EVALUATION OF THE WRF PERFORMANCE OVER THE UNITED ARAB EMIRATES

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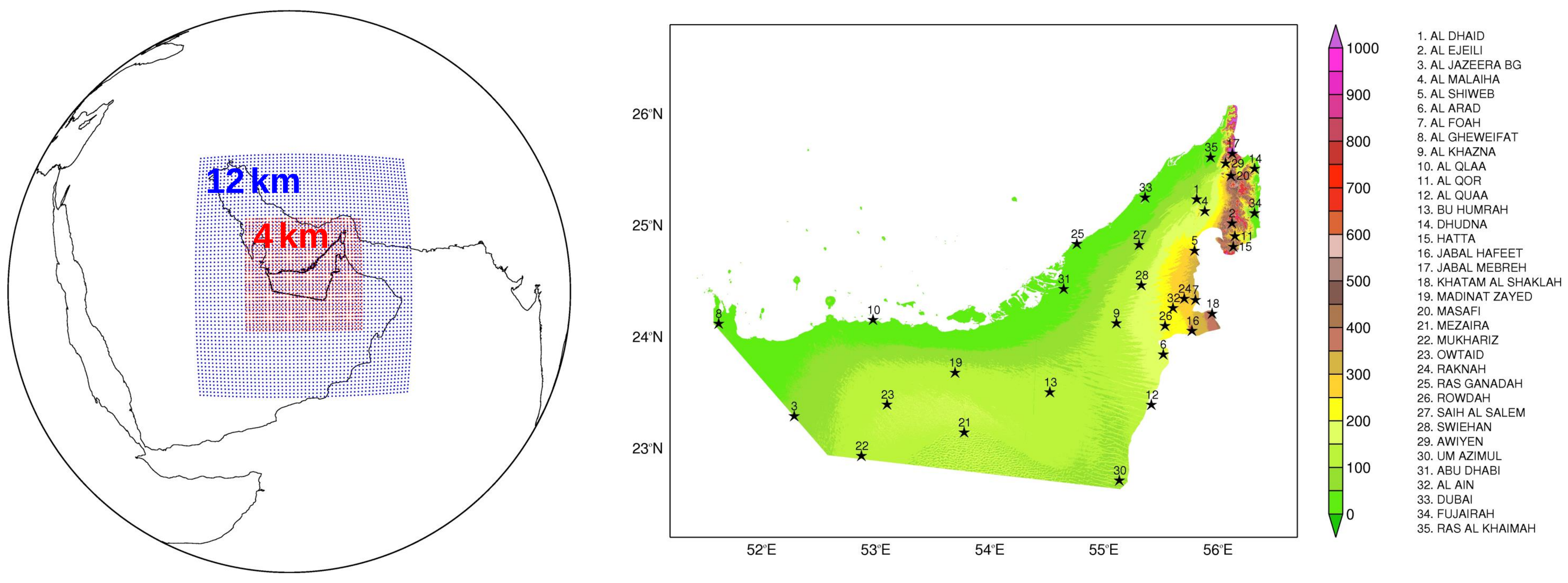
1. Experimental Setup

In this study, the Weather Research and Forecasting model version 3.7.1 (WRF; Skamarock et al., 2008) is used to dynamically downscale the 0.25° × 0.25° Global Forecast System (GFS) data over the United Arab Emirates (UAE), for the period September 2017 – June 2018. Each run is initialized daily at 06 UTC and lasts 72 h, with the first 6 h regarded as model spin-up. WRF is run in a two-nested configuration (grid resolutions of 12 and 4 km), with 46 vertical levels, concentrated in the Planetary Boundary Layer (PBL). The output of the innermost grid is stored every 1 h. The physics parameterization schemes employed are given in the table below. They are the same as those used in Chaouch et al. (2016), Weston et al. (2018) and Valappil et al. (2019), and are found to give the best performance for this region.

Physics Options	Parameterization Scheme
Microphysics	WRF Single-Moment Three-Class Scheme (WSM3)
Radiation (Short-wave)	Rapid Radiative Transfer Model (RRTM)
Radiation (Long-wave)	Rapid Radiative Transfer Model for GCM Applications (RRTMG)
Land Surface	Noah Land Surface Model (Noah LSM)
Planetary Boundary Layer	Quasi-Normal Scale Elimination (QNSE)
Cumulus *(12 km grid only)*	Kain-Fritsch (KF), with subgrid-scale cloud feedbacks to radiation

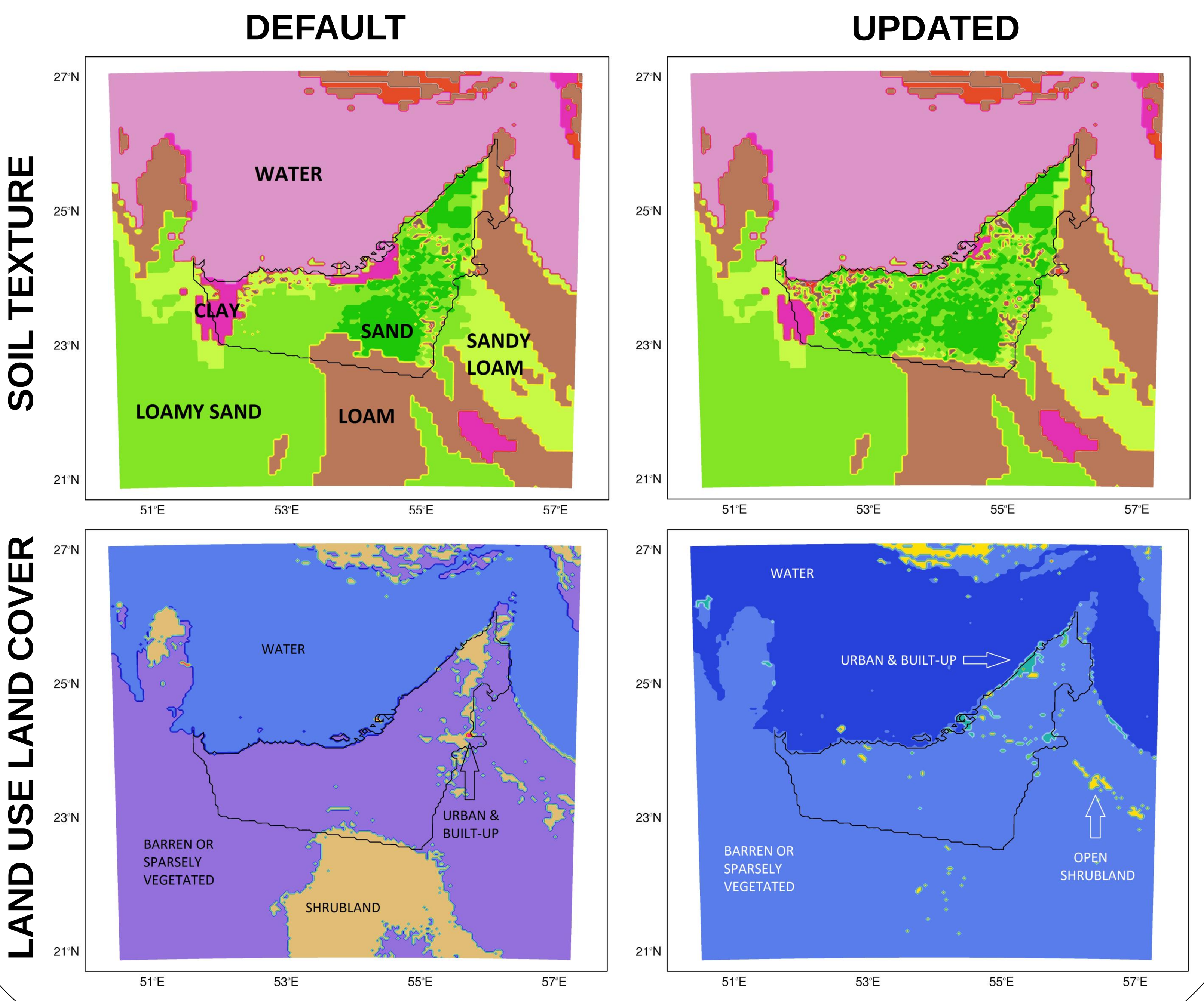
The figures below show the model grids, and the location and names of the 35 weather stations whose hourly observations are used for model evaluation.



Two sets of runs are conducted: in the first, the default soil texture and Land Use Land Cover (LULC) generated by the WRF Preprocessing System (WPS), are employed. In the second, the two fields are updated following a dedicated field campaign conducted as part of the UAE Rain Enhancement Project (UAEREP). The figures below show the default and updated fields.

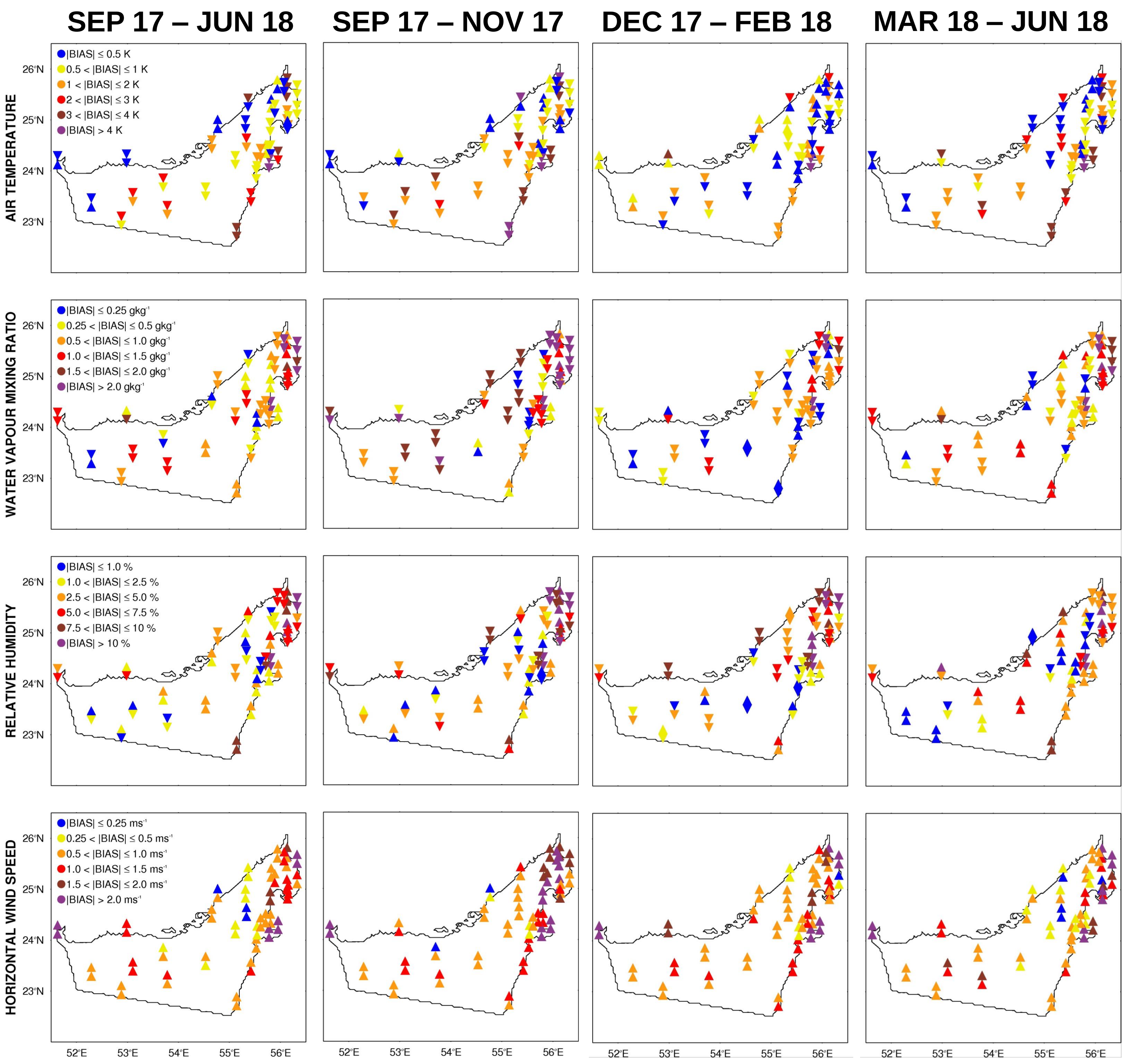
The soil texture refers to the size distribution of primary mineral particles in the soil, and controls the soil's physical and hydraulic properties. The main difference between the soil texture maps is the replacement of some of the loamy sand, sandy loam, and clay regions with sand. For a given soil texture, the soil parameters are defined in "SOILPARM.TBL". As shown in Fonseca et al. (2019), and for arid regions, the most relevant parameter is the soil porosity. As sand has a lower porosity than the loamy/clay textures, when they are replaced by sand the soil will be more compact or less porous and therefore will have an effectively larger thermal inertia, giving cooler daytime and warmer nighttime surface temperatures.

The LULC gives information about the land's physical type and how it is being used (e.g. urban, cropland, desert, etc.), determining surface properties such as the albedo, emissivity, and roughness length. It plays an important role on the heat and momentum exchanges between the surface and atmosphere. The surface properties controlled by the LULC are defined in the file "VEGPARM.TBL". The main modifications are the replacement of some of the shrubland with barren/sparsely vegetated over southern parts of the UAE, and some of the barren/sparsely vegetated with urban/built-up in particular around the main cities of Abu Dhabi, Dubai, Sharjah, Ras Al Khaimah and Fujairah. When switching from a desert to urban LULC, the temperatures are higher, consistent with the fact that urban areas are hotter than rural areas due to the effect of anthropogenic heat (e.g. Wong et al., 2015), and the near-surface winds are weaker.

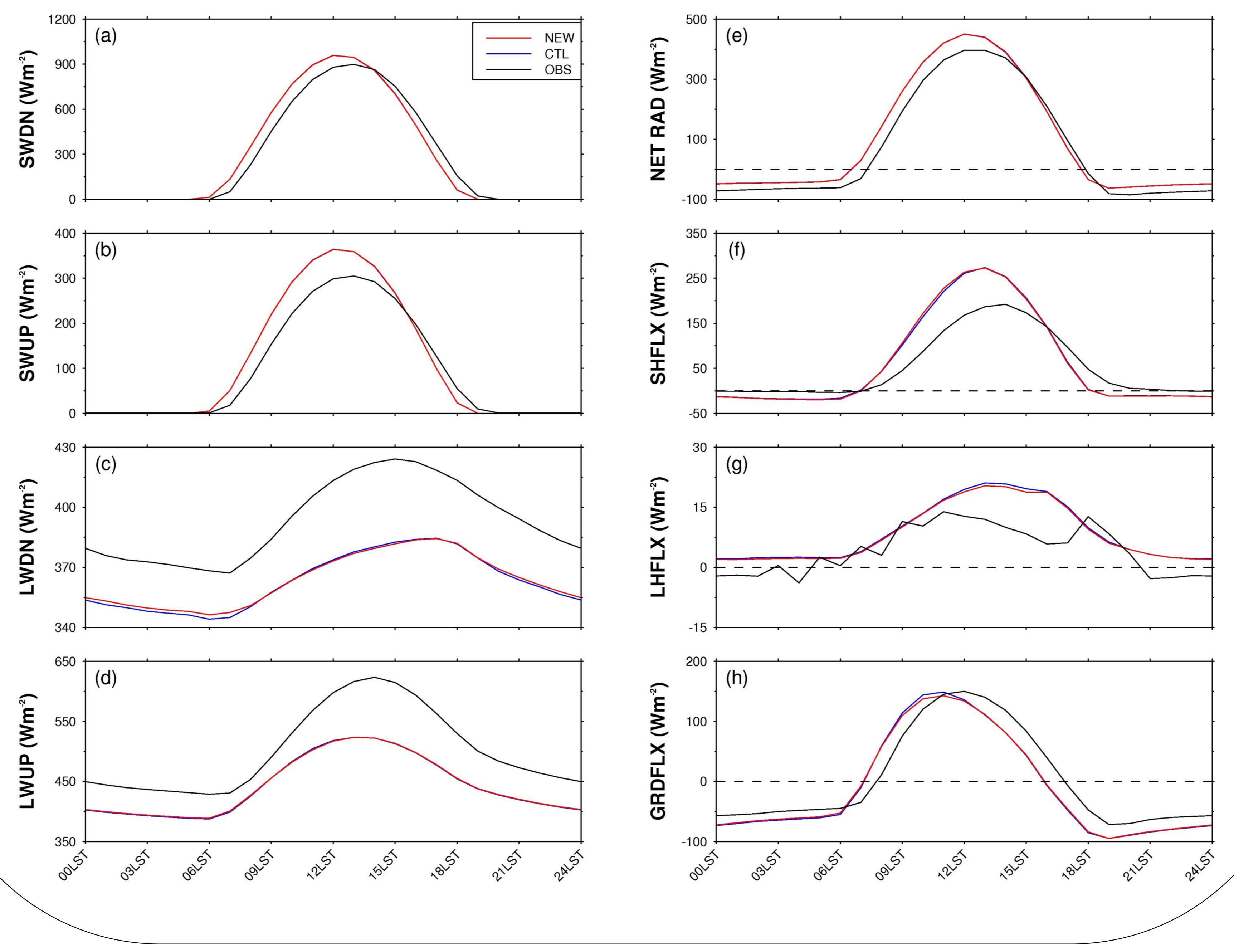


2. WRF Evaluation

- The figures below show the WRF bias for the simulation with the control configuration (top symbol) and modified configuration (bottom symbol), for full period and each season separately. The scores are shown for the air temperature (K), water vapour mixing ratio (g kg^{-1}), relative humidity (%), and horizontal wind speed (m s^{-1}), at the location of the 35 weather stations. An upward (downward) pointing triangle indicates that WRF overestimates (underestimates) the observed value, with the shading denoting the magnitude.



- WRF has a cold bias over the UAE, typically of 1-2 K, more significant in the autumn and spring seasons. This cold bias has been noted by Chaouch et al. (2016), Weston et al. (2018) and Valappil et al. (2019), and may arise from deficiencies in the Land Surface Model (LSM), an incorrect representation of surface properties and concentration of greenhouse gases and dust in the atmosphere, and is also inherited from the GFS data used to drive WRF (e.g. Zheng et al., 2012). However, when the soil texture and LULC are updated, there is some improvement in the bias, both in the inland desert due to a change of the soil texture to sand, and in Dubai, where the rather large cold bias in excess of 4 K is corrected when the LULC is updated from barren/sparsely vegetated to urban/built-up;
- The water vapour mixing ratio changes very little between the two sets of simulations, generally less than 0.5 g kg^{-1}. WRF has a tendency to underestimate the observed water vapour mixing ratio (and RH), with this dry bias also present in the GFS data (e.g. Müller and Janjic, 2015). At all stations and seasons, the model overestimates the strength of the near-surface wind. This has been reported by other authors, such as Gunwani and Mohan (2017) over arid regions in India, and may be attributed to a deficient simulation of its subgrid-scale fluctuations and/or a poor parameterization of the surface drag;
- The figure below shows observed and modelled diurnal cycle of surface downward/upward short-wave and long-wave radiation fluxes, net radiation flux, sensible and latent heat fluxes (positive if upwards from the surface), and ground heat flux (positive if downwards into the soil), at Al Ain. The fields are averaged over 1st Sep – 18th Oct 2017 and 1st Feb – 30th June 2018. The small difference between the predictions of the two WRF runs is consistent with the fact that the soil texture and LULC are not updated at this site;
- WRF overestimates the observed surface albedo (0.380 in the model, 0.334 in the observations), which is consistent with the colder air temperatures. However, the downward short-wave flux is overestimated and the downward long-wave flux underestimated, suggesting reduced cloud cover in the model, consistent with the findings of other authors (e.g. Kumar et al., 2012; Wehbe et al., 2019). The model warms up too fast in the morning and cools down too fast in the evening, as pointed out by Weston et al. (2018).



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