REQUEST FOR A SPECIAL PROJECT 2017–2019

MEMBER STATE: …The Netherlands……………….……………………………………

Principal Investigator[1]**:** …G Lenderink……………………….……

Affiliation: …KNMI (Royal Netherlands Meteorological Institute)….……

Address:
…Utrechtseweg 297 ……………………………………….……
…Postbus 201, 3730 AE De Bilt ………………………….……
…The Netherlands………………………………………….……

E-mail: …lenderin@knmi.nl……………………………….……

Other researchers:
…Kai Lochbihler (KNMI)…………………………….……
…Pier Siebesma (KNMI and TUD)……………….……

Project Title:

Spatial and temporal dependencies extreme precipitation in a warming climate using large eddy simulation (SPACELES)

If this is a continuation of an existing project, please state the computer project account assigned previously.	**SP** _________________	
Starting year: (Each project will have a well-defined duration, up to a maximum of 3 years, agreed at the beginning of the project.)	2017	
Would you accept support for 1 year only, if necessary?	YES XX	NO ☐

Computer resources required for 2017-2019: (To make changes to an existing project please submit an amended version of the original form.)		**2017**	**2018**	**2019**
High Performance Computing Facility	(SBU)	5 MSBU	5MSBU	
Accumulated data storage (total archive volume)[2]	(GB)	12000GB	15000GB	

***An electronic copy of this form must be sent via e-mail to**:* *special_projects@ecmwf.int*

Electronic copy of the form sent on (please specify date):

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Continue overleaf

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[1] The Principal Investigator will act as contact person for this Special Project and, in particular, will be asked to register the project, provide an annual progress report of the project's activities, etc.

[2] If e.g. you archive x GB in year one and y GB in year two and don't delete anything you need to request x + y GB for the second project year.

Principal Investigator: Geert Lenderink……………………………………

Project Title: Spatial and temporal dependencies extreme precipitation in a warming climate using large eddy simulation (SPACELES)…

Extended abstract

It is expected that Special Projects requesting large amounts of computing resources (1,000,000 SBU or more) should provide a more detailed abstract/project description (3-5 pages) including a scientific plan, a justification of the computer resources requested and the technical characteristics of the code to be used. The Scientific Advisory Committee and the Technical Advisory Committee review the scientific and technical aspects of each Special Project application. The review process takes into account the resources available, the quality of the scientific and technical proposals, the use of ECMWF software and data infrastructure, and their relevance to ECMWF's objectives. - Descriptions of all accepted projects will be published on the ECMWF website.

1. Scientific background

Convective precipitation extremes are increasingly causing severe damage due to local flooding, landslides and land erosion. However, convective processes occur at scales far finer than those resolved in climate models. For that reason mesoscale atmospheric models are currently being applied in order to assess changes in convective dynamics in a warming climate. These models – often referred to as convection permitting models – are typically run at a resolution of 2 km, thereby only resolving the largest motions of convective clouds. Here, we go one step further and apply a Large Eddy Simulation (LES) model which is specifically designed to explicitly resolve convective dynamics.

In order to assess the impact of changes in precipitation extremes in a warming climate, both the (peak) intensity and the total volume of rain of an event are two important key parameters. From observations in the Netherlands, but also elsewhere, it is known that changes in short duration peak intensity could scale as two times the Clausius-Clapeyron relation: 14 % per degree, hereafter 2CC scaling (Lenderink and van Meijgaard 2008; Lenderink et al. 2011; Loriaux et al. 2013). This is found by analysing hourly precipitation as a function of dew point temperature; see Figure 1 where we show the results for the Netherlands and also for Hong Kong, noting that despite the differences in climate the results are actually surprisingly close together. So, each degree dew point temperature rise implies 7 % more moisture (according to the CC relation) and a 14% increase of the extreme intensities.

Our hypothesis is that this 2CC dependency is caused by a local feedback in a convective cloud due to the influence of latent heating on the strength of the updrafts in the convective cloud. In a simple updraft model of convective core, we could show that this mechanism indeed plays a role; however we did not obtain a factor 2 enhancement, but a factor 1.5 instead (Loriaux et al. 2013). Partly, this lower factor of increase in the updraft model may be explained by the missing feedback from the cloud dynamics onto the boundary layer dynamics, through for instance cold pools, and we therefore need a model that captures these turbulent interactions.

The above 2CC scaling is still strongly debated in the literature (Westra et al. 2014). Apart from the above physical explanation for the 2CC scaling, other scientists have argued that it could also be explained by a statistical effect which is unrelated to the dynamics/physics of convective extremes (Haerter and Berg 2009). This statistical effect is (or could be) caused by variations in the frequency of occurrence of different precipitation types with (dew point) temperature for instance due to the seasonal cycle. Later work by the same authors using a comprehensive analysis of rain radar data however showed that short duration precipitation intensities indeed scale beyond the CC relation, but the same analysis also revealed a statistical effect (Berg et al. 2013).

To summarize, although it is now commonly accepted that short duration extremes could scale beyond the CC relation, it is unclear whether a 2CC behaviour is a "general" property of convective extremes. And if this is the case it is important to know the physical explanation, and for which conditions it will manifests itself in a climate change setting.

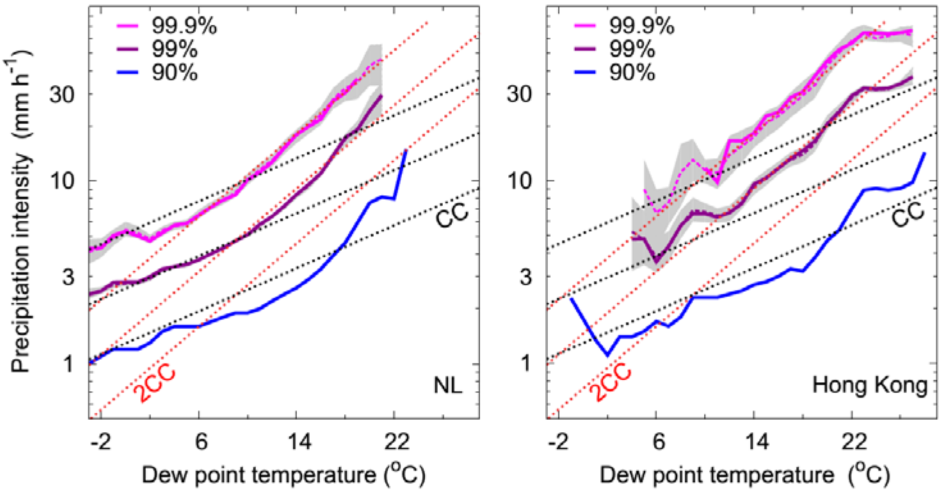

Figure 1. Dependency of hourly precipitation extremes on dew point temperature derived from ~30 stations in the Netherlands (left) and Hong Kong (right). Dew point temperatures are taken 4 hours before the event. Shown are results for the 90, 99 and 99.9th percentile of wet events. Solid line: raw data, stippled lines: estimated from a GPD fit, including uncertainty estimates (grey shading). Red and black linear lines show (exponential) dependencies of 7 and 14 % per degree.

Turning to total volume of precipitation in a convective storm uncertainties may well be even larger. We conceptualized this in Figure 2 (figure by Lenderink from Westra et al. (2014)). There are two important controlling factors. First, the rate at which water vapour can be converted to rain. Here, the strength of the dynamics, with condensation in the updraft leading to the formation of cloud droplets and ice, and also the microphysics play a role. This determines the intensity of precipitation. As argued above there is reasonable support that intensity will increase in excess of the Clausius-Clapeyron relation. The other controlling factor is the moisture budget, with the amount of moisture following the Clausius-Clapeyron relation per cubic meter of air in a warmer climate. If the cloud accesses moisture from the same area the total volume of rain will also has to follow the CC relation. Given the super CC behaviour of the intensity it will have to shorten in time or become smaller in space (situation b in Figure 2).

Given the stronger dynamics of convective systems in a warmer climate, it may also be expected that convective systems become bigger in scale, accessing moisture from a larger area. In fact, observations in the Netherlands provide evidence that this is indeed the case, and also that is a large effect. This is found by estimating the size of precipitation events from the hourly station observations following the methodology in Loriaux et al. (2016), considering hourly precipitation measurement that are connected in time and space (with a radius of 50 or 70 km). For these events we find a substantial increase in cloud size at the high dew point temperature range.

If cloud clusters indeed increase in size with increasing temperatures, storm precipitation volumes could also increase in excess of the CC relation. This is substantially more than commonly assumed in climate change assessments. There is limited support for such a strong increase in storm precipitation volumes from short integration with a mesoscale model (Attema et al. 2014; Lenderink and Attema 2015) where it is found that also daily sums could increase beyond the CC scaling.

So, the dynamics of storm clouds and the degree to which they organize in clouds clusters are playing a crucial role in this context. In order to capture this we have to rely on models that capture both the turbulent dynamics of clouds, but also the dynamics of the boundary layer, including cold pools. Therefore, we rely on a LES model run at a resolution of 200 m (or below). With the LES model we will do experiments using "observational based" forcing conditions for present-day climate conditions, and surrogate warming experiments (see e.g. Attema et al. 2014; Singleton and Toumi 2013; Loriaux et al. 2013)

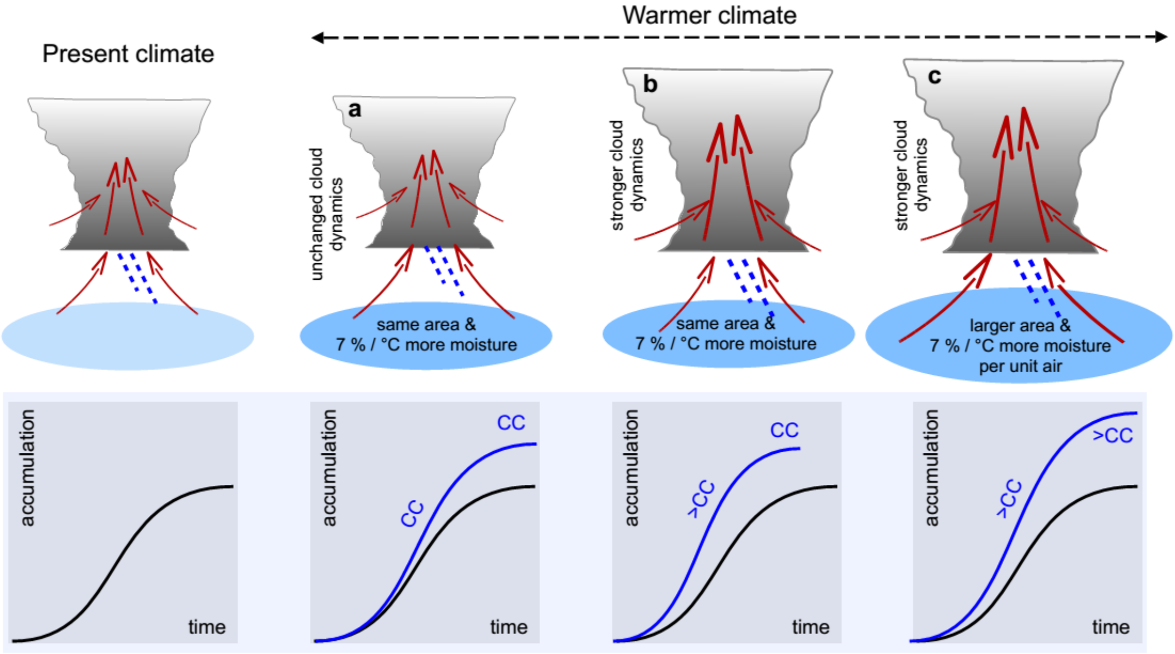

Figure 2. Conceptual framework of the response of cloud dynamics, precipitation intensity and accumulated precipitation in a warmer climate (see text for details) (Westra et al. 2014)

2. Specific scientific questions and application of the results

With this research we aim to answer the following questions:

- What are the controlling factors that govern cloud organization? What are the influences of wind shear, instability and moisture content?
- How does precipitation intensity depend on warming? Does this response depend on the degree of organization of the convective clouds ?
- How does the degree organization of convective clouds respond to a warming scenario, and how does this impact changes in storm rainfall volume?

Analysis of the runs will be done using a cloud tracking algorithm, which is currently being developed.

The impact of these runs will increase our understanding and predictive capacity to foresee future changes in precipitation, such as for instance applied already in the Dutch climate scenarios (Lenderink and Attema 2015). But, also it will lead to better constraints on parameterization of convection in present-day weather and climate models.

3. Runs to be performed and computation requirements

The Dutch Atmospheric Large Eddy Simulation (DALES) model is a high resolution turbulent resolving community model that has been developed jointly by KNMI, Technical University Delft (TUD), Utrecht University and Wageningen University. For the dynamics a fifth order central difference scheme is used, while the sub-grid turbulence is parameterized by an eddy diffusivity approach using a Turbulent Kinetic Energy (TKE) closure. It contains a comprehensive physics package for cloud microphysics, radiation and soil processes (Heus et al. 2010). It runs well on massive parallel machines and has a perfect weak scaling behaviour (Schalkwijk et al. 2015b) and has been used semi-operational at the KNMI testbed for a period of more than a year (Schalkwijk et al. 2015a).

Run will be one day long, simulating a convective day for the Netherlands based on atmospheric forcing derived from a combination of observations and a downscaling of ERA-interim (Loriaux et al. 2016). We have experience with forcing the LES in this way, and a paper explaining this methodology has just been submitted (Loriaux et al., submitted). In that paper we mainly looked at short duration intensity, and the runs were performed on a much smaller domain at the Netherlands national computing centre SURFsara. In this project we will repeat and expand on these experiments employing a much bigger domain in order to be able to investigate cloud organization. One additional reason to take a large domain is that for a small domain the moisture constraint (how much moisture is supplied by the forcing of the model) has a rather large influence on the result. For these experiment we therefore will use 2000x2000 grid points horizontally with approximately 200 vertical levels, equivalent to 400 x 400 km^2 and up to 18 km height.

Give the domain size, these runs are computationally expensive. At present a run with a quarter domain size takes 60 h on 240 cores at KNMI computing facility. We estimate one run of the full domain to be equivalent to 200.000 SBU (0.2 MSBU).

In total we expect to perform 40 simulations, by varying wind shear, stability and relative humidity, and performing the analysis with 3 different levels of “global” warming. Given the computational cost of one simulation (0.2 MSBU) we therefore expect a total computational expense of 8 MSBU for performing the runs over a period of 2 years. We added 2 MSBU to calibrate the system, setting up the experiments, and post processing output. The output of such a simulation is huge, order a few Tb per run. We therefore specifically allocated computing time to post process the data using a cloud tracking algorithm.

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