Importance of anthropogenic heat flux in simulating sensible and latent heat fluxes in an urban environment

M. J. Best [a,c] and C. S. B. Grimmond [b,c]

Background

- ❑ First International Urban Model Comparison project (PILPS-Urban):
  - Used dataset from (Coutts et al. 2007a. 2007b)
  - Provided atmospheric forcing data to run urban models offline
  - Evaluated models using observed fluxes of Q^*, Q_H, Q_E (and ΔQ_S from energy balance closure)
- ❑ Conclusions from PILPS-Urban include (Grimmond et al. 2010, 2011, Best and Grimmond 2012):
  - Representing vegetation is critical in urban areas
  - Models without an anthropogenic heat flux (Q_F) do at least as well as models that include this flux
- ❑ Over the seasonal cycle models with no Q_F have (Fig. 1):
  - Smallest root-mean-square error (RMSE) for all fluxes
  - Smallest summer mean bias errors (MBE) in Q_H
  - Negative MBE for Q_H in winter unlike other models

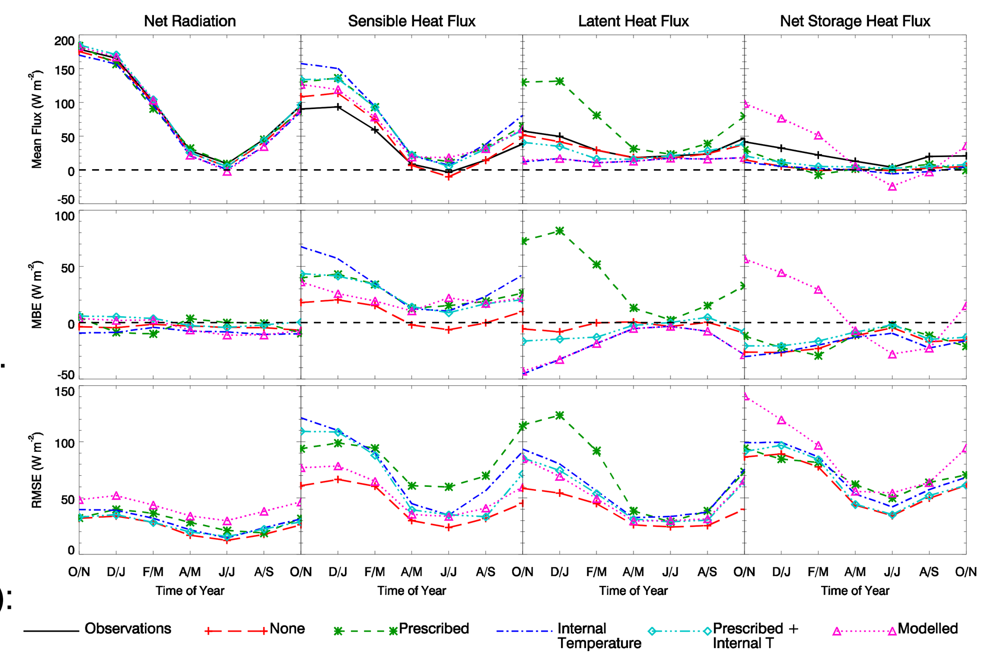

Fig. 1 Median of the mean modelled flux, mean bias error (MBE), and root-mean-square error (RMSE) for the surface fluxes determined for two month periods, for the models classified by the representation of Q_F

Objective: Why did models that neglect Q_F do so well in PILPS-urban?

Methods

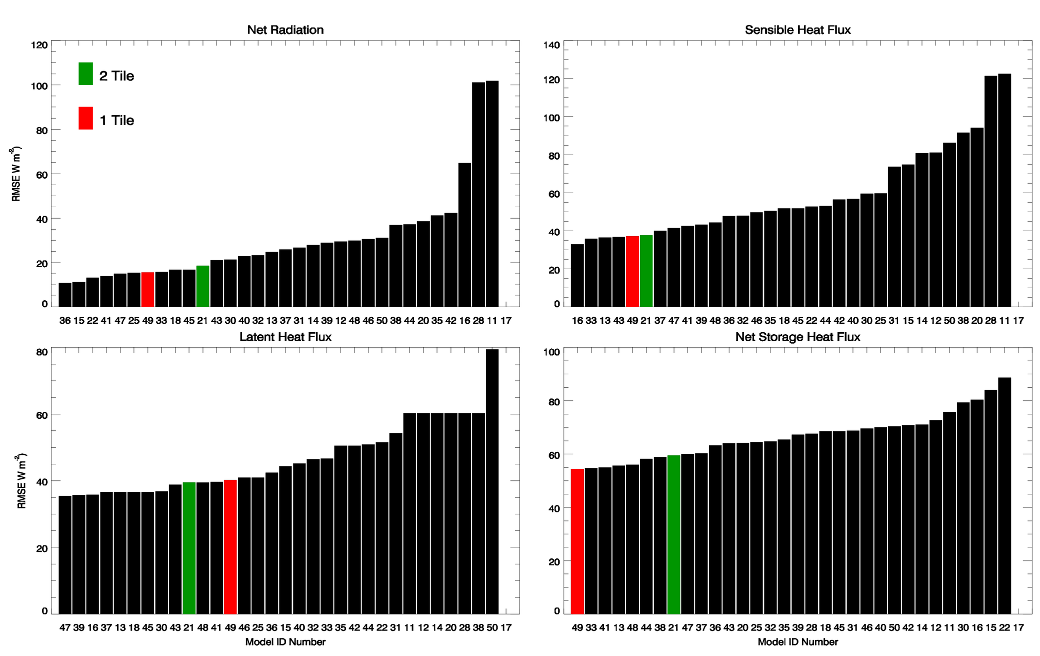

Fig. 2 PILPS-Urban models ranked according to RMSE at stage 4 for each flux. Model ID numbers between 1 and 50 were randomly assigned to the models for anonymity. The models highlighted in colour are the two versions of JULES with wet initial soil moisture

Joint UK Land Environment Simulator (JULES)

(Best et al., 2011)

- ❑ JULES is used to investigate the impact of including Q_F
- ❑ 4 JULES versions were run for PILPS-Urban, combined from:
  - Urban surfaces: 1 and 2
  - Initial soil moisture: dry and wet
- ❑ Performs well compared to other models (Fig. 2) especially for Q_H
- ❑ JULES runs neglected Q_F in PILPS-Urban
- ❑ In this study, JULES is re-run with wet initial soil moisture for the PILPS-Urban case with no vegetation (No Veg), no Q_F (None) and various temporal profiles for Q_F (Fig. 3)

Anthropogenic flux

- ❑ Taken from the observational dataset
- ❑ Average flux ~ 17 W m^{-2}
- ❑ Maximum flux ~ 26 W m^{-2}
- ❑ Applied to JULES in a number of ways with differing temporal profiles (Fig. 3a):
  - i. Average flux over whole simulation period (Av)
  - ii. Monthly mean flux (Mon Av)
  - iii. Average diurnal cycle over whole simulation period (Av Diur)
  - iv. Monthly varying diurnal cycle (full temporal resolution of observed Q_F) (Mon Diur)
- ❑ Figure 3b shows maximum and minimum diurnal cycles from (iv), along with average diurnal cycle from (iii)

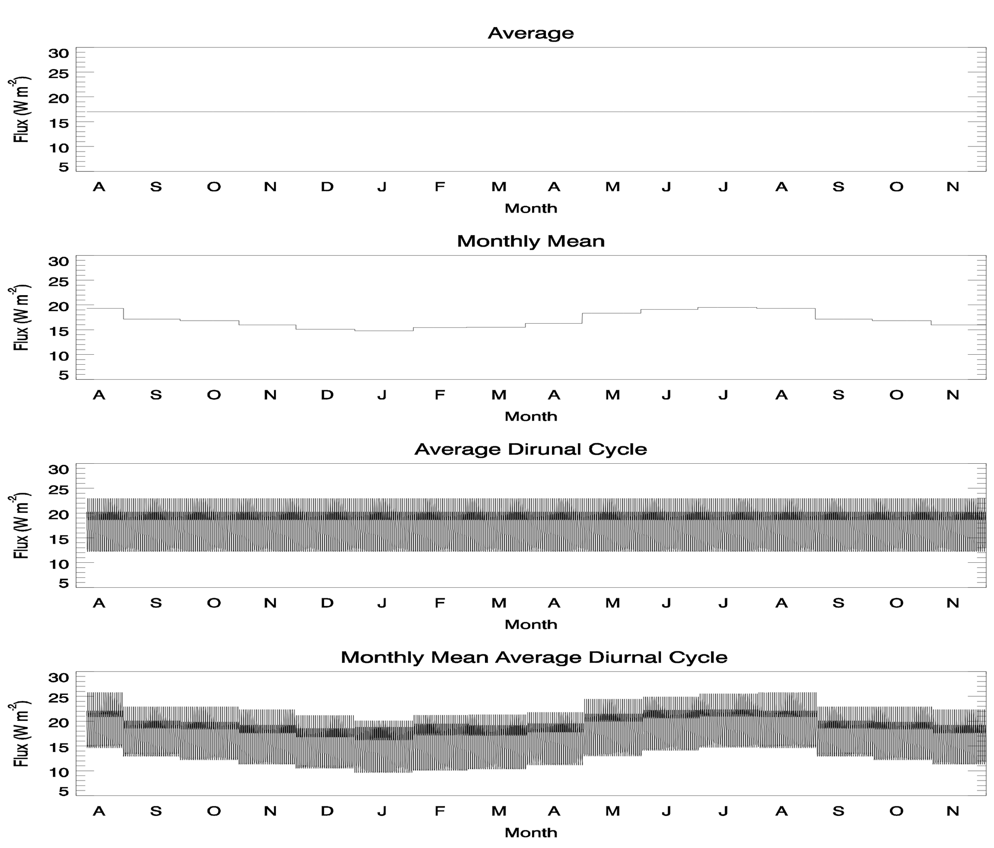

Fig. 3a Temporal pattern of Q_F used with JULES for each 30 min timestep

Implementation of Q_F

- ❑ Each Q_F temporal profile was used in JULES inthe following ways:
  - ➢ For 1 urban surface type runs:
    - Applied to urban surface (1 Tile)
  - ➢ For 2 urban surface types runs:
    - Applied to both roof and canyon surfaces proportional to area fractions (2 Tile, Both)
    - Applied only to canyon surface (2 Tile, Canyon)
    - Applied only to roof surface (2 Tile, Roof)
  - ➢ Q_F for each surface scaled to ensure overall Q_F is the same for all runs

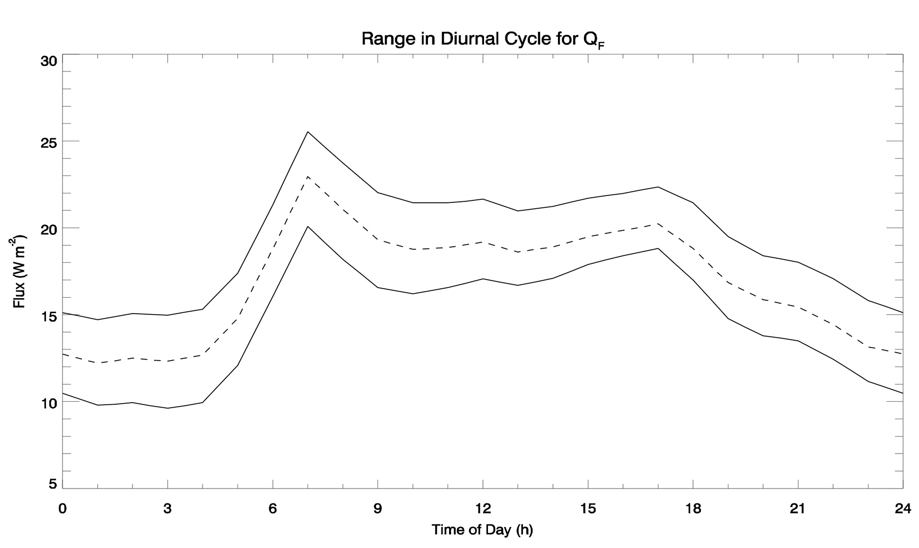

Fig. 3b Maximum (July) and minimum (January) diurnal cycles of Q_F (solid lines) from monthly mean average diurnal cycle profile and diurnal cycle of Q_F (dashed line) from averaged diurnal cycle profile

Analysis of model results

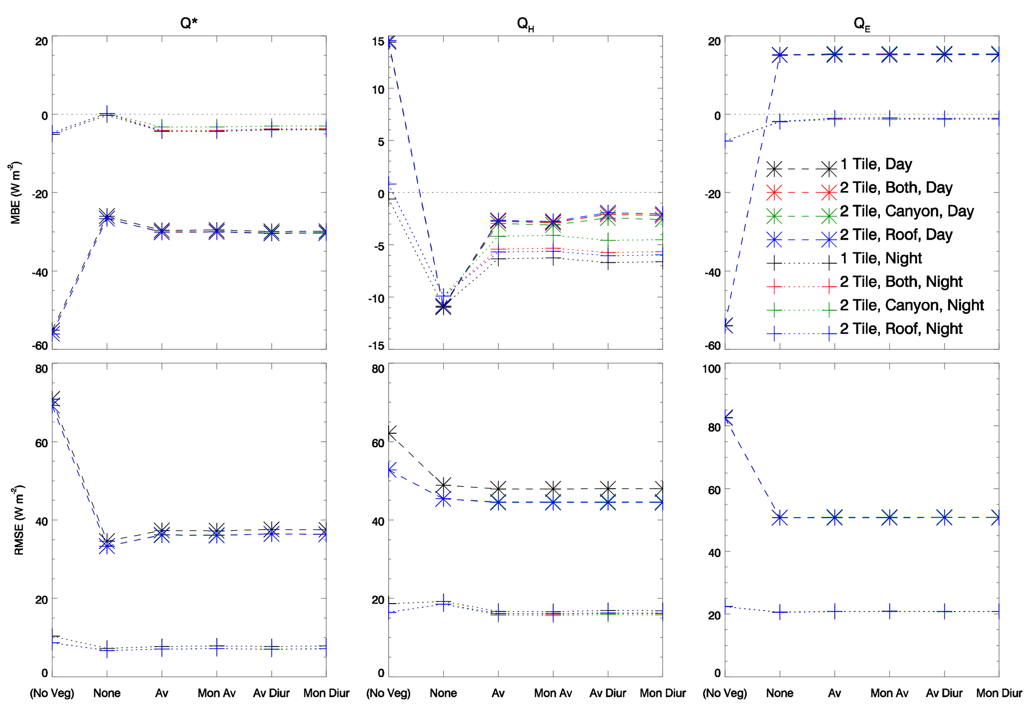

Fig. 4 Overall MBE and RMSE for Q^*, Q_H and Q_E for JULES runs with no vegetation, no Q_F and each temporal Q_F profile (Fig. 3). Results are shown for the various implementations of Q_F when the fluxes are evaluated for day time ($Q^*\geq0$) periods, and for night time ($Q^*<0$) periods (see key). See x-axis codes in methods

Overall impact of including Q_F

From analysis of Figure 4:

- ❑ Impact is smaller than that for representing vegetation (No Veg - None)
- ❑ More important than which temporal pattern of Q_F (Fig. 3) is selected
- ❑ Applying Q_F to canyon - larger impact than applying to roof or roof + canyon (Both)
  - Differences in implementation larger at night when Q_F is a more significant flux relative to Q^*
- ❑ Reduces MBE and RMSE for Q_H during day and night
- ❑ Increase in MBE and RMSE for Q^* during day and night
  - However, known JULES albedo issues!
- ❑ Little impact on MBE or RMSE for Q_E during day and night

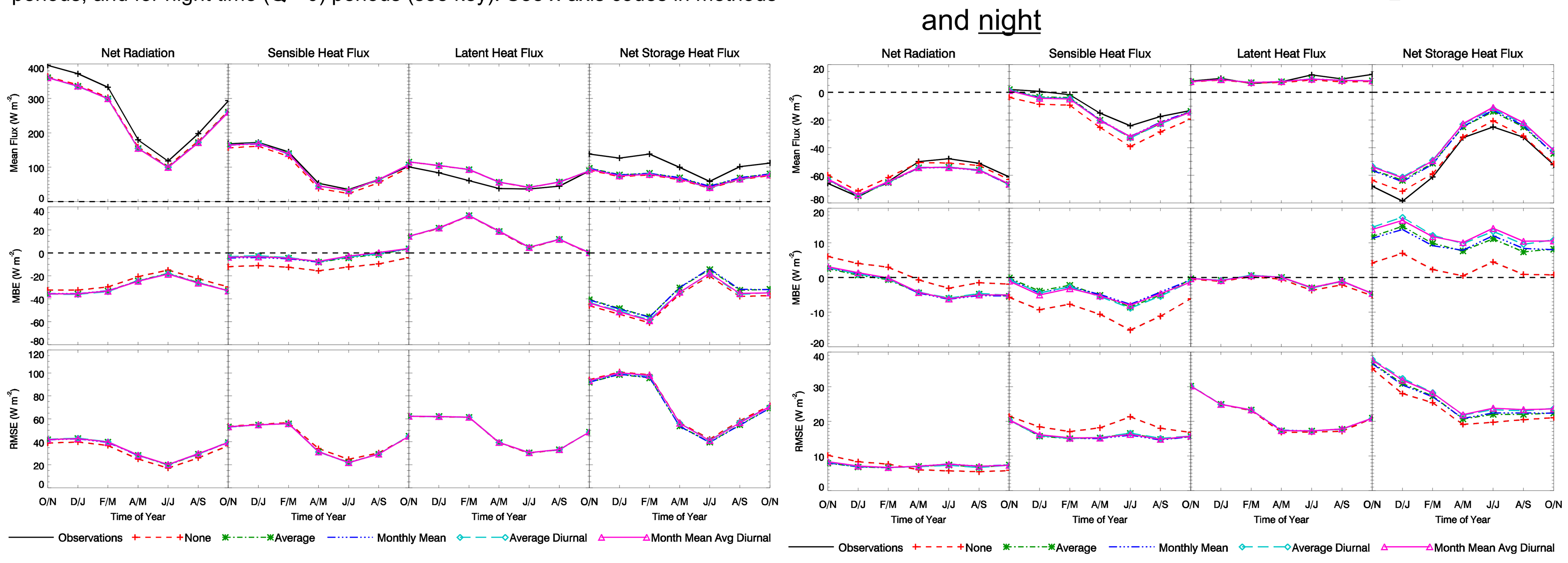

Fig. 5 (rows) Mean modelled flux, MBE, and RMSE for the (columns) surface fluxes performance analysed for (left) day time and (right) night time data determined for two month periods, for the different temporal Q_F profiles (Fig. 3)

Impact of including Q_F seasonally

Analysis of variations through the year (Fig. 5):

- ❑ Consistent impact on MBE for **all fluxes** *throughout the year*, independent of temporal Q_F profile (except for ΔQ_S)
- ❑ Reduces RMSE for Q_H for day in *winter*, but only at night in *summer*
- ❑ Reduces the negative MBE in Q_H *throughout the year* for day and night
- ❑ Reduces negative MBE in ΔQ_S for day, but increases positive MBE for night *throughout the year*
- ❑ Having a diurnal cycle in Q_F gives a slight increase in MBE during night for ΔQ_S *throughout the year* and slightly less reduction in the negative MBE during day, compared to no diurnal cycle

Including Q_F impact on diurnal cycles seasonally (Fig. 6)

- ❑ Generally has only a small impact on the diurnal cycle for **all fluxes** *throughout the year*
- ❑ During the night in *winter*, reduces the negative MBE in Q_H
- ❑ Increases the positive MBE for ΔQ_S at night *throughout the year*

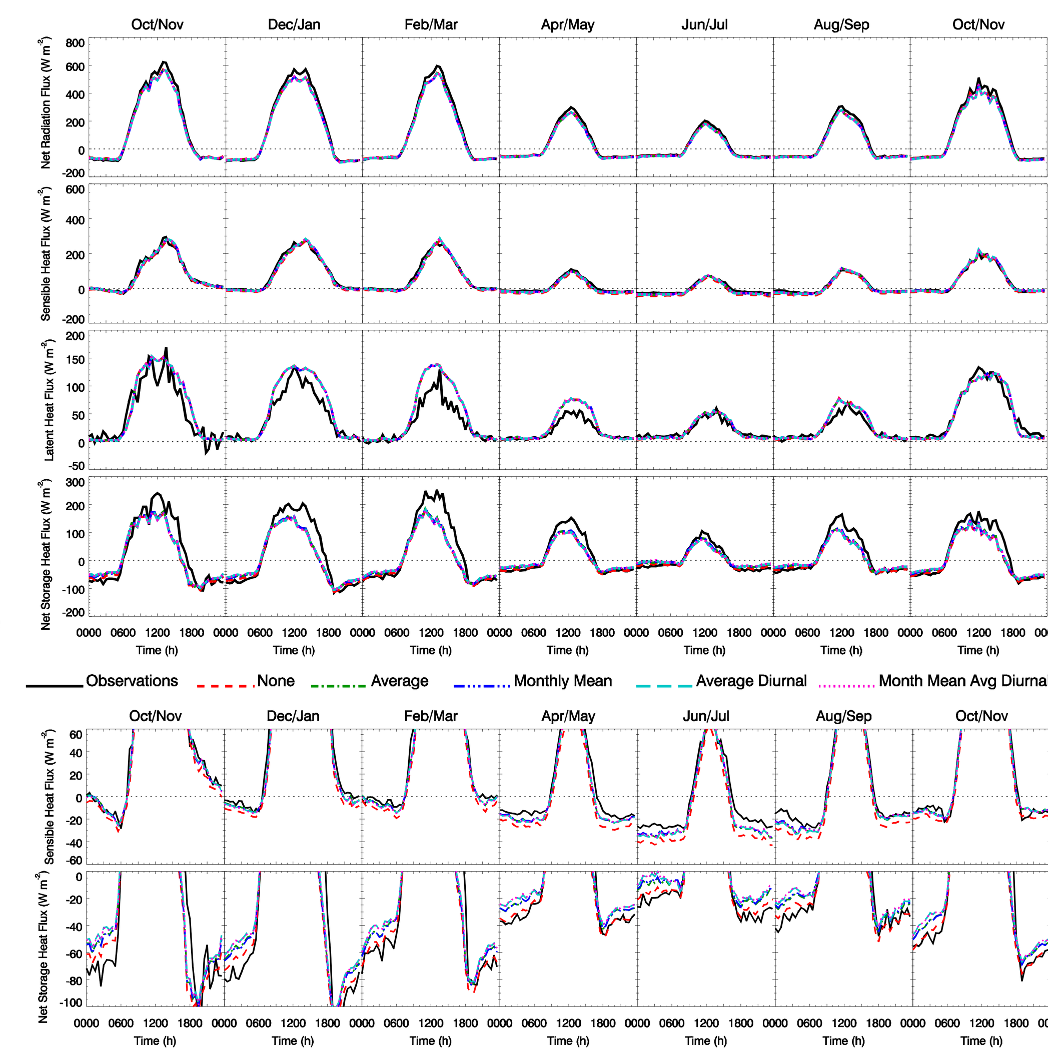

Fig. 6 Plot of the average diurnal cycle for each 60 day period throughout the seasonal cycle, for each temporal Q_F profile. Note scales are different for each flux. (Bottom two rows) with smaller range to show details for Q_H and ΔQ_S.

Conclusions

- ❑ For the dataset used in PILPS-Urban, including Q_F:
  - Has a smaller impact on model errors than including a representation of vegetation
  - Has a larger impact than including the temporal variations in Q_F
  - Increases the errors for Q^*, but this may be linked to albedo problems in JULES
  - Gives consistent offset in MBE for each flux throughout the year
  - Improves the overall errors for Q_H
  - Gives greater improvements to RMSE for Q_H in the winter than the summer
  - Gives greater improvements to Q_H at night in the winter than the summer
  - Reduces the negative MBE in ΔQ_S during the day time, but increases the positive MBE in the night
  - Has larger errors at night for ΔQ_S throughout the year
  - Gives slightly better results without a diurnal cycle in Q_F than when it is resolved
- ❑ As Q_F is small for the site analysed, this could explain the relatively small impact of including Q_F on the simulations
- ❑ Including Q_F does show some benefit for Q_H, especially on winter nights when the radiative forcing is small
- ❑ The increased errors in the nocturnal ΔQ_S are consistent with insufficient energy being stored during the day time and released during the night time, and could be related to energy partitioning issues between ΔQ_S and Q_H as concluded by Best and Grimmond (2014)
- ❑ The majority of models that included a representation of vegetation in PILPS-Urban also neglected Q_F, so the results for models with no Q_F are more related to vegetation rather than anthropogenic heating
- ❑ For areas with larger Q_F, it is likely this term would lead to greater improvements so should be included

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[a] **Met Office** FitzRoy Road, Exeter, Devon, EX1 3PB United Kingdom
Tel: +44 1392 885680 **Fax:** +44 1392 885681
Email: martin.best@metoffice.gov.uk
[b] Department of Meteorology, University of Reading, Early Gate, Reading, RG6 6BB United Kingdom
[c] King's College London, Department of Geography, London, WC2R 2LS, United Kingdom

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