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**Article (Accepted version)
(Refereed)**

Original citation:

Hazeleger, W., van den Hurk, B.J.J.M., Min, E., van Oldenborgh, G.J., Petersen, A.C., Stainforth, D. A., Vasileiadou, E. and Smith, L. A. (2015) *Tales of future weather*. [Nature Climate Change](#), 5 (2). pp. 107-113. ISSN 1758-678X

DOI: [10.1038/nclimate2450](https://doi.org/10.1038/nclimate2450)

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This version available at: <http://eprints.lse.ac.uk/61171/>

Available in LSE Research Online: March 2015

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1 **Tales of Future Weather**

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21

22 **Society is vulnerable to extreme weather events and, by extension, to the**
23 **human impact on future events. As climate changes weather patterns will**
24 **change. The search is on for more effective methodologies to aid decision-makers both**
25 **in mitigation to avoid climate change and in adaptation to changes. The traditional**
26 **approach employs ensembles of climate model simulations, statistical bias correction,**
27 **downscaling to the spatial and temporal scales relevant to decision-makers, and then**
28 **translation into quantities of interest. The veracity of this approach cannot be tested,**
29 **and it faces in-principle challenges. Alternatively, numerical weather prediction models**
30 **in an altered climate setting can provide tailored narratives of high-resolution simulations**
31 **of high-impact weather in a future climate. This Tales of Future Weather approach will**
32 **aid in the interpretation of lower resolution simulations. Arguably, it potentially**

33 **provides a complementary and more realistic and more physically consistent pictures of**
34 **what future weather might look like.**

35

36 **Introduction**

37

38 Science-informed policy is aided by robust, reliable insights into the changes in weather likely to be
39 experienced by individuals, by sectors and by nations. Vulnerability to high impact weather,
40 whether it takes the form of weather extremes or changes in local climate which, while not
41 necessarily extreme in the meteorological sense, carry significant societal consequences, has
42 generated a demand for local climate information. In response, climate services targeting a variety
43 of lead times are being considered world-wide¹. The extent to which this demand can be met with
44 high fidelity remains unclear^{2,3,4}. In this paper we propose a novel alternative methodology
45 compared to current approaches, and discusses its strengths and weaknesses.

46

47 Quantitative information of a probabilistic nature at local scales would prove of great value if
48 robust, actionable, trustworthy, and reliable (hereafter, "decision-relevant") information on the
49 probability of future weather phenomena could be provided. Such information, if decision-relevant,
50 would aid evaluation of the effectiveness of measures for coping with future events⁵. One
51 traditional methodology for constructing such information, hereafter called MoCoDoT (model-
52 correct-downscale-translate), is to use a current generation of climate models to simulate events
53 on global and regional scales, downscale these simulations to generate local geophysical
54 information and then translate the results into quantities of interest. The downscaling procedure is
55 usually one-way, it attempts to correct for biases in the global climate model which provided the
56 original simulation but does not allow feedbacks to the global model or insure consistency at the
57 local scale. The local climate information thus generated is then used to provide information for
58 decision makers. An example is flood risk assessment using socio-economic models to compute the
59 damages of flooding and the costs and benefits of protective measures⁶. While desirable, obtaining
60 the probabilities of future events may be considered beyond the pale when multi-model ensembles
61 do not provide a good proxy for the true probability of future events³; this is widely acknowledged
62 to be the case⁷. The aim of this Perspective, which expresses the views of the authors, is to
63 propose an alternative approach that takes a qualitatively different path using both climate models
64 and weather models to better focus on specific weather events; events that expose the

65 vulnerability of society. It then examines the strengths, weaknesses and benefits of this new
66 approach to science as well as decision making.

67

68 The linking of severe weather events to rising greenhouse gas concentrations in the atmosphere,
69 along with a number of recent demonstrations of societal vulnerability to severe weather, has led
70 to significant media and scientific attention. Hurricanes Katrina, Sandy and Haiyan, the European
71 heat waves in 2003, 2006 and 2010, floods in Asia and Australia in 2011, floods in central Europe
72 in 2013 and floods in the UK in the winter of 2013/2014 are vivid examples. Mitigation measures
73 are considered to reduce the impacts to which society is exposed, while adaptation measures can
74 reduce the vulnerability of society to those phenomena that do occur. The understanding and
75 advancement of each is aided by decision-relevant information about future weather, ideally in
76 terms of reliable probability distributions. Yet the common MoCoDoT approach described above is
77 severely hampered by the inherent difficulty of predicting climate, given the existence of non-linear
78 feedbacks in the climate system and structural model error/inadequacy in today's best climate
79 models^{3,7,8}. Many phenomena of importance in the evolution of the climate system are simply not
80 simulated within climate models; while the Tales approach cannot supply these missing feedbacks
81 into the climate simulation, it does allow decision-makers access to simulations of the high-impact
82 weather phenomena and allows climate scientists an additional means to identify internal
83 inconsistency.

84

85 Further, the traditional MoCoDoT approach does not easily support methods used by many
86 potential users of climate information. The decision-relevant aspects of high-impact weather events
87 that are not necessarily extreme in the meteorological sense, often involve multi-dimensional, non-
88 linear combinations of several variables. This is the case, for instance, when design criteria for
89 infrastructure are based on benchmark synoptic events from the past; the design aim is for the
90 infrastructure to survive the range of behavior up to these thresholds. The frequency with which
91 such thresholds will be exceeded will without doubt change in a different climate. Realistic
92 representation of synoptic events under projected future climate conditions could prove more
93 relevant to and more digestible by those planning for changes in high-impact weather. Such
94 information could then be more easily considered alongside other determinants of societies'
95 vulnerability such as wealth, resilience and perceptions⁹.

96

97 The paper is structured as follows. The next section contains an assessment of the forecast skill of
98 current climate models. In the two sections that follow, a methodology is presented which
99 emphasizes local vulnerability and which focuses on simulating weather events and their impact in
100 a future climate as realistically and coherently as possible. This is achieved through active
101 participation of stakeholders in the process and the use of high-resolution weather models that are
102 well-evaluated and calibrated for representing synoptic weather events in an initialized forecast
103 setting using observational data. With these models high impact events are deduced. Important
104 parts of the methodology include the choice of relevant events, the selections of boundary
105 conditions, and the interdisciplinary construction of storylines which is discussed in the penultimate
106 section. The storylines could be obtained from a number of sources including climate models and
107 physical understanding, while the relevant events and boundary conditions should be chosen to
108 inform the needs of stakeholders, guided by conditions seen in past events. The paper concludes
109 with a discussion section, in which we argue that the “tales of future weather” approach (hereafter,
110 Tales) can alleviate many of the challenges to interpretation faced by the MoDoCoT approach.

111
112 While the Tales methodology cannot account for fundamental inadequacy in today’s best weather
113 models, we argue it can provide information which remains of use even as climate models develop
114 and simulations of the 21st century themselves change. The Tales approach informs users about
115 climate change impacts by making use of both catalogues of past weather analogues and realistic
116 synoptic weather events possible in future climates.

117
118

119 **Climate forecast quality**

120
121 The value of climate predictions with the MoCoDoT method relies on the fidelity of multi-decadal
122 forecasts from climate models. Predictability of meteorological variables beyond the limits provided
123 by the background observed climatological information itself is difficult to achieve for two distinct
124 reasons: first the actual loss of information given the apparently chaotic nature of the system, and
125 second the structural imperfections in weather and climate models. Predictability is certainly lost if
126 the probabilities extracted from models become indistinguishable from those of the (seasonally
127 varying) climatology; this decay might happen in a few weeks if only the atmosphere was
128 modelled, or extend to months, years or decades when slower oceanic processes which impact the

129 atmosphere are simulated realistically^{10,11,12}. On longer time scales, predictability might arise from
130 external forcing or realistically simulated internal variability^{3,13}. Processes which are not simulated
131 realistically result in model-based probabilities that need not resemble targeted climatological
132 probability distributions. The time scales on which such model inadequacy dominates the forecast
133 is more easily identified in forecasts that can be evaluated empirically^{12,14}. While it is widely
134 appreciated that model-based simulation adds significant skill to probability forecasts of weather
135 out to about two weeks¹⁵, their value added on seasonal to annual timescales is less clear^{10,16}. On
136 decadal time-scales there is currently little if any evidence that they significantly outperform the
137 probability forecasts of empirical models¹⁴, with the possible exception of the North Atlantic
138 circulation¹². On daily to weekly time scales today's models are clearly superior to empirical models
139 at local scales.

140

141 Multi-decadal climate forecasting is much more complicated than weather forecasting because (i)
142 "confirmation" is no longer possible given the timescales⁴ of interest and (ii) there is no relevant
143 observed "climatology" with which to compare the forecast. The diversity of simulations under
144 today's models does not reflect the uncertainty in our future^{3,4} even under the assumption of a
145 given emission scenario. And, of course, large uncertainties remain in emission scenarios
146 themselves.

147

148 These caveats rule out interpreting the simulations as literally true potential futures: taking today's
149 climate simulations as reflecting conditions over the next century at face value. However it is
150 done, downscaling introduces a new layer of additional uncertainty to the numbers generated .
151 Clearly the criterion for optimising climate change related decisions is not to be found in assuming
152 there is skill in a naïve interpretation of a downscaled ensemble of climate model simulations^{5,17}.

153

154 Perhaps the highest impact MoCoDoT application, generating probability distributions of detailed
155 and high resolution (up to 5 kilometers) climate forecasts for use in planning energy, water,
156 transport and social impacts, is found in the British UKCP09 project. This project is fully
157 probabilistic, with output probabilities established within a "Bayesian framework"¹⁸. The limitations
158 of any approach that uses climate model output in this way have been outlined above and
159 discussed in literature^{2,3,19}. An alternative approach that also relies on downscaling is to provide a
160 limited set of scenarios that span a range of plausible realisations of future climate. The Dutch

161 climate scenarios (KNMI'06 and KNMI'14 released in 2006 and 2014)^{20,21} are examples of such an
162 approach. These scenarios are also based on global and regional model output and statistical
163 downscaling procedures. In this case a limited set of physically consistent scenarios are
164 constructed, without providing probabilistic information. Other recent examples of regional climate
165 scenarios are CH2011²² for Switzerland, using global and regional model output to generate 3
166 scenarios distinguished by emission pathways, and the "climate change in Australia" scenarios²³.

167

168 Given structural model error and the nature of the climate forecasting problem, one can never
169 expect to provide decision-makers with robust, reliable probability forecasts that have been proven
170 effective in past applications. One can do more, however, than downscale and compute relative
171 frequencies from large model ensembles exposed to a particular forcing. 'What if' scenarios and
172 "analogue" simulations, tales of future weather informed by weather model simulations, offer a
173 complementary methodology which can more fully explore the uncertainty of future climate for
174 decision makers today. A Tales approach is more resilient in several relevant and important
175 aspects.

176

177 **Tales of Future Weather**

178

179 In general, scenarios describe a system under hypothetical conditions. In climate science these
180 hypothetical conditions are guided by the range of expected changes to the dominant drivers of the
181 climate system. Scenarios account for uncertainties both in the drivers and in the system's
182 response to them. They can be regarded as storylines in which information on both socio-economic
183 and climate change are combined in one narrative, providing heuristic tools that can enhance social
184 learning and engage stakeholders²⁴.

185

186 The details of the description of the hypothetical climate conditions will vary according to the
187 problem of interest. One approach is to provide general statistical terms; this is the usual way
188 climate change scenarios are presented. We suggest that a better approach provides storylines of
189 realistic synoptic weather events in present and future climate settings related to local
190 vulnerability. Such detailed descriptions of synoptic weather in a future climate and its impact has
191 considerable value to users: it is vivid, it can be related to relevant past weather analogues, it can
192 be easily linked to the every day experience of the users, and it allows exploring vulnerabilities in a

193 realistic synoptic weather setting. Relating such information on extremes to everyday experiences
194 is linked to higher levels of concern of extreme weather²⁵, which is necessary for decision-making.

195

196 How might one construct tales of future weather to inform adaptation decisions and mitigation
197 policy? The use of global high resolution atmosphere models that resolve the synoptic scales
198 (model grid spacing currently about 10 km and expected to improve in the nearterm), the
199 reliability of which are well understood within the frame of numerical weather prediction, allows a
200 more physically coherent expression of what weather in an altered climate could feel and look
201 like²⁶. It is possible to provide a limited set of future weather scenarios that explore a range of
202 plausible realizations of future climate. The scenarios are imposed onto the boundary conditions
203 (sea surface temperatures, atmospheric composition, land use etc.) of a high resolution model. The
204 boundary conditions may be obtained from traditional coupled climate model simulations of future
205 climate but they could equally well be inspired by other sources, including paleoclimate data,
206 sensitivity experiments with coupled models, archives of past meteorological analyses and
207 forecasts, or even simple constructions of physically credible possibilities. The synoptic patterns
208 related to the 2003 heat wave or the 2013 floods in Europe, for instance, could be simulated
209 repeatedly using expert elicited patterns of changes in sea surface temperatures and radiative
210 forcing representative of a warmer world. In this way a wider range of plausible realizations of an
211 alternative climate can be considered than with traditional coupled climate model experiments.

212

213 An important difference of the Tales approach with MoCoDoT is that the selection of boundary
214 conditions is tailored to the specific case of interest; users are part of the process through the
215 identification of the event types of interest. Another advantage is that the impacts of biases in the
216 climate model simulations can be investigated, and both the effectiveness of current approaches
217 and the impact of known deficiencies can be evaluated. Specifically, the consistency of the local
218 environments produced in the Tales' simulations can be compared with those indicated in the
219 coarse grained climate model which inspired that Tale, allowing new tests of
220 internal consistency with lead time. The dynamic coherence of the global high resolution weather
221 model provides spatial coherence and physical consistency across both space and time within each
222 Tale. Even today's best weather models remain, of course, imperfect; nevertheless the range of
223 extreme events that they can simulate realistically is extended significantly beyond the lower
224 resolution "extreme" "weather" simulated in today's global climate models.

225

226 Such synoptic resolving simulations are technically feasible, as shown in earlier studies^{26,27,28,29}. In
227 particular regional high resolution models have been used at time and spatial scales of interest to
228 explore changes in weather phenomena. The novelty of our approach, however, includes the
229 transdisciplinary of the construction of Tales presented in the next section. Also, we advocate the
230 use of global higher resolution models in the large scale forcing of regional climate, as errors in
231 that forcing may create a large errors in the simulated regional climate changes³⁰.

232

233 **Transdisciplinary Story Lines**

234

235 Storyline development requires an inter- and transdisciplinary approach. The actors include the
236 users of climate information, the climate system specialists, numerical weather prediction experts,
237 and the communicators of climate scenario information. The scene that will be portrayed in a
238 scenario depends highly on the particular vulnerabilities of the system as perceived by the users
239 involved; there is no common approach to describing it. We can, however, describe a number of
240 the relevant elements for a storyline on the implications of future weather. Box 1 describes an
241 example of coastal defence in a low lying delta to illustrate the different elements. The approach,
242 however, is generic, taking the local vulnerability as a central element and does not rely on this
243 specific case set in the midlatitudes.

244

245 1) The drivers of vulnerability

246 Traditionally emission scenarios have been related to storylines³¹. The current Representative
247 Concentration Pathways (RCPs)³² provide a collection of alternative future emission pathways
248 without direct simulation (and thus omitting potentially important feedbacks). Current research³³
249 explores the implications (and tests the internal consistency) of combining a given RCP with a
250 given Shared Socioeconomic Pathway (SSP). The aim is to ease consideration of adaptation
251 measures and non-climate drivers of vulnerability (such as urbanisation trends, land management
252 policies and issues around air quality) within the narrative.

253

254 2) Description of relevant analogues from current and past climate

255 Past extreme weather events are stored in our collective memory. In Europe the dry summer of
256 1976 and the hot summers of 2003, 2006 and 2010 stand out. In the USA hurricanes Katrina and

257 Sandy will not soon be forgotten. These extreme weather events expose the vulnerability of
258 society. In hydrology, 'representative standard years' (such as 1976 for Europe³⁴) are used to
259 investigate sensitivities of water management systems to dry weather conditions. It is interpreted
260 as an analogue for a possible future dry summer. Historical 'reference years' ensure physical
261 consistency and consistent spatiotemporal variability. Their disadvantages include the fact that
262 return times are badly defined and that the available characteristics of an event (timing, spatial
263 structure, compound conditions) are dictated by the observation network that was in place on the
264 day. In the Tales approach, a thorough synoptic description of a relevant analogue, the
265 mechanisms at play and the consequences of the weather extreme, and a description of possible
266 future synoptic events are essential parts of the storyline. Earlier research^{25,35} has shown that
267 societal actor's prior experience of similar extreme weather events influence adaptive measures
268 and preparedness for future extremes. An adequate description of the physical mechanisms and
269 implications of relevant analogues from the past can positively influence adaptive capacity. This
270 results in the following elements in the Tales approach that describe the analogues:

271

272 2a Statistical description of the analogues

273 The statistical characteristics of an event provide information on the severity of the event
274 as compared to other events in current climate. The impact of recent trends in climate can
275 be included in the statistical analysis. We will not be able to assess the changes in
276 frequency for the events in the future.

277

278 2b Physical description of the analogues

279 A synoptic description of a relevant analogue, accompanied with a description of the
280 physical mechanisms at play, contributes to an understanding of the event and to the
281 plausibility of the scenario. An example is the high amount of rainfall along the Dutch coast
282 in August 2006. The preceding record-warm month warmed the North Sea and lead to
283 enhanced moisture convergence and convection near the coast³⁶. The drought in the UK in
284 March 2012 followed by a month of high precipitation is another example. Box 1 describes
285 an example of a compound event of high precipitation followed by a storm surge in 2012 in
286 the Netherlands.

287

288 2c Consequences of the analogue

289 The consequences of an event can be put in the context of the vulnerability of society to
290 extremes. Having historic analogues allows these to be considered in much greater detail.
291 The example of extreme rainfall in the coastal area mentioned above exposed the
292 vulnerability of the urban water management system and vulnerability of agriculture in
293 greenhouses in the west of The Netherlands. Communicating such a link of the weather
294 event to impacts and consequences on key sectors is a key to effective adaptive responses;
295 it increases preparedness for environmental risks³⁷.

296

297 3) Description of synoptic weather patterns in a future climate setting

298 Rather than attempting to describe quantitatively the changes in the statistics of weather which are
299 themselves uncertain, Tales provides specific cases of synoptic weather events in a future climate
300 setting. The boundary and initial conditions of the atmospheric model used to create the synoptic
301 events constrain the setting. As noted above, these can be derived from traditional climate model
302 simulations, yielding the advantages of higher resolution and the use of a well-evaluated and
303 calibrated weather model. Tales, however, can also consider a wider range of plausible boundary
304 conditions. Alternative boundary conditions for the high resolution model can be chosen to reflect:
305 a) the interests of the users in terms of the types of events likely to be relevant to their decisions,
306 and b) a wider scientific perspective on the potential large scale consequences of climate change
307 than that which can be obtained from coupled climate model ensembles. The high resolution
308 models can be used in two different ways. Events of interest can be selected from long simulations
309 under either present-day or alternative boundary conditions. A second approach is to conduct
310 many short simulations designed explicitly to study synoptic events of interest. In the latter case,
311 interesting initial conditions can be chosen via data assimilation to drive the model near synoptic
312 events of interest³⁷. This approach may provide probabilities for changing impacts/extremes given
313 certain types of weather patterns, but it cannot provide probabilities for the changing likelihood of
314 such patterns.

315

316 Regional high resolution models with boundary conditions reflecting a future state have been used
317 before²⁷. Also, in Japan, USA/UK (e.g. Athena³⁹ project), and The Netherlands (Future Weather
318 project using EC-Earth^{40, 26}) high resolution global atmosphere models are already being used with
319 boundary conditions from a future climate scenario though without the user focus described above.
320 These provide a good technical basis for describing plausible future synoptic weather events.

321

322 *4) Wider scientific perspectives on the future climate setting*

323 Scientific findings are important for generating plausible storylines and for designing the NWP
324 model simulations. For instance, recent studies show that the increase in extreme rainfall with
325 temperature is much stronger than expected from the Clausius-Clapeyron relation. Physical
326 mechanisms have been identified to explain the effect⁴¹. Similarly, changing spatial gradients
327 depending on the land use, land-sea contrast or orography are relevant for explaining plausible
328 changes in regional climate. Other examples are the possible change in stationary eddy patterns in
329 the atmosphere driven by melt of Arctic sea ice in summer and the shift in stationary wave
330 patterns and weather regimes due to weakening of the jet stream^{42,43}. A wider perspective can
331 include a description of climate surprises which could plausibly be generated by nonlinear
332 feedbacks, for example a description of the effect of a collapse of the thermohaline circulation in
333 the Atlantic Ocean, or disruption of the monsoon circulation. The relevance of each Tale can be
334 debated within the context of our knowledge of the weather model's performance in the present
335 climate. Such discussions, involving both decision makers and scientists, will aid our ability to
336 interpret the future weather we may (chose to) face.

337

338 **Discussion**

339

340 In this paper we have argued for a novel, complementary approach to delivering climate change
341 information for use in society. The traditional MoCoDoT approach (model the entire climate system,
342 "correct" for biases, downscale to the scales of interest and finally translate into terms suitable for
343 application) has limitations^{2,9,17}. Firstly the simulation models are known not to provide high fidelity
344 representations of processes which are expected to be important. Secondly, the nature of the
345 problem means that the impact of such shortcomings can be neither confirmed nor quantified. A
346 third issue relates to communication of decision-relevant information. Climate impacts often
347 depend on the simultaneous combination of weather variables (concurrent values of temperature,
348 humidity, wind speed and pressure, for example) that need to be analysed in combination over
349 time. In many professions, design constraints are phrased in terms of "reference" years or as
350 events which represent the type of conditions which the system is expected to withstand. The Tales
351 methodology enables this approach, and does so over wider range of boundary and initial
352 conditions than that provided by traditional climate modelling; one can even "zoom in" on a case of

353 particular interest to decision makers. Of course, one must acknowledge that high resolution
354 weather models cannot simulate realistically all high-impact events of interest; structure errors in
355 weather models persist and some can be identified in practice. Nevertheless, we can deploy the
356 whole of our scientific understanding to question what are credible boundary conditions governing
357 the future. This approach allows interaction with users from the very beginning. The use of weather
358 prediction models that are well-calibrated with observations and for which the skill is known for
359 phenomena of interest, and thus have a theoretical and empirical basis, reduces but does not
360 eliminate the impact of systematic model error; it also increases the range of tests of internal
361 consistency available to us. The Tales approach extends the MoCoDoT approach by allowing us to
362 further explore and better evaluate the known range relevant and plausible conditions.

363

364 Current projections regarding detailed changes in climate system are largely derived from climate
365 models. As the value of these models for climate forecasts cannot reliably be expressed in
366 statistical terms, one has to arrive at *qualitative* judgments on the methodological virtue of
367 modelling exercises. Determining the methodological virtue of a finding *a priori* is not
368 straightforward. The broader the relevant peer community, the more likely it is that the different
369 epistemic values held by different groups of experts will impact the assessment of methodological
370 quality. Criteria such as (1) theoretical basis, (2) empirical basis, (3) comparison with other
371 simulations and (4) acceptance/support within and outside the direct peer community are relevant
372 in expressing the level of methodological reliability, or 'pedigree'^{44,45,46}. The Tales approach
373 addresses these issues by avoiding a naïve realist interpretation of climate model simulations as
374 forecasts, by focusing on individual meteorological events which are more easily communicated
375 and utilised, and by allowing closer comparison with the core science, and our physical
376 understanding. That is, we advocate to use well-evaluated and calibrated physics-based models
377 with empirical data. In these ways storylines relating to weather events of the past, present and
378 future can be generated, enriching the climate science discussion beyond the analysis of results
379 obtained from coordinated model ensembles like CMIP5.

380

381 Our approach allows exploration of the consequences of a set of specific weather cases. Precise
382 probabilities are neither available nor required, although the weather events must, of course, be
383 examined and deemed physically plausible. A discussion of the basis for that plausibility will
384 accompany the storyline allowing its assessment by users deciding whether it is a suitable basis for

385 action. Scientific insight and criticism of plausible events directly relevant to the decision maker is
386 ingrained in the process.

387

388 Robust, decision-relevant probabilities were not available under traditional approaches. The
389 structure of the storyline approach ensures that the nature of the information is obvious within
390 Tales. While our method accepts the fact that today's climate models cannot produce long-term
391 decision-relevant probability forecasts, this in no way suggests climate models have no value;
392 indeed they still play a key role. Models are valuable tools in generating and testing the
393 understanding which helps us create the storylines. The emphasis is on their use to generate
394 plausible background conditions for weather phenomena consistent with larger scale changes in
395 the climate system.

396

397 The development of storylines is founded in physical process understanding as this is the basis for
398 confidence in plausible future physical climates. Just as importantly, their insights must be
399 expressed in a manner meaningful to policy and decision makers. This translation creates the need
400 for transdisciplinary collaboration in targeting plausible weather events future and investigating
401 their societal consequences. Stakeholders are not end recipients of authoritative information from
402 scientists but become co-producers of the scenarios. A truly interactive process of co-development
403 of scenarios raises both scientific and stakeholder perspectives transparently, and
404 deals with each in a balanced manner.

405

406 After consideration of the Tales approach and further testing of the proposed methodologies for
407 different cases for which local vulnerability to climate change is assessed, we call for a careful re-
408 evaluation of the design of climate model experiments. Long time frame (multi-decadal to
409 centennial) simulations remain informative for the study of physical interactions involving slow
410 feedbacks in the Earth system which can be simulated with sufficient fidelity. For the provision of
411 regional scale information on any time scale, however, we suggest a new emphasis on high
412 resolution time slice experiments driven by as wide a range of plausible large scale / global
413 settings. Some, but not all, of these settings can be based on traditional modelling directly from
414 global climate models, those experiemnts will come with the bonus of informing our view of the
415 internal consistency of envisioned future impacts. The information from traditional climate model
416 ensembles can complement the Tales approach; Tales embraces the traditional approach where

417 traditional modelling provides a framework for the narratives, it aids traditional modelling through
418 tests of internal consistency, and it allows decision makers access to more usable information
419 which is more relevant to their needs. In short, a Tales approach improves the use of our current
420 scientific understanding to better imagine what weather the future might hold.

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624 **Acknowledgements:** W.H., G.J.v.O., and B.vd.H. were co-sponsored by Knowledge for Climate
625 Theme 6 project E.M, and E. V. were co-sponsored NWO/KvK project Bridging the Gap between
626 stakeholders and climate scientists (NWO 830.10.008). L.A.S. and D.S. acknowledge the support of
627 LSE's Centre for Climate Change and Economics and Policy funded by the ESRC and Munich Re and
628 UK EPSRC grant EP/K013661/1 L.A.S. is grateful for the continuing support of the Master and
629 Fellows of Pembroke College, Oxford.

630

631 **Contributions:** W.H., D.S., A.P., B. vd. H.,G.J. v O., and L.S. developed the main idea of Tales,
632 W.H. wrote the majority of the first draft; A.P., W.H., E.M., and E.V. provided insights on
633 interactions between climate scientists and users reflected in the text; G.J.v.O. provided input on
634 the forecast quality section; B.vd.H. provided insights on local vulnerability reflected in the article
635 and the box; L.S. and D.S. provided insights on the impacts and identification of model
636 inadequacies in climate simulation models. All authors contributed at different stages to drafts of
637 the article with a major final edit by D.S. and L.S.

638

639 **Box: A Tale on a compound event in a low lying Delta**

640 Even in the highly managed hydrological system of The Netherlands, large decisions on
641 infrastructure changes are often incident-driven. This box describes elements of a Tale of Future
642 Weather for decision-makers on local water management in the region. An event in early January
643 2012 exposed the vulnerability of the northern parts of the Netherlands to flooding. 20-30 mm/day
644 of rain fell during a few consecutive days due to passing of synoptic pressure systems. The sluicing
645 capacity from the inland waterways to the North Sea is 10 mm per day, but strong north-westerly
646 winds at the end of the period of high rainfall created a surge that prevented sluicing at low tide
647 (Figure Box). This led authorities to order evacuation of the region and there was a call for extra
648 measures to protect for future events like these. The return times of the precipitation event and of
649 the winds were very modest (3-7 years). The event is an example of a compound event where
650 neither precipitation nor surge were extreme, but the two in combination had a large hydrological
651 impact for this region. Such events are not well simulated in most global climate models because of
652 the synoptic details. Simulations were made with a global atmospheric model derived from a global
653 numerical weather prediction model (EC-Earth) at very high resolution of about 20 km. Future
654 boundary conditions were obtained by adding sea surface temperature anomalies obtained from a
655 climate model to current sea surface temperature conditions²⁶. The model was combined with a
656 simple hydrological model. Figure Box 1 shows four selected time series from those simulations
657 similar to the analogue (excluding a scenario of future sea level rise). This figure demonstrates
658 that complex synoptic events with large hydrological impact similar to the one observed are well
659 captured in such simulations, and thus provide input to the Tale. Further information, including
660 expert knowledge on physical understanding on potential changes in storminess^{7,26,47,48} and on the
661 changes in the hydrological cycle when temperature rises^{7,49}, can also be included; so can 'what-if'
662 scenarios on future sea level rise^{50,51}. The Tales approach allows the exploration of local
663 vulnerability using information from these more physically coherent synthetic events. The Tales
664 approach also includes information on the local vulnerability and identified regions of interest. In
665 large parts of the Groningen and Friesland provinces, the water drainage system depends on
666 passive sluicing at low tide rather than pumping; and the storage of water in inland lakes is not
667 possible here. These aspects complement the details of the synoptic information for assessing the
668 local vulnerability of the region to climate change. The model information of this specific case
669 added with 'what-if' scenarios of sea level rise and on changes in extreme rainfall have been
670 provided to water managers and aid in designing adaptation measures in a realistic setting now.

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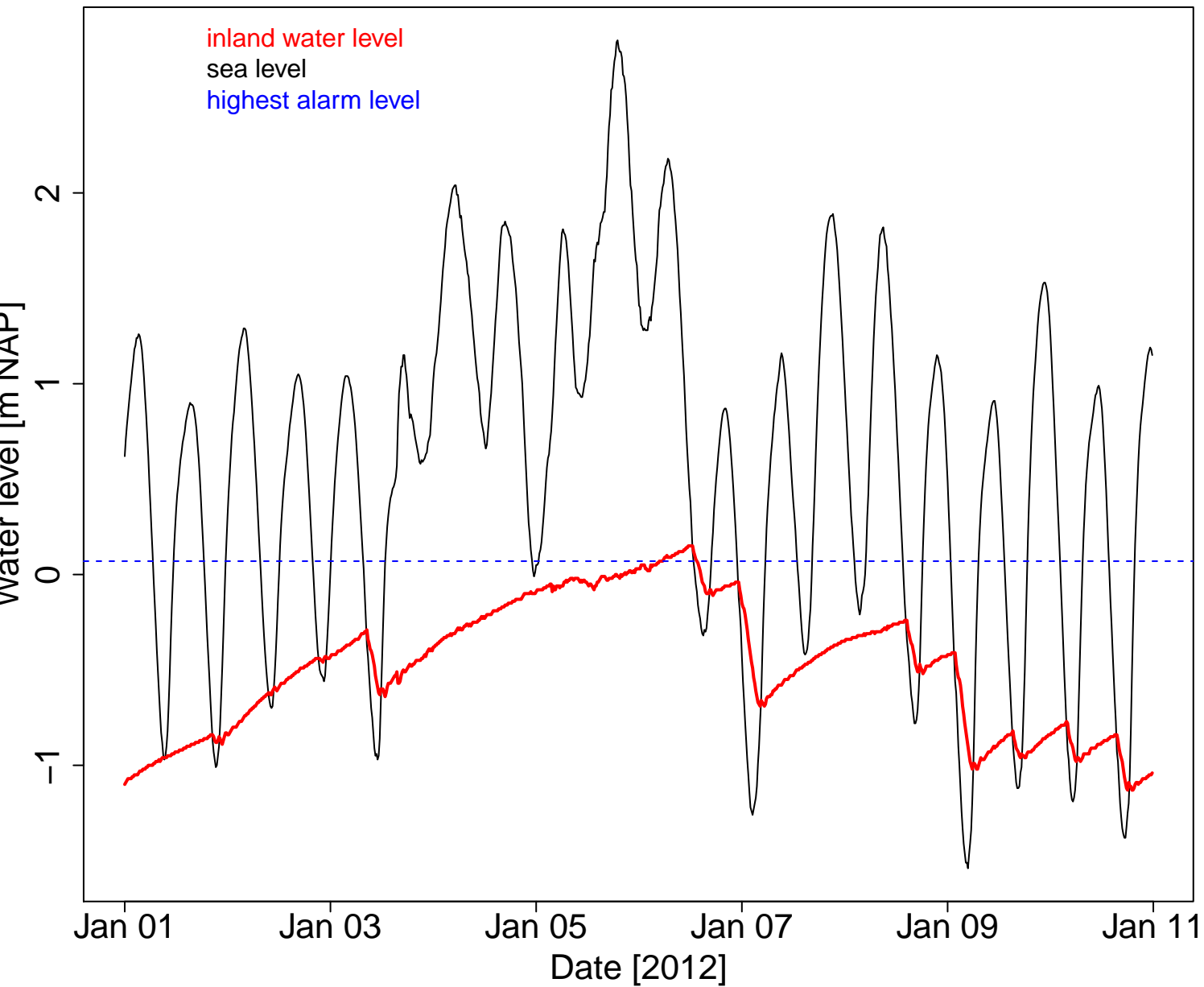
673 Figure caption:

674

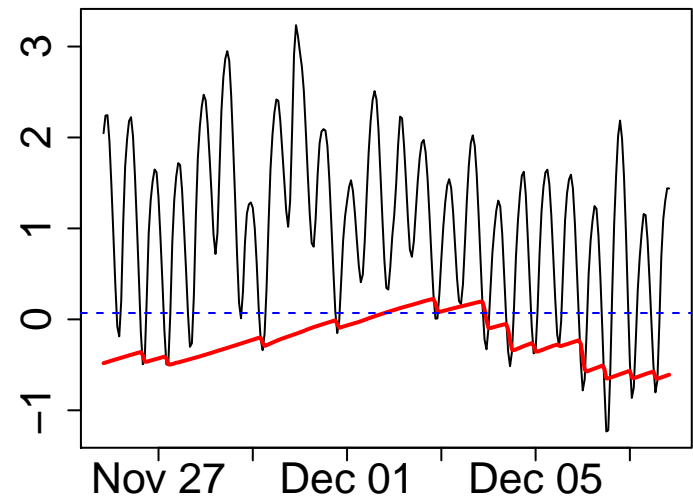
675 Figure B1. Example of restricted discharge options leading to flooding as shown by observed time
676 series of the water level (meters above a mean sea level denoted by NAP) at the North Sea side
677 (black) and inland side (red) at the "R.J. Cleveringsluizen" sluices, Lauwersoog (53,24°N, 6,13°E) in
678 early January 2012. The purple line section denotes the period of elevated alert conditions and the
679 dashed line indicates the highest alarm level. A similar set of four events, excluding the impact of
680 sea level rise, derived snap shot weather simulations with an Numerical Weather prediction model
681 using boundary conditions of the second half of the 21st century are shown on the right.

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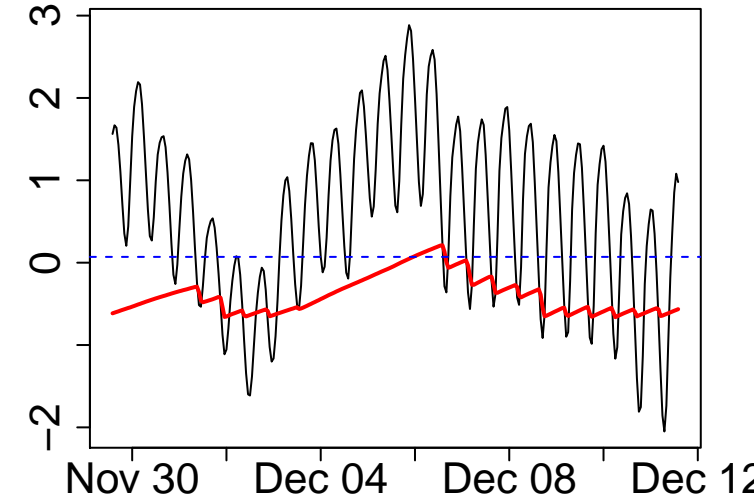
Observed water levels



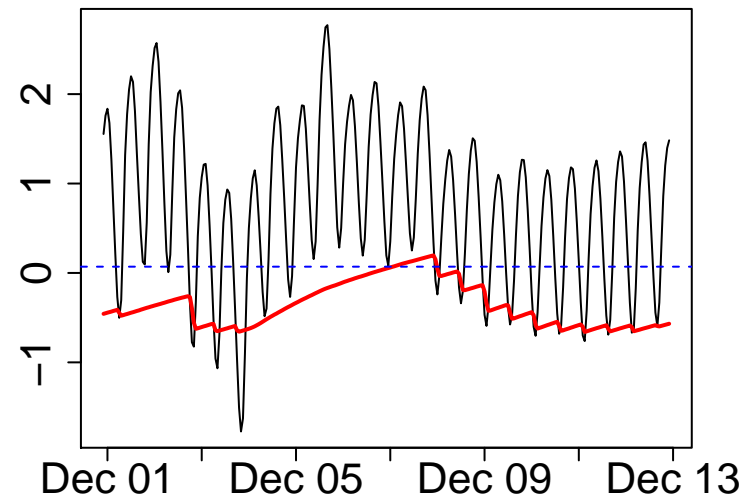
Scenario 1



Scenario 2



Scenario 3



Scenario 4

