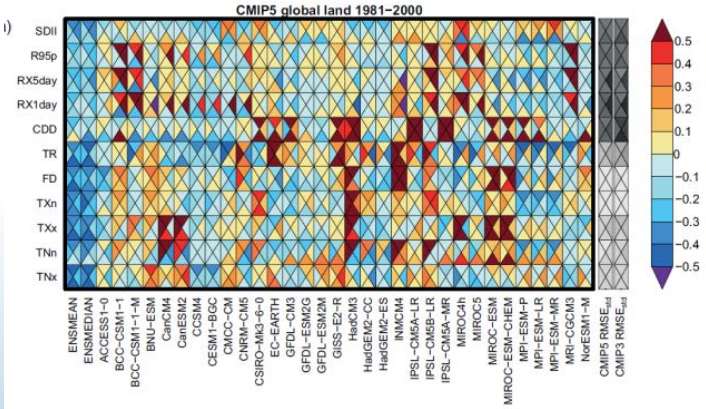
- **HighResMIP**
  (The High Resolution Model Intercomparison Project)
  - A multi-model approach to the systematic investigation of the impact of horizontal resolution

The Copernicus Project: "Development of C3S software for data analysis from climate models"

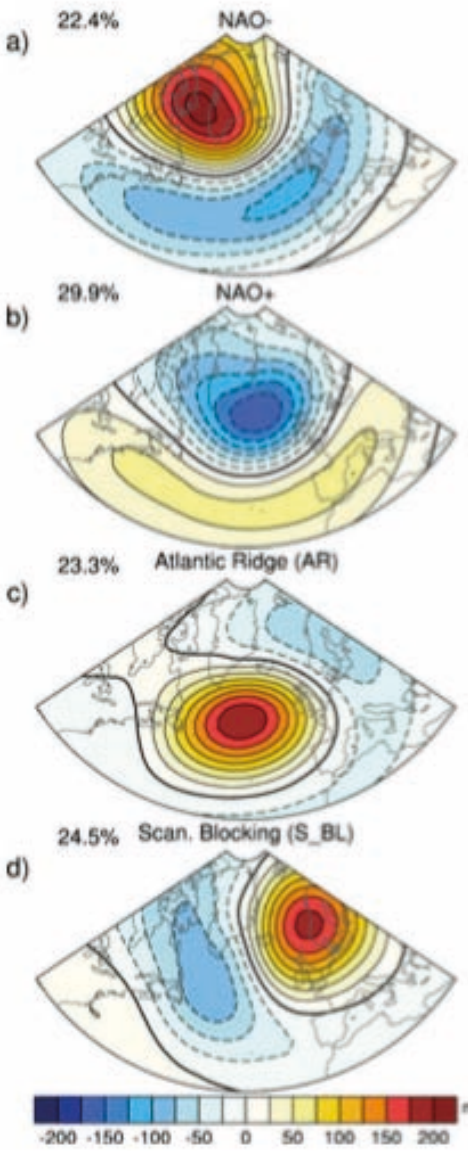
- This project (2016-2018) will, with a consortium formed by KNMI, ISAC-CNR, BSC, DLR, NLeSC, SMHI, U.Reading, develop a software solution allowing to calculate and present metrics, statistics, time series, and products tailored to applications from climate model data

- This will allow to make climate model data accessible to users, other researchers and stakeholders with derived products tailored to applications in specific sectors, including water, insurance and coastal areas.



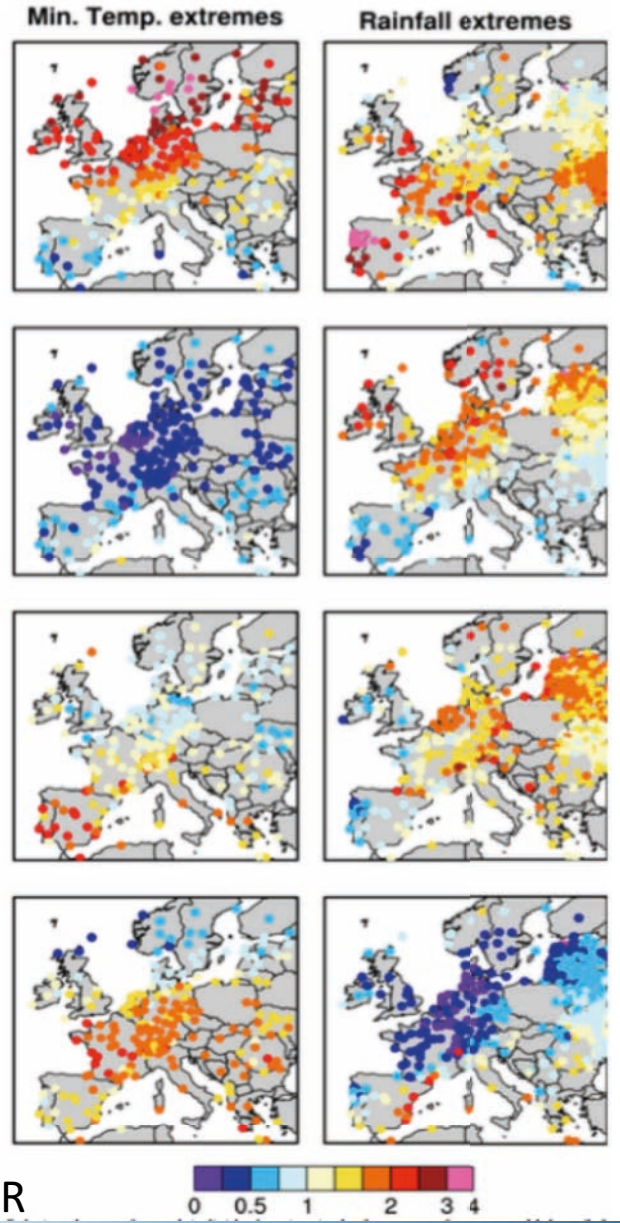


NEED FOR ENSEMBLE SELECTION



Clusters based on wintertime circulation anomalies (500hPa)

Tailored ensemble selection



Relative changes in the frequency of extreme cold days and wet days

S. Corti, ISAC-CNR

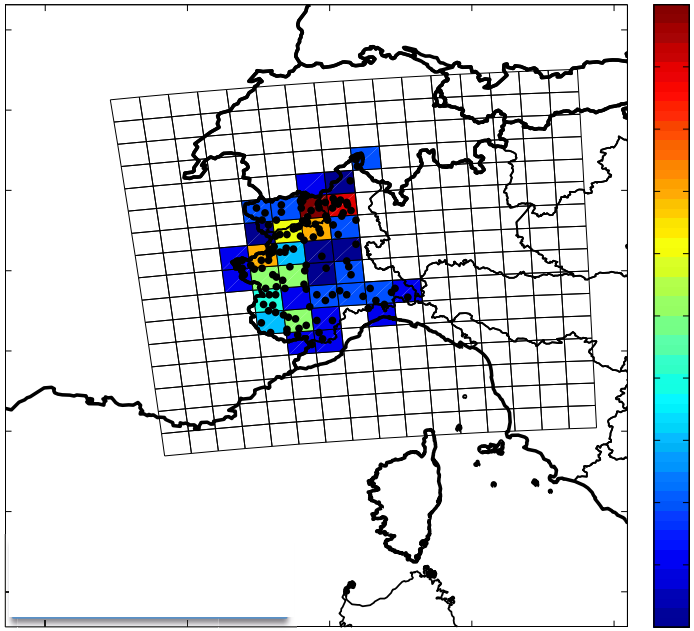
Stochastic downscaling

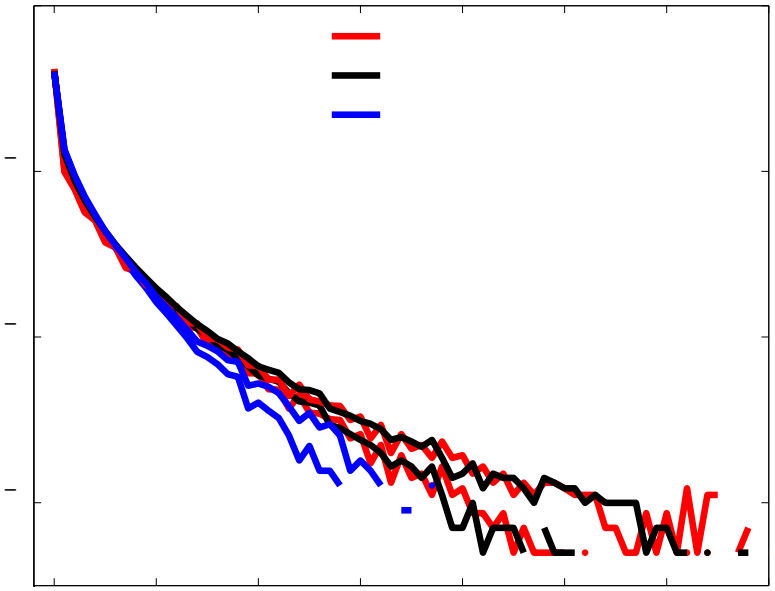
RainFARM (Rainfall Filtered Auto Regressive Model)

- 122 rain gauges
- 1958-2001
- Daily resolution

- Altitude max: 2526 m
- Altitude min: 127 m

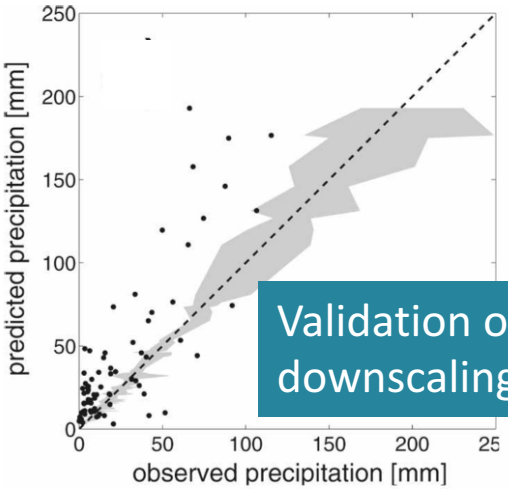
PROTHEUS: Δx≈30km





* *D'Onofrio, D.; Palazzi, E.; von Hardenberg, J., Provenzale A., Calmanti S.; Stochastic Rainfall Downscaling of Climate Models. J of Hydrometeorology 15 (2), 830-843 (2014)*

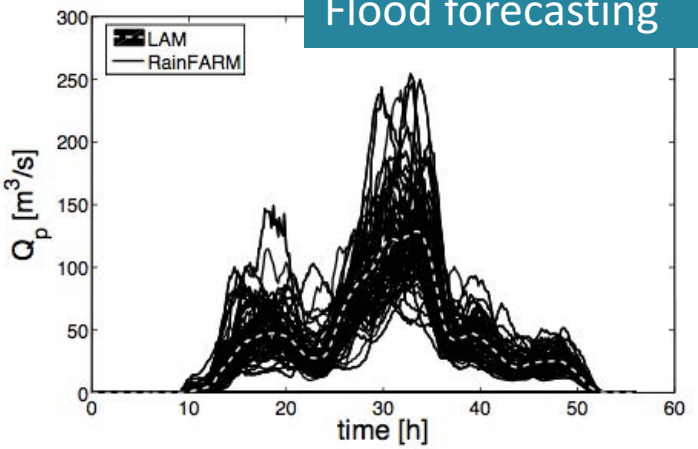
Applications of Stochastic Downscaling



Validation of forecasts via downscaling

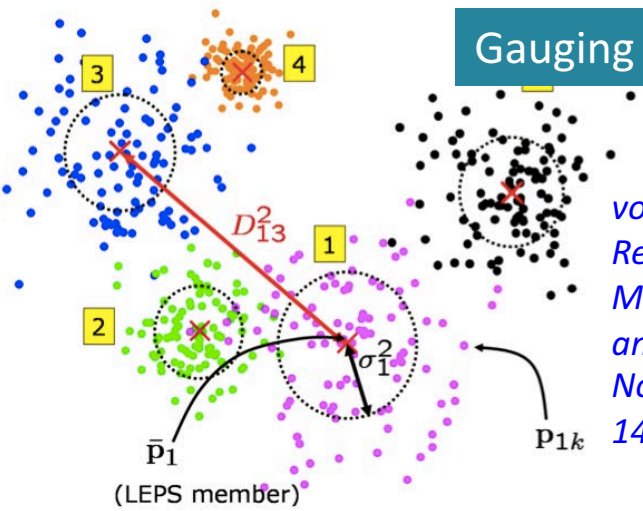
E. Brussolo, J. von Hardenberg, L. Ferraris, N. Rebora, A. Provenzale. Verification of quantitative precipitation forecasts via stochastic downscaling. Journal of Hydrometeorology, 9, 1084-1094 (2008)

Flood forecasting



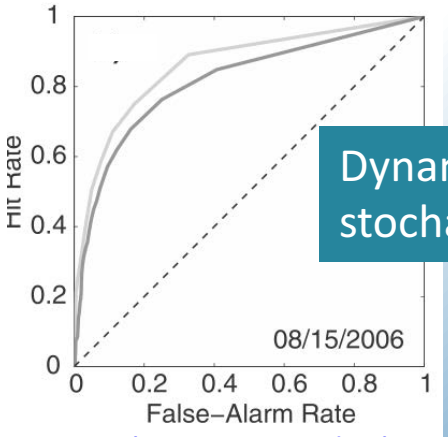
N. Rebora, L. Ferraris, J. von Hardenberg, A. Provenzale, Rainfall downscaling and flood forecasting: a case study in the Mediterranean area. NHESS, 6, 611-619 (2006).

Gauging uncertainty



von Hardenberg J, Ferraris L, Rebora N, Provenzale A , Meteorological uncertainty and rainfall downscaling . Nonlinear Proc. Geophysics, 14, 193-199 (2007)

Dynamical vs. stochastic ensembles



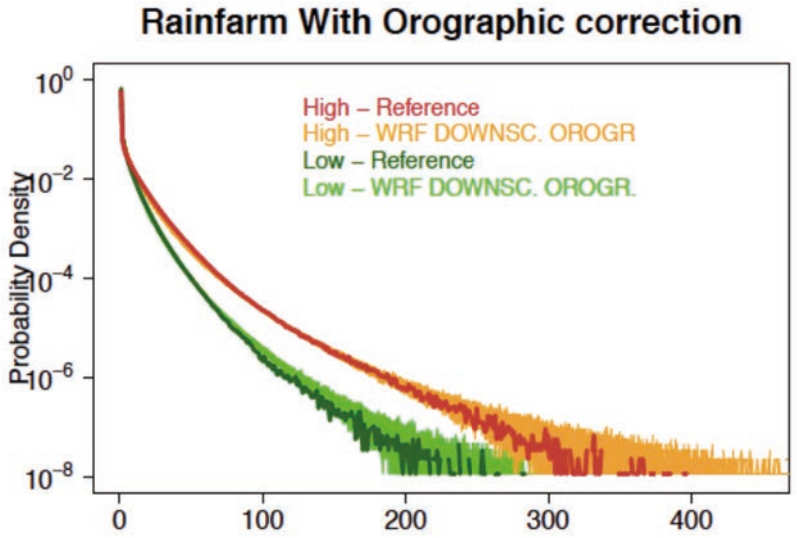
E. Brussolo, J. von Hardenberg, N. Rebora. Stochastic versus Dynamical Downscaling of Ensemble Precipitation. J. of Hydrometeorology 10(4), 1051-1061 (2009)

STOCHASTIC DOWNSCALING WITH OROGRAPHIC CORRECTIONS

In a perfect model scenario

Development of an improved stochastic downscaling technique for RainFARM capable of reproducing a realistic small-scale precipitation climatology

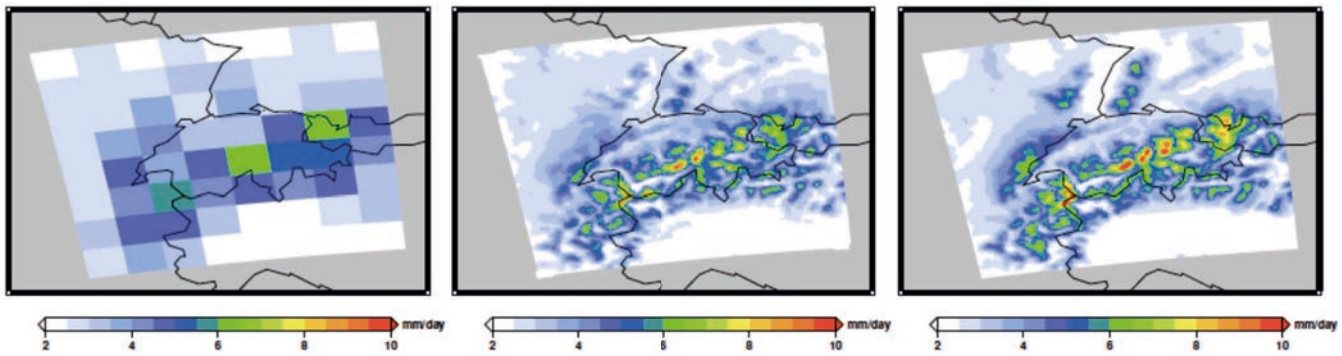
Based on the availability of a reference fine-scale climatology



WRF at 0.64°

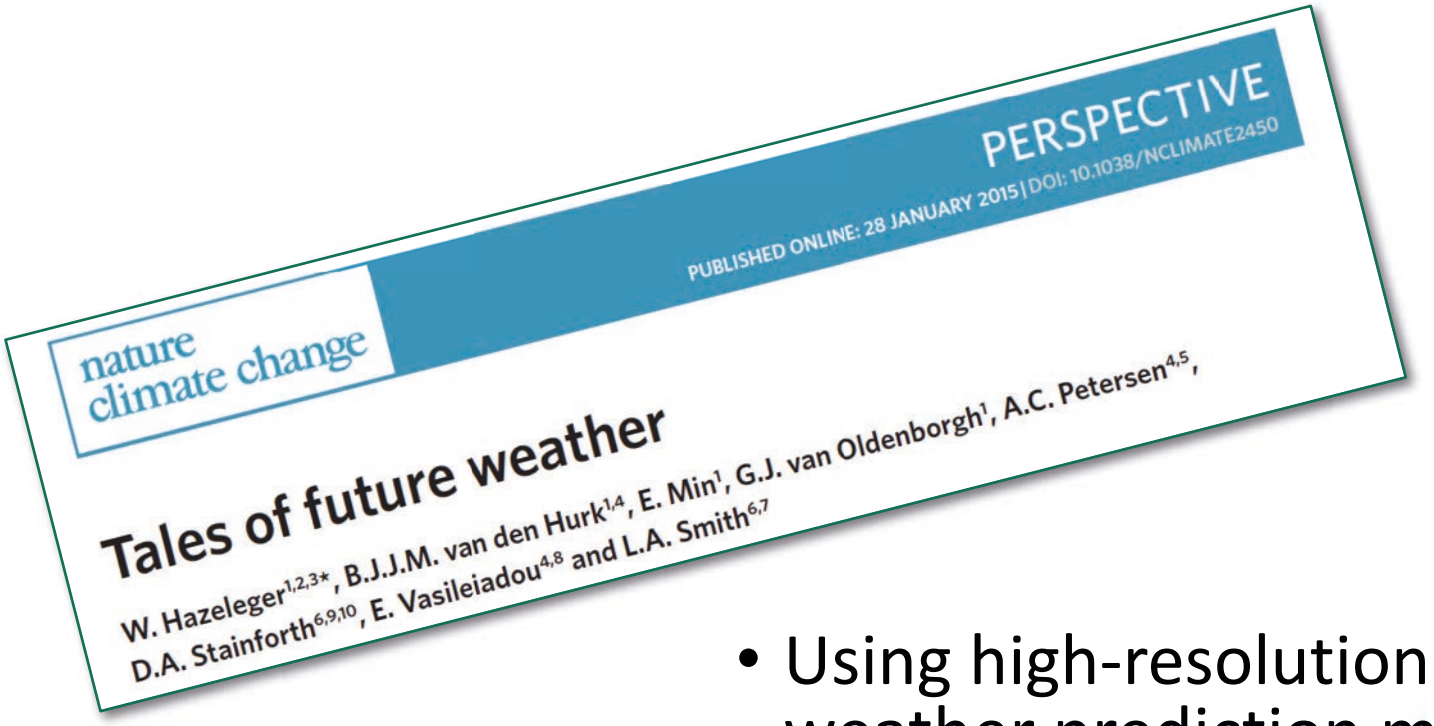
Downscaled

WRF at 0.04°



OTHER APPROACHES?

to a ensemble climate model projections-downscaling chain



- Using high-resolution numerical weather prediction models to explore high-impact weather events in a future climate
- Can be tailored for specific applications