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Supplement of

Assessment of precipitation and temperature data from CMIP3 global climate models for hydrologic simulation

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Supplementary Material

Supplement: Estimating potential evapotranspiration for climate change impact assessments

Projected changes in water and energy at the catchment scale are the fundamental basis of all hydrologic climate change impact assessments. Hydrologic models require time-series of precipitation and, usually, potential evapotranspiration to represent the interaction of water and energy within a catchment. Therefore, for hydrologic climate change impact assessments, an estimate of potential evapotranspiration (PET) is required. For the practitioner the question is which PET method to adopt? Here we briefly review three questions that influence the choice of PET equation: (1) does the equation represent all relevant processes; (2) what PET information does a hydrologic model actually use; and (3) are future projections of variables used to estimate PET reliable?

S.1 Does the PET equation represent all relevant processes?

McMahon et al. (2013) discuss a range of PET equations used in rainfall-runoff modelling. Frequently adopted methods to represent PET include Penman (Penman, 1948), Penman-Monteith (Monteith, 1965), FAO reference crop (Allen et al., 1998), Morton (Morton, 1983) and pan evaporation data. Ideally to represent future PET conditions the method adopted should adequately capture all changes in the energy and aerodynamic components of the evaporative process.

The potential danger of using a PET equation that does not adequately represent all relevant processes is highlighted by recent trends in pan evaporation data. Over the past several decades the magnitude of evaporation from Class-A pans has decreased (between -1 to -4 mm year^{-2}) while at the same time annual temperatures have risen (Roderick et al., 2009a). Roderick et al. (2009b) warn against using temperature only PET estimates for climate change studies as they would suggest that rising temperature would lead to rising evaporative demand; the opposite of what has been observed from pan data recently. Roderick et al. (2009b) attribute much of the observed decline in pan evaporation to declines in radiation and/or wind speed. Donohue et al. (2010), using the Penman formulation and gridded Australian data (1981-2006), attributed increasing surface temperature with contributing +1.5

mm year^{-2} toward evaporative demand. However, the temperature contribution was more than offset by negative contributions from changes in wind speed (-1.3 mm year^{-2}), net radiation (-0.6 mm year^{-2}) and actual vapour pressure (-0.4 mm year^{-2}) to give an overall decrease in evaporative demand of -0.8 mm year^{-2}. Donohue et al. (2010) also compared the performance of five formulations of differing complexity namely Thornthwaite (Thornthwaite (1948), Priestly-Taylor (Priestley and Taylor, 1972), Morton point and areal (Wang et al., 2001) and Penman (1948)) and preferred Penman, the most complex form, based on its ability to best capture the dynamics of evaporative demand. Overall, Roderick et al. (2009a, 2009b), Chen et al. (2005) and Hobbins et al. (2008) conclude that PET estimates based only on T are problematic, particularly in energy limited environments (cold and polar climates), for climate change studies.

S.2 What PET information does a conceptual hydrologic model actually use?

Whether conceptual hydrologic models require, or make use of, detailed PET data was assessed by Andréassian et al. (2004) and Oudin et al. (2005a, 2005b). They found that hydrologic models perform as well (if not better) when calibrated with mean monthly estimates of PET, or with temperature based estimates of PET, rather than time varying estimates of PET or more complex Penman based PET (Penman, 1948, Allen et al., 1998). Catchments used in their studies were located in France (Andréassian et al., 2004; Oudin et al., 2005a, 2005b), USA (Oudin et al., 2005a, 2005b) and Australia (Oudin et al., 2005a, 2005b). The vast majority of their catchments have a temperate climate (not strongly water or energy limited on an annual basis). Under these conditions the hydrologic models appear to be largely insensitive to the complexity of the PET data used to drive them. During calibration conceptual hydrologic models are flexible enough to extract the PET information they need from whichever PET data (simple or complex) are used (see Chapman, 2003). Thus, as long as PET estimates are broadly correct in terms of seasonal pattern and annual mean and the hydrologic model was calibrated on that PET data then model performance is likely to be acceptable. For example, Oudin et al. (2005b) tested 27 PET formulations, of varying complexity, over 308 catchments using four daily conceptual models and proposed a simple temperature (mean daily temperature for a given Day-of-Year) and extra-terrestrial radiation (estimated from latitude and Day-of-Year) method that performed as well as the daily Penman method. In summary, a complex estimate of PET is not necessary for successful hydrologic modelling in catchments that are not strongly water or energy limited on an annual basis.

S.3 Are future projections of variables used to estimate PET reliable?

In the previous two sections we have seen that a simple PET formulation may be good enough for hydrologic modelling, but not good enough to represent projected changes in PET. The final question relates to whether GCMs are able to provide reliable outputs on which to base a complex estimate of PET? Kay and Davies (2008) used IPCC third assessment report runs for 5 GCMs and 8 regional climate models nested within the Hadley Centre GCM to calculate PET using Penman-Monteith and the temperature/radiation (T/R) method of Oudin et al. (2005b). They compared their two PET estimates derived from GCM data against observation based gridded values of Penman-Monteith PET for Britain. Overall, the GCM estimate of PET using T/R performed better than GCM Penman-Monteith at reproducing observed Penman-Monteith for all climate models. Future values of PET based on Penman-Monteith were also more variable than those based on T/R, which they suggest may reflect reliability issues with GCM variables, other than temperature, used to estimate Penman-Monteith. Kingston et al. (2009) also highlight reliability issues with GCM inputs to the Penman-Monteith equation. Although confidence in GCM-simulated temperature is generally high, Kingston et al. (2009, page 4) note “less confidence can be placed in cloud cover and vapour pressure”, which influence GCM-simulation estimates of net radiation at the evaporating surface and relative humidity. Overall, Kay and Davies (2008) suggest hydrologic modellers should be pragmatic and use as many GCMs as possible and estimate PET in a consistent way for any impact analysis.

S.4 Discussion and summary

Ideally, estimates of PET should be based on methodologies that include all key evaporative processes to ensure future changes in PET are accurately represented. A Penman based equation is thus an ideal methodology to adopt. However, the reliability of future PET estimates is dependent on the reliability of GCM projections of input variables. For example, the Penman equation requires inputs of air temperature, net radiation at the evaporating surface, wind speed and relative humidity. In this paper we have found that mean monthly and mean annual temperature are well reproduced by CMIP3 GCMs. However, reported confidence in GCM estimates of net radiation at the evaporating surface, wind speed and relative humidity is much lower. For example, Johnson and Sharma (2009) have shown that in terms of their Variable Convergence Score (VCS, scaled between 0 and 100, where 100 is perfect convergence between GCMs) the predictions of the surface wind and specific humidity have VCS scores of approximately 40, net longwave radiation about 20 compared with surface temperature and net shortwave radiation of about 70 and precipitation at 10. Therefore, although Penman based methodologies have the capacity to represent future trends due to changes in all key evaporative processes, GCM projections of those process variables, other than temperature, may be unrealistic. Thus at this time PET based on Penman may actually increase uncertainty in future PET, as seen in Kay and Davies (2008). PET based on Penman will be preferable once GCM projections of net radiation at the evaporating surface, wind speed and relative humidity become more reliable.

As GCM projections of temperature are considered reliable, here we adopt temperature as a surrogate for PET. Such an approach is likely to provide sufficient PET information for successful hydrologic modelling if the model is calibrated on that data. However, by adopting this approach we acknowledge that the projected trend in PET will be an increase, when in reality the trend may increase or decrease due to changes in temperature, net radiation at the evaporating surface, wind speed and/or relative humidity. We note the error in PET trend is unlikely to be important for hydrologic modelling of water limited catchments, where changes in precipitation are the main driver of changes in runoff. However, in energy limited catchments, PET is a key driver of runoff and errors in PET trend will result in errors in runoff trend.

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