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**Impacts of long term climate change during the
collapse of the Akkadian Empire**

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13 **Abstract**

14 Four thousand years ago what is often considered to be the world's first empire, the Akkadian
15 Empire, collapsed. Proxy data has suggested a regional aridification event coincided with this
16 collapse, but there is a lack of records collected from within the Mesopotamian region, where
17 the Akkadian Empire was based. Here we analyse a suite of simulations from the HadCM3
18 climate model covering the last 6000 years. The results show that long-term drivers produced
19 a shift to a more arid climate, showing minima in both precipitation and river flow at 2000
20 BCE, whilst temperatures were colder at 2250 BCE. These changes were sufficient to have a
21 negative impact on the natural vegetation in Mesopotamia, suggesting that this climate
22 change would have also impacted the agriculture sustaining local communities. We suggest
23 that the combined effects of climate change and land mismanagement would lead to
24 shortages of water and food, which may have contributed to social disruption and the collapse
25 of the Akkadian Empire. We also find examples of resilience through the surviving cities such
26 as Tell Brak and Tell Mozan. These could provide lessons for adapting to climate change in the
27 future, as modern-day climate change threatens food and water security.

28

29 **Highlights**

- 30 • Mesopotamia experienced significant climate change around 4.2kyrs ago
- 31 • Simulations show a Holocene low in Tigris-Euphrates water availability at this time
- 32 • Mesopotamia experienced reduced rainfall due to changes in Western Disturbances
- 33 • This affected sustainability in the region and contributed to societal collapse

34

35 **Keywords**

36 Climate, Mesopotamia, 4.2kyr event, societal collapse, Holocene

37

38 **Introduction**

39 Approximately 4,200 years ago, the first unequivocally urban polities controlled large areas
40 of Africa and Asia. However, within 200 years each of the four major civilisations of this
41 period, the Old Kingdom of Egypt, the Indus Valley civilisation, the Longshan culture of China,
42 and the Akkadian Empire in Mesopotamia, underwent significant societal transformations.
43 The extent and nature of these transformations is much debated (Middleton, 2018), but they
44 have been characterised as collapse events (Szczęsny, 2016). The socio-political shifts visible
45 during this period are associated with a period of increasing aridification, inferred from
46 various natural archives such as speleothem, dendrology, and sediment records.

47

48 The Egyptian Old Kingdom experienced a reduction in Nile River flow and a decrease in lake
49 levels, shown by diatom assemblages found in sediment cores from the Omo River, Lake
50 Turkana, and the Nile delta (Butzer, 2012; Krom et al., 2002; Halfman et al., 1992).
51 Furthermore, this water shortage was recorded on the tomb inscription of Ankhtifi alongside
52 details of starvation, famine, and civil war (Butzer, 2012). Meanwhile, the Indus Valley
53 civilisation suffered from drought as a result of changes in both the Indian summer monsoon
54 and winter rains from Western Disturbances (Giesche et al., 2019). This has been shown in
55 pollen records and in sediment cores from Lonar Lake and the Indus delta. (Giesche et al.,
56 2019; Prasad et al., 2014; Staubwasser and Weis, 2006; Staubwasser et al., 2003).

57 Archaeological evidence suggests this had significant effects on settlement and social
58 organisation, although these do not fit into a simple collapse narrative (Petrie et al., 2017).
59 Also affected by changes in the monsoon were those of the Longshan culture, who resided in
60 the Yellow River valley of China. Here, soil records and oxygen isotope data showed a
61 transition to a drier climate (Li et al., 2015; Shao et al., 2006; Xu et al., 2002). In addition, the
62 changes in settlements' size and location can be traced through the ceramic records (Dong et
63 al., 2013; Underhill et al., 2008). Significantly, these three locations are heavily impacted by
64 the monsoonal systems of the Indo-Pacific region, whereas Mesopotamia is solely reliant on
65 Mediterranean sourced weather, through the winter rainfall of the Western Disturbances.
66 Furthermore, northern Mesopotamia differs in the timing of collapse. Although the Akkadian
67 Empire likely fell sometime between 2200 BCE and 2100 BCE, several urban centres persisted
68 until 2000 BCE before experiencing a similar decline, while others continued into the Middle
69 Bronze Age.

70

71 The debate about the nature of the 4.2kyr event has taken on a new significance and become
72 more widespread with the definition of Holocene Stages. The latest Stage, the Meghalayan
73 Age, is bounded by the event (Walker et al., 2012). Of the great civilizations that experienced
74 the 4.2kyr event, perhaps the most controversial is the Akkadian Empire, with suggested
75 impacts ranging from the complete collapse of society due to a long, intense period of
76 droughts (Weiss, 2017) to very limited socio-political reorganisations affecting particular
77 areas, themselves, part of long term cyclical trends in the move to centralisation and
78 urbanisation (Schwartz, 2007, 2017). Here we look to an ensemble of climate model

79 simulations to examine how the past climate may have changed, and to identify what specific
80 impacts this may have had on the communities living in the Mesopotamian region.

81

82 **Methods**

83 **HadCM3 Climate Model**

84 To model the changing climate for the last 6000 years, the Hadley Centre coupled general
85 circulation model (GCM), known as HadCM3, was used (Gordon et al., 2000; Pope et al., 2000).

86 The model is able to successfully simulate historical climate change responses to
87 anthropogenic and natural forcings (Met Office 2016; Stott et al., 2000). It encompasses an
88 atmospheric model which has a resolution of $3.75^\circ \times 2.5^\circ$ with 19 hybrid levels, alongside an
89 ocean component with a horizontal resolution of $1.25^\circ \times 1.25^\circ$ with 20 levels. At the latitude
90 of Mesopotamia ($\sim 35^\circ\text{N}$), this atmospheric resolution corresponds to roughly 278km north-
91 south and 340km east-west.

92

93 Precipitation simulations are produced by using both a penetrative convective scheme and a
94 large-scale precipitation and cloud scheme. The penetrative convective scheme includes an
95 explicit downdraught representation and calculates convective rainfall. The large-scale
96 precipitation calculations however, use the water and ice contents of clouds where the radius
97 of cloud droplets are a result of water content and droplet number concentration.
98 Furthermore, evaporation of falling precipitation is also modelled (Johns et al., 2003; Johns et
99 al., 1996). Although HadCM3 would be considered relatively low resolution by the standard

100 of the most state-of-the-art climate models, it is able to capture the broad scale features of
101 observed precipitation across the Mesopotamia region (Figure 1).

102

103 HadCM3 uses a river-routing scheme, creating an effective basin-wide scheme on both annual
104 and monthly scales. This scheme has predefined river catchments with associated coastal
105 outflow points, to which runoff is transported to (Falloon et al., 2011; Johns et al., 1996). As
106 the Euphrates and Tigris river basin formed in the Neogene and has remained largely constant
107 throughout the Holocene (Nicoll, 2010), despite significant changes in the river channels and
108 delta (Morozova, 2005), these runoff values give us a reliable measure of the simulated total
109 moisture balance on a basin-wide scale and overall water availability in the region.

110

111 To simulate vegetation change, the Top-down Representation of Interactive Foliage and Flora
112 Including Dynamics (TRIFFID) vegetation model was used. TRIFFID is a dynamic model and
113 thus changes the plant distribution and soil carbon depending on the CO₂ fluxes at the land-

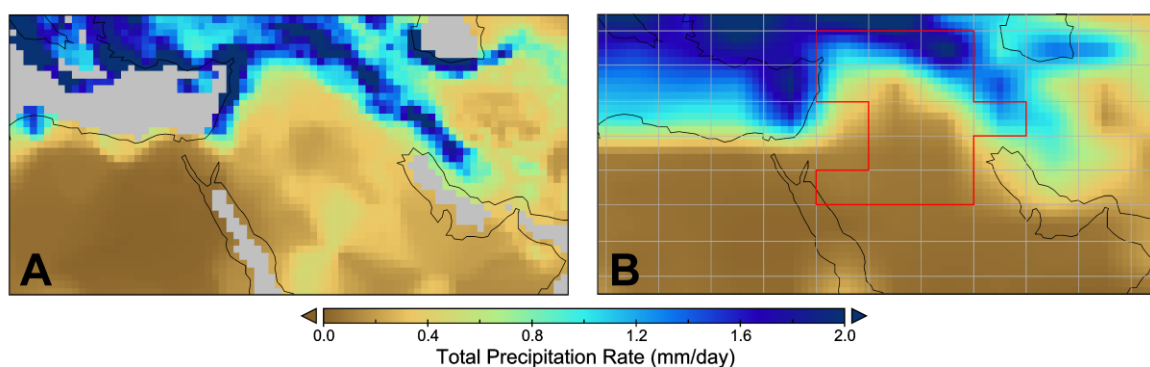


Figure 1. Comparison of average observed precipitation from 1901-2013 from the Global Precipitation Climatology Centre (GPCC; Schneider et al., 2016) dataset (A) and the simulated pre-industrial precipitation from the HadCM3 climate model interpolated to the same 0.5°x0.5° global grid (B). Grey grid in B is the HadCM3 native grid and the red outline is the Tigris-Euphrates river basin, as defined in the HadCM3 model river routing boundary conditions.

114 atmosphere interface (Cox, 2001). TRIFFID simulates five plant functional types: broadleaf
 115 tree, needle-leaf tree, C3 grass, C4 grass, and shrub. Each of these have their areal coverage,
 116 leaf area index, and canopy height updated with changes in the carbon flux. Additionally, four
 117 non-vegetative land cover types are recognised: urban areas, water, barren, and ice (Cox,
 118 2001). Having a coupled vegetation model embedded in the climate simulations allows us to
 119 incorporate an element of land surface change in response to changing climate, although no
 120 anthropogenic land use change has been included.

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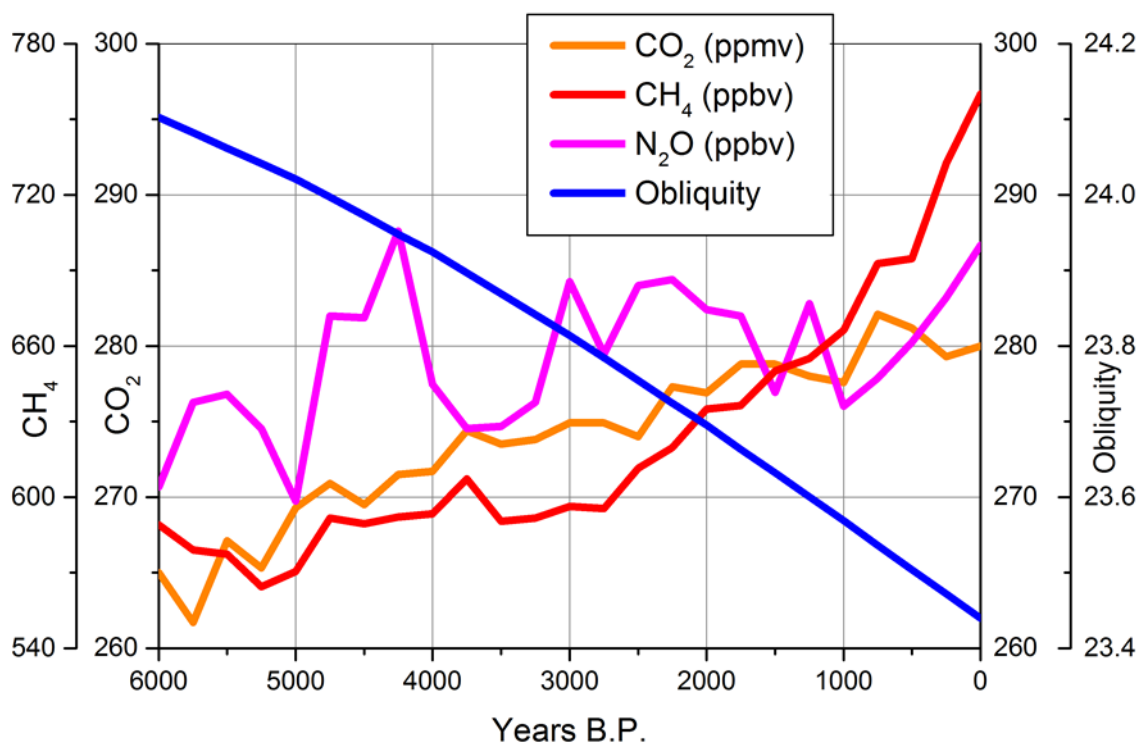


Figure 2. Parameters used in each of the snapshot simulations in the ensemble for the last 6000 years. Atmospheric carbon dioxide (Monnin et al., 2004), methane (Blunier et al., 1995; Flückiger et al., 2002) and nitrogen dioxide (Flückiger et al., 2002) concentrations and obliquity component of the full orbital solution (Laskar et al., 2004) for each simulation representing a snapshot every 250 years of the last 6000. All other parameters are kept the same as the standard pre-industrial simulation.

122 **Holocene Simulations**

123 To be sure to identify any change around 2000 BCE and assess its significance, the snapshot
124 simulations were run every 250 years from 4000 BCE to the pre-industrial climate. This gives
125 us a measure of the equilibrium climate response to the imposed changes in Holocene climate
126 forcings in a computationally efficient experimental design. In these simulations only the
127 orbital forcing and greenhouse gases were changed (Figure 2). Orbital solutions came from
128 Laskar et al. (2004), atmospheric carbon dioxide levels (Monnin et al., 2004) and nitrogen
129 dioxide levels (Flückiger et al., 2002) from EPICA ice core records and methane concentrations
130 were taken to be the average of Antarctic and Greenland ice core values (Blunier et al., 1995;
131 Flückiger et al., 2002), as this is less well mixed in the atmosphere. Each simulation was run
132 for 250 model years, in order to reach a quasi-equilibrium state, with the final 50 years
133 providing an averaging period for the climatological means. Therefore we are not explicitly
134 attempted to simulate the 4.2kyr event, but have snapshots at 2250 BCE and 2000 BCE that
135 should capture the impact of long-term climate changes.

136

137

139 Hydroclimate

140 Figure 3 shows the simulated mean annual precipitation rate for the Tigris-Euphrates river
 141 basin over the last 6000 years. The minimum rainfall in the basin coincides with the time of
 142 Akkadian Empire collapse, between 2200 BCE and 2000 BCE. From 2250 BCE to 2000 BCE
 143 there is a decrease of approximately 7% (0.1 mm/day). The precipitation rate then increases
 144 by around 14% (0.2 mm/day) from 2000 BCE to 1750 BCE. Latest Holocene precipitation rates
 145 in the Tigris-Euphrates river basin are much higher than those during the collapse, by more
 146 than 21% (0.3 mm/day) on average (Figure 3). These changes could be considered small, but

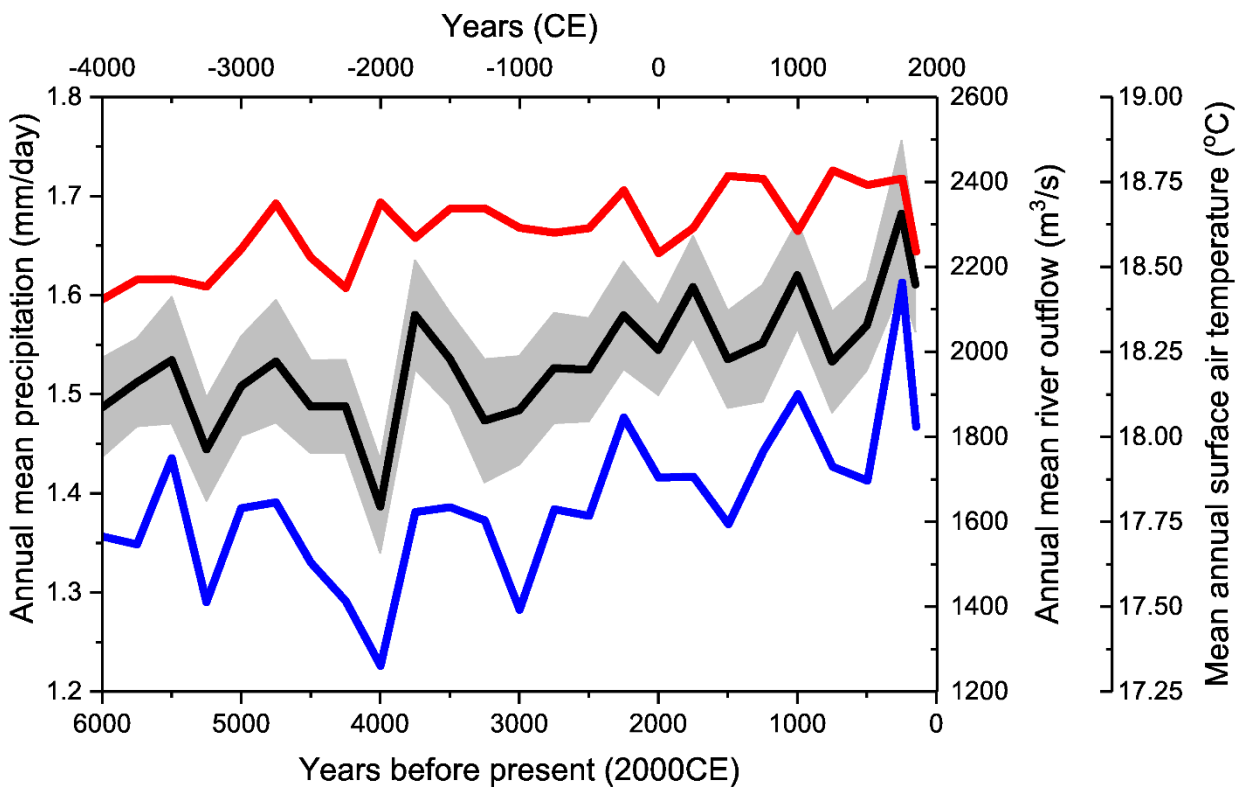


Figure 3. Annual mean precipitation (black) over the Tigris-Euphrates river basin, for each of the snapshot simulations over the last 6000 years. The shading represents standard error in the average for each simulation. Also shown is the mean annual river outflow (blue) and mean annual surface temperature (red) for the Tigris-Euphrates basin, for each of the simulations.

147 the methodology may not capture the full magnitude of transient or decadal climate changes.
148 However, other civilizations have shown large sensitivities to precipitation reductions
149 (Medina-Elizalde and Rohling, 2012).

150

151 Although HadCM3 has a simplified river routing model, the river outflow provides an
152 integrated indicator of basin scale hydrological conditions, incorporating precipitation,
153 evaporation and soil moisture processes. The river outflow from the Tigris-Euphrates basin
154 also shows a minimum at 2000 BCE (Figure 3). From 2750 BCE the outflow steadily decreased

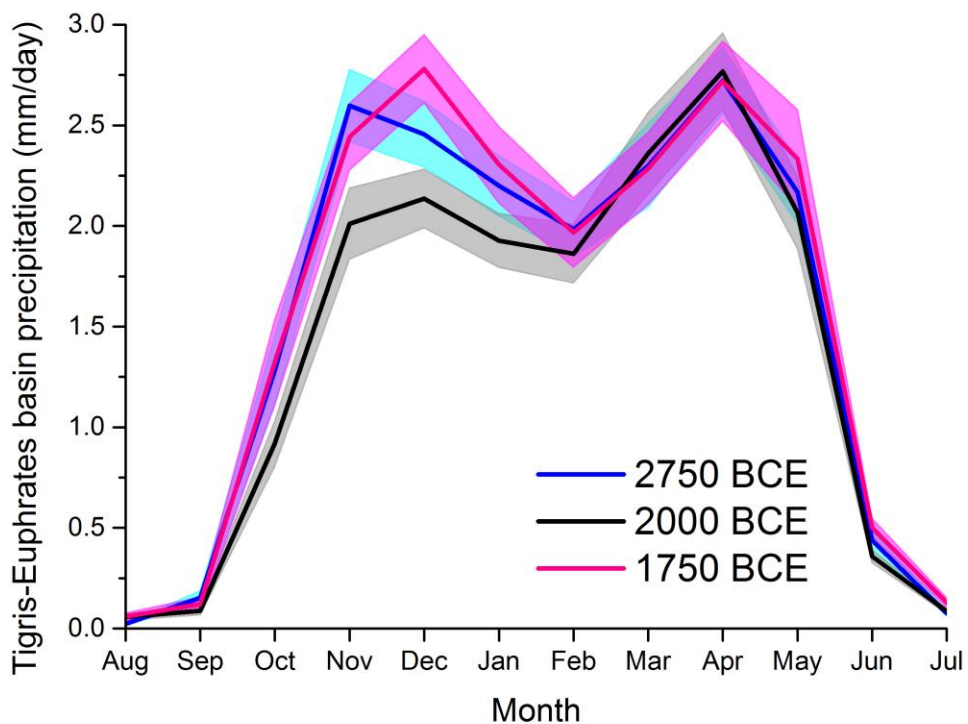


Figure 4. Annual cycle of monthly mean precipitation across the Tigris-Euphrates basin at 2000 BCE (black), prior to the significant decline in precipitation (2750 BCE; blue) and after the recovery (1750 BCE; magenta). The shading represents standard error in the average for each simulation.

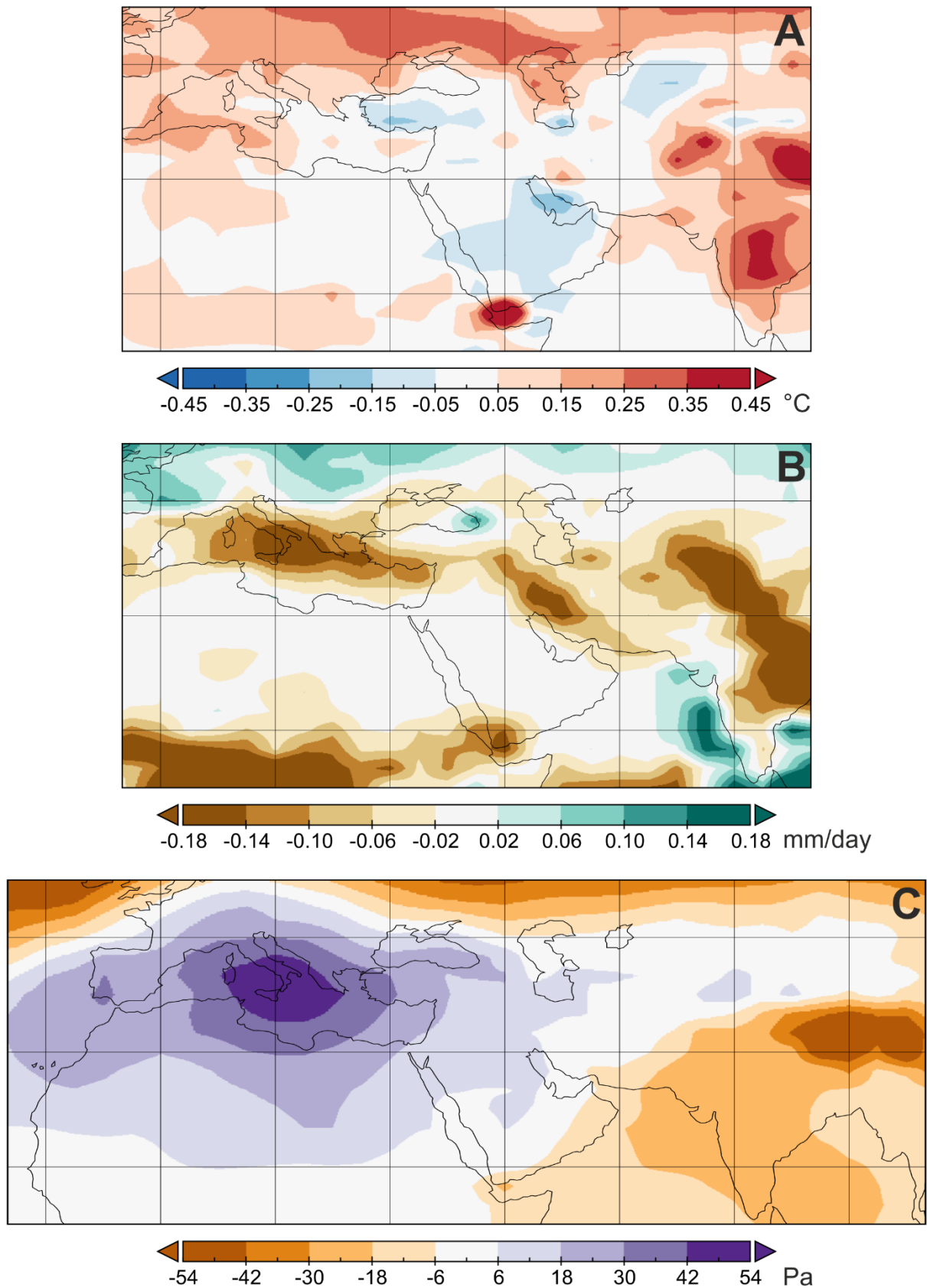


Figure 5. Spatial pattern of (a) mean annual precipitation change, (b) temperature change and (c) mean sea level pressure across the Mesopotamia region from 2750 to 2000 BCE. All panels show values at 2000 BCE minus 2750 BCE.

155 from 1,685 m³/s to reach 1,288 m³/s in 2000 BCE, representing a 30% decrease, only to

156 change back for the following snapshot 250 years later. Figure 4 shows the monthly outflow
157 of the Tigris-Euphrates basin, for the years 2750 BCE, 2000 BCE, and 1750 BCE. The decreases
158 seen in the annual mean outflows occur primarily in the months of peak flow, particularly in
159 the early months of the wet season.

160

161 The hydrological changes in the Tigris-Euphrates river basin are primarily driven by reductions
162 in the precipitation, which on the longer term affects the whole of the Mesopotamian region
163 (Figure 5b), but is particularly focussed on the northern part of the Akkadian Empire at the
164 time of its collapse (Figure 6b). The rains of the wet season are produced by the Western
165 Disturbance low pressure weather systems. These are sourced in the Mediterranean basin
166 and travel eastward, supplying winter rainfall across Central Asia (Madhura et al., 2015). The
167 primary reason for changes in this system can be seen by examining the changes in the broad
168 mean sea level pressure patterns (Figure 5c). Our simulations show mean state increases in
169 sea level pressures over the Mediterranean at 2000 BCE (Figure 5c), suggesting a lower
170 incidence of low pressure systems forming. This, along with a reduced pressure gradient
171 between the Mediterranean and the Himalaya, would reduce the atmospheric driving force
172 for Western Disturbances and reduce rainfall across the Mesopotamian region.

173

174 **Vegetation change and links to agriculture**

175 The gross primary productivity (GPP) is the total amount of carbon fixed by plants and thus
176 can equate to plant growth over a certain period (Roxburgh et al., 2005). The simulated GPP

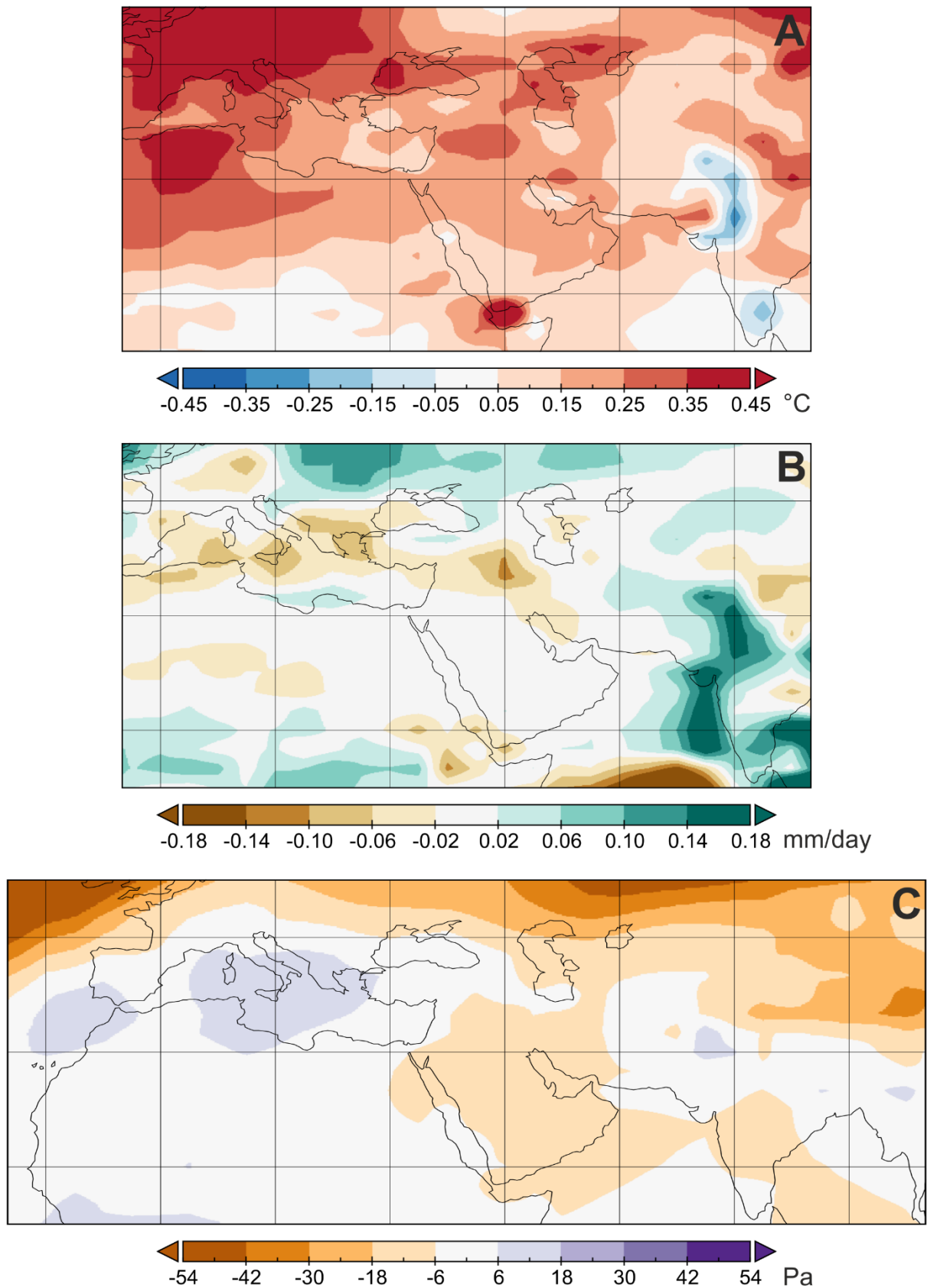


Figure 6. Spatial pattern of (a) mean annual precipitation change, (b) temperature change and (c) mean sea level pressure across the Mesopotamia region from 2250 to 2000 BCE. All panels show values at 2000 BCE minus 2250 BCE.

178 through this time period shows a significant drop across the Mesopotamian region at 2000
179 BCE (Figure 7a), although these reductions are largely reversed by 1750 BCE. The net primary
180 productivity (NPP) is the carbon uptake remaining after taking the plant respiration from gross
181 primary productivity (Roxburg et al., 2005). Therefore, NPP can also be related to the plant
182 biomass. A similar signal is found in NPP, with a temporary minimum at 2000 BCE, and this
183 is also seen within the C3 grass plant functional type, which could be related to the main
184 Mesopotamian crops (Figure 7b). Overall, these data suggest a significant climatic impact on
185 the Mesopotamian biosphere, which would surely be reflected in agricultural yields. Murray-
186 Tortarolo et al. (2016) found that longer and more intense dry seasons correlated with a
187 decrease in NPP throughout the whole year. Changes in the dry seasons are smaller in these
188 simulations (Figure 4), but the signal is towards a longer, drier dry season.

189

190 **Discussion**

191

192 **Change in Western Disturbances**

193 The rainfall in much of Mesopotamia is solely driven by the Mediterranean low-pressure
194 systems, also known as the Western Disturbances (Riehl, 2012; Babu et al., 2011; Winstanley,
195 1973). During winter the Mediterranean Sea is warmer than the neighbouring land, creating
196 low-pressure systems. These are then driven by westerly winds, moving the system eastwards

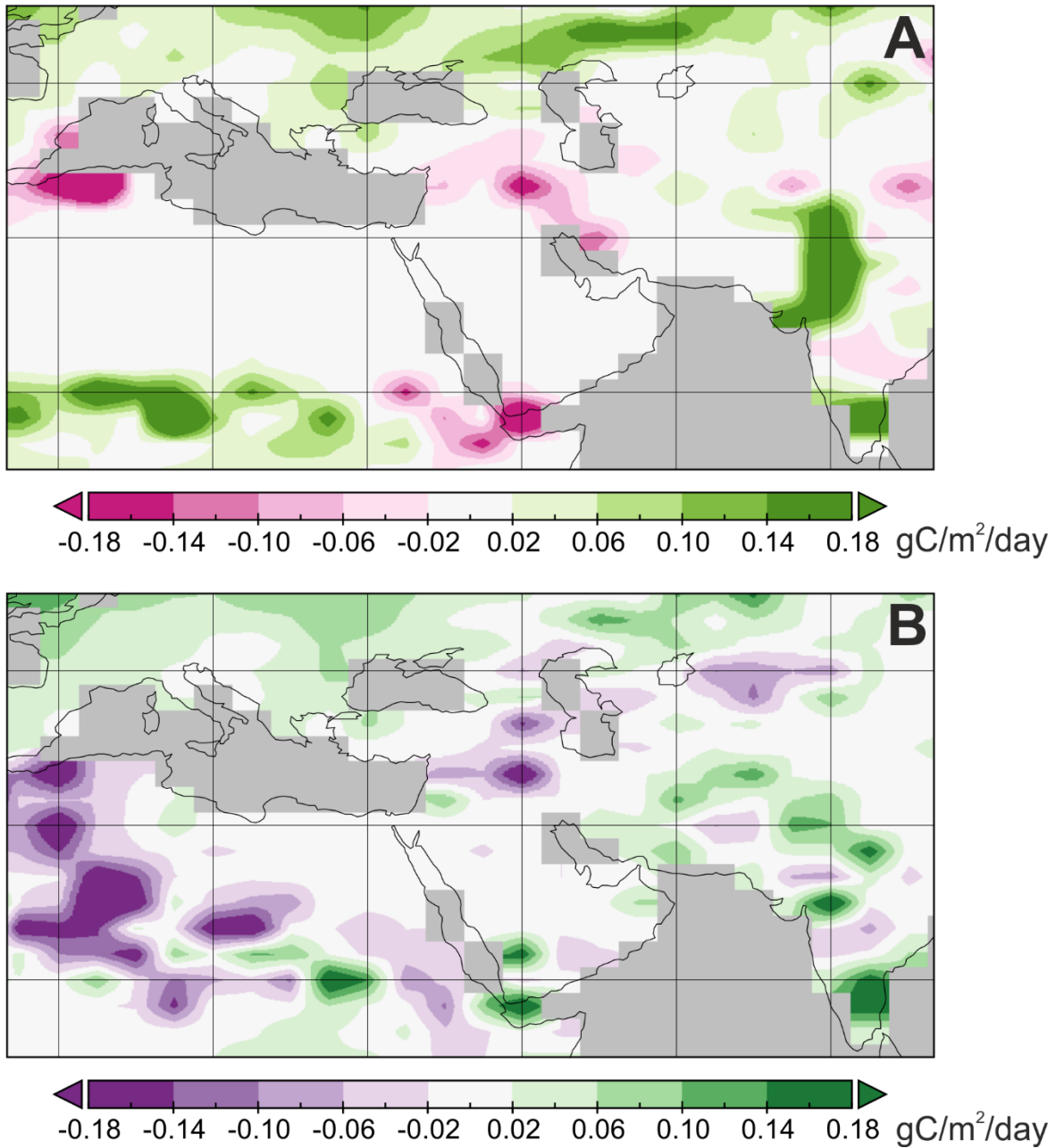


Figure 7. (a) Total gross primary productivity and (b) net primary productivity of C3 grass plant functional type change between 2250 and 2000 BCE simulations from the TRIFFID global dynamic vegetation model (Cox, 2001). All panels show values at 2000 BCE minus 2250 BCE.

197 over the Mesopotamian region (Babu et al., 2011). The weakening of the simulated Western
 198 Disturbances, associated with changes in the Mediterranean lows (Figure 5c) and the regional
 199 pressure gradients (Hill, 2019), resulted in the observed decrease in precipitation which the
 200 region, especially the north, was reliant on. Consequently, the flow of the Tigris and Euphrates

201 rivers would have decreased (Figure 3), reducing the water available for irrigation in southern
202 Mesopotamia. As a whole, the weakened Western Disturbances would have created drier
203 weather throughout Mesopotamia for this period.

204

205 This shift to a drier climate is likely to have been amplified by the biogeophysical feedback
206 effects of changing soil moisture (Charney et al., 1975). As soil moisture decreases, it leads to
207 a decrease in the available atmospheric water content over the land. This creates a drier
208 atmosphere and reduces precipitation, in turn amplifying the decrease in soil moisture and
209 causing a change in vegetation (Krakauer et al., 2010; Baudena et al., 2008). This change may
210 include a shift to vegetation types that are more drought-tolerant and an overall decrease in
211 vegetation coverage, further reducing the water vapour available in the atmosphere due to
212 the decrease in evapotranspiration. Changes and decreases in vegetation may also lead to a
213 decrease in surface roughness, resulting in a decline in turbulence and its associated cloud
214 formation (Eltahir, 1998) and changes to surface albedo that can affect precipitation (Charney
215 et al., 1975).

216

217 On an archaeological timescale, studies derive evidence for palaeoenvironmental conditions and
218 variability from proxy datasets including pollen, diatom and foraminifera records and stable
219 isotopes held in natural archives such as speleothems. This is problematic in the area investigated
220 here because the nearest high quality proxies are located outside the main region of interest,
221 either in the Southern Levant or Eastern Turkey. Although new data from Kurdistan is beginning
222 to emerge, at present this is restricted to later periods (Flohr et al., 2016). Of the available proxies
223 located close to the study region, Lake Van in eastern Turkey (Lemcke and Sturm, 1997), Soreq

224 Cave in Israel (Bar-Matthews et al., 2011) and Jeita Cave in Lebanon (Cheng et al., 2015) show
225 a shift to increased aridity over this time period. However, the proxy values are within the
226 range of fluctuations seen over the middle to late Holocene, perhaps reflecting the fact that
227 these records are on the periphery of the Mesopotamia region. The record of enhanced dust
228 activity, which has been related to regional aridity (Carolin et al., 2019), suggested a
229 prolonged period of drier conditions, at least from 4.5 kyrs ago, which came to an abrupt end
230 shortly after 4 kyrs ago. This seems to match very well with the regional precipitation
231 simulated here, both in the extent and timing, which may reflect the spatial dependency
232 suggested for this speleothem record (Carolin et al., 2019).

233

234 **Impact on northern Mesopotamia**

235 In contrast to the irrigated landscapes of southern Mesopotamia, there is very little evidence
236 for large scale water management systems in northern Mesopotamia prior to the Iron Age.
237 This means that winter and spring rainfall levels have a direct impact on the crop growing
238 season. Reductions in precipitation during these seasons would decrease soil moisture and
239 cause a large amount of stress to the crops, resulting in reduced yields (Riehl, 2008;
240 Morozova, 2005). Increased water stress has also been indicated by archaeobotanical data
241 which showed variations in $\delta^{13}\text{C}$, specifically during the grain-filling period (Riehl et al., 2012).

242

243 Model results also suggest a decrease in both GPP and NPP (Figure 6), reflecting a decrease
244 in both the rate of growth and the overall biomass. It can be inferred that an overall decline
245 in crop yield would have also occurred, causing increased stress on current and stored

246 resources. Modelling involving population sizes, crop types and agriculture areas based on
247 evidence from landscape archaeology indicate that many settlements in northern
248 Mesopotamia at this time operated close to the limits of sustainability (Kalayci, 2016;
249 Wilkinson, 1994). Even relatively minor decreases in yield, especially over multiple years,
250 would have likely exhausted reserves, causing migration or famine (Ur, 2010). Evidence for
251 attempts to mitigate drought are present in the archaeobotanical data, which suggests there
252 was a change in crops cultivated in northern Mesopotamia around the time of 2100 BCE (Riehl
253 et al., 2012). Crop species with low drought tolerances seem to have seen reduced cultivation,
254 including garden pea, einkorn wheat, free-threshing wheat and various species of flax, with
255 many all but disappearing. In some instances inhabitants switched to more drought tolerant
256 species, for example from garden peas to bitter vetch peas (Riehl et al., 2012).

257

258 Barley is a key component of agriculture, particularly in southern Mesopotamia, before,
259 during and after 2100 BCE (Riehl et al., 2009), due to its short reproductive cycle and high
260 economic value (Riehl, 2012; Riehl and Bryson, 2007). Emmer wheat, which has a high drought
261 tolerance and was an important cultivar in northern Mesopotamia, saw a significant drop at
262 2100 BCE, although, this may be a result of declining local populations being unable to sustain
263 the demanding labour required to process and prepare the wheat for consumption (Riehl et
264 al., 2009). However, at Tell Mozan and Tell Brak, cities in northern Mesopotamia that
265 managed to survive the 4.2kyr event, emmer wheat continued to be harvested. There is little
266 evidence to suggest that either Tell Mozan or Tell Brak practised irrigation. It has been shown
267 that Tell Mozan had higher proportions of free-threshing wheat, whilst Tell Brak favoured
268 Barley (Riehl, 2012). Despite this, they both farmed emmer wheat throughout this period of

269 climatic instability and neither suffered collapse. This suggests that societies with a greater
270 diversity of crop species had greater resilience than those which practiced monoculture
271 farming.

272

273 **4.2ka event and ancient civilization collapse**

274 Egypt, the Indus Valley, and the Yellow River Valley all experienced aridification events and a
275 subsequent decline of urban sites and overall population around 2200 BCE (Li et al., 2017;
276 Welc and Marks, 2014; Staubwasser et al., 2003). The main climatic changes identified at this
277 time were cooling and drying, which have been associated with changes in the Bond Cycle as
278 well as changes in sea surface temperatures of the North Atlantic and Indian Ocean (Szczęsny,
279 2016; Booth et al., 2005). These other riverine civilisations appeared to experience the aridity
280 associated with the 4.2kyr event and this cooling simultaneously; their decline shortly
281 followed (Li et al., 2017; Welc and Marks, 2014; Staubwasser et al., 2003). Mesopotamia
282 experienced little change in temperature (Figure 3), although there may have been a
283 minimum around 2250 BCE, however the precipitation and river flow data (Figure 4) suggest
284 an offset of increasing aridity to 2000 BCE, which is consistent with well dated records of
285 enhanced dust activity (Carolin et al., 2019). As the precipitation in northern Mesopotamia is
286 produced by the Western Disturbances, its response to the change in orbital forcing and
287 incoming solar radiation is offset from the largest changes in the main monsoonal systems of
288 the Indo-Pacific region, which occur at a lower latitude. The resilience of the civilisation can
289 also contribute to the timing of civilisation collapse. As northern Mesopotamia's agriculture
290 was largely C3 crops, they were resilient to the decreasing temperatures, but not the

291 increasing aridity. As a result, the new environment was no longer suitable to sustain the yield
292 of C3 grasses needed to sustain the population.

293

294 Collapse should be considered and understood within the context of the episodic phases of
295 fluctuating city growth and decline. Lawrence et al. (2016) investigated the relationship
296 between the size and population of urban sites and climate change. This study found that the
297 first urban sites in Northern Mesopotamia had appeared during the Late Chalcolithic, a time
298 of high atmospheric moisture. This may have allowed the large-scale extensification of
299 agriculture to provide for significant increases in the size of urban centres (Styring et al.,
300 2017). Following 2000 BCE there was an apparent decoupling of climate and settlement
301 patterns which would have impacted the long-term stability and sustainability of these cities.
302 Between the Late Chalcolithic and the 2000 BCE transition to the Middle Bronze Age, there
303 were two cycles of social expansion and decline (Ur, 2010). Many of the cities of northern
304 Mesopotamia were deserted by the end of the 3rd millennium BCE. Archaeological data
305 suggests that if the cities were repopulated, it would have been a “clean break” from the
306 previous societies (Ur, 2010). This is likely the result of operating close to the limits of
307 sustainability, evident as the largest of settlements were required to outsource products to
308 sustain their populations (Lawrence et al., 2016; Ur, 2010; Wilkinson, 1994). As freshwater
309 and crops declined, the stress on the remaining available resources increased. As a
310 consequence, the complex nature of Mesopotamian society could not be sustained leading
311 to famine, hunger, migration, and possibly conflict.

312

313 Evidence shows that the settlements in the southern part of Northern Mesopotamia, where
314 rainfall was lower, were abandoned earlier than those in the more northern region (Riehl et
315 al., 2012, Schwartz 2017), which also seems to fit with the precipitation change simulated in
316 this study (Figure 5b and Figure 6b). A decline in one area may have led to migration to the
317 surviving cities, increasing the population. This would therefore also increase the demand for
318 food and, as a result, increase agricultural intensity. However, an increase in the farming
319 intensity would have been unsustainable under the declining soil moisture conditions of the
320 time, without expansion of the farmed area (Wilkinson et al., 2007). Therefore, where it
321 occurred, the collapse of urban sites in Mesopotamia could be strongly attributed to the over
322 exploitation and mismanagement of land. However, management and mitigation played a
323 large role in the trajectories of many cities. This is suggested as settlements in dry areas, such
324 as Tell Brak and Tell Mozan, survived. Although these cities did appear to shrink, other
325 populations in relatively moist locations collapsed completely (Frahm and Feindberg, 2013;
326 Wilkinson et al., 2007). Archaeobotanical data suggests that Tell Brak and Tell Mozan were
327 the only known locations to continue to harvest emmer wheat, while many other locations
328 shifted towards monocultures of species with higher yields and less labour-intensive
329 processes. This act could be considered as a form of buffering which increased their resilience,
330 contributing to their survival (Riehl et al., 2012). In other areas, a greater integration of sheep
331 and goat herding into the economy may have allowed communities to switch between
332 agricultural and pastoral resources depending on which was more likely to generate better
333 yields (Wilkinson et al., 2014). How far the Akkadian Empire played a role in mitigating or
334 driving the collapse of particular areas is still open for debate, and depends on the general
335 degree of control it is considered to have had over the region (Middleton 2019). However,

336 the uneven nature of the changes in the settlement record argues against a pan-regional
337 factor such as a large political entity playing a significant causal role.

338

339 **Conclusions**

340 Overall, the model and proxy data signal changes in climate between 2250 BCE and 2000 BCE
341 in Mesopotamia. This climatic change is driven by reduced Western Disturbances over the
342 region and resulted in a decrease in precipitation, initiating a shift towards more arid
343 conditions. This reduced water availability pressured societies to move towards farming more
344 water efficient species. However, large urban populations were already surviving on the edge
345 of sustainability. In order to cope with the reduced moisture, certain groups may also have
346 attempted to change cropping practices, either by extensification of farmed areas or
347 intensification, through increased manuring or violation of fallowing. Shifts to greater reliance
348 on pastoral resources may also have played a role. Our models suggest that the climate
349 changes associated with the 4.2kyr event in Mesopotamia may not be directly correlated to
350 changes in the monsoonal systems, which severely impact other key civilizations that showed
351 change around 4.2yrs ago. This may explain why regional scale comparisons of settlement
352 decline have not produced clear patterns (Wilkinson et al., 2014; Wossink, 2009). Progress on
353 this topic will require detailed analysis of settlement patterns and archaeobotanical data to
354 establish how different crops being grown may have allowed communities in different sites
355 and regions to respond to the changes identified. Further climate modelling work would also
356 enable a more detailed and nuanced picture of the changes surrounding the 4.2kyr event to
357 emerge. Further work is required to understand quite how these changes impacted the
358 Akkadian Empire, or how community choices were constrained or enabled by being part of

359 larger political units. Outside the Akkadian imperial zone, it seems likely that the degree to
360 which the different small scale polities which remained in the region were able to adapt to
361 the new conditions likely determined their survival. Today, the Mesopotamian region is also
362 suffering from water stress and lower crop yields and recent droughts, made more likely by
363 anthropogenic climate change (Kelley et al., 2015). The drought centred on 2008 was
364 probably a contributor to political upheavals in the region, but land management policy
365 probably determined the magnitude of the impacts (Eklund and Darcy, 2017; De Châtel,
366 2014). The history of Mesopotamia and the recent drought in the region, show the
367 importance of agricultural policy and practice in mitigating the impact of reductions in water
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369

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381

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