Supplementary Material: Multiple linear regression analysis.

In order to distinguish the driving factors behind the differences in the PBL climatologies, in addition to the correlation analysis presented in the main manuscript we also used a multiple linear regression across the model ensemble. We regressed the boundary layer climatologies against the corresponding values of horizontal and vertical resolution, surface sensible heat flux, and near-surface wind speed in the models. In order to make fair comparisons between the different predictor variables we first standardized all variables i.e. the mean was removed and then divided by the standard deviation. This was done for the area-averaged global and over-land values (Supplementary Figure 1) and for the gridpoint-wise values (Supplementary Figure 2) since we anticipated that e.g. even if model vertical resolution is not a good predictor of any given global-mean climatology, it might well be a good predictor for regions with consistently shallow PBLs, such as in the Arctic.

The results did not add substantial insight into the primary causes of differences in the model climatologies. The only significant result in the area-averaged regression analysis (Supplementary Figure 1) was the negative relationship between sensible heat flux and boundary layer depth in the diurnal minimum and seasonal maximum climatologies.

In the gridpoint-wise analysis: there was no large areas where the horizontal resolution had a statistically-significant effect on the PBL climatologies (not shown); however there were large regions over ocean where the vertical resolution had a significant negative relationship with PBL depth and over-land there is a strong positive relationship between vertical resolution and PBL depth in the diurnal minimum climatologies(Supplementary Figure 2A). The surface sensible heat flux is negatively related to PBL depth in the diurnal minimum climatologies and positively related in the diurnal maximum(Supplementary Figure 2B,C), which is consistent with expectations. And finally we see many regions of the globe where difference in near-surface wind speed (which drives mechanical turbulence) is positively related to PBL depth in the diurnal and seasonal minimum i.e. at times when buoyancy-driven turbulence is relatively weak (Supplementary Figure 2D,E).
Supplementary Figure 1. The coefficient of regression from a multi-linear regression of the climatology of the boundary layer height against the horizontal and vertical resolution of the models, and the corresponding climatology of surface sensible heat flux and near-surface wind speed. All variables were standardized prior to multi-linear regression and the error bars indicate the 95% confidence intervals. This regression was performed for the climatologies of the diurnal minimum (Min), maximum (Max), height range (DHR), seasonal minimum (Smin), seasonal maximum (Smax), and seasonal height range (SHR). The top chart shows the result for the global average, and the bottom for the over-land locations.
**Supplementary Figure 2.** Maps of the coefficient of regression from the multiple-linear regression analysis performed gridpoint-wise for (A) the vertical resolution and PBL depth at the diurnal minimum; (B) the surface sensible heat flux and PBL depth at the diurnal maximum; (C) the surface sensible heat flux and PBL depth at the diurnal minimum; (D) the wind speed and PBL depth at the diurnal minimum; and (E) the wind speed and PBL depth at the diurnal maximum.
Supplementary Figure 3. The ensemble mean of the percentage of cases where a PBL depth was found within the range 10 m to 4 km for (A) Winter (December-January-February), (B) Spring (March-April-May), (C) Summer (June-July-August), (D) Autumn (September-October-November), and (E) Annual mean.
Supplementary Figure 4. The climatological-mean in the diurnal minimum of the PBL depth from (A) the ensemble-mean of the models and (B) ERA-Interim with (C) the difference between the two climatologies (Ensemble mean – ERA Interim) and (D) the normalised difference between the two climatologies ((Ensemble mean – ERA Interim) / ERA Interim). E shows the cumulative-probability distribution function for the climatological-mean in the diurnal minimum of the PBL depth given in fraction of land covered for each of the individual
models (grey), the ensemble mean value (black), the ERA Interim reanalysis (red), and the MERRA reanalysis (blue).
Supplementary Figure 5. The climatological-mean in the diurnal maximum of the PBL depth from (A) the ensemble-mean of the models and (B) ERA-Interim with (C) the difference between the two climatologies (Ensemble mean – ERA Interim) and (D) the normalised difference between the two climatologies ((Ensemble mean – ERA Interim) / ERA Interim). E shows the cumulative-probability distribution function for the climatological-mean in the diurnal maximum of the PBL depth given in fraction of land covered for each of
the individual models (grey), the ensemble mean value (black), the ERA Interim reanalysis (red), and the MERRA reanalysis (blue).
Supplementary Figure 6. The gridpoint-wise, statistically significant (p<0.05) Pearson correlation coefficient between the models for (A) The vertical resolution and climatological mean PBL depth; (B) The vertical resolution and the diurnal minimum PBL depth; (C) The vertical resolution and the seasonal minimum PBL depth; (D) The surface sensible heat flux and the PBL depth at the diurnal maximum; (E) climatological mean surface sensible heat flux and climatological mean PBL depth; (F) climatological mean wind speed and climatological mean PBL depth.
Supplementary Figure 7. The climatological-mean in the Seasonal minimum of the PBL depth from (A) the ensemble-mean of the models and (B) ERA-Interim with (C) the difference between the two climatologies (Ensemble mean – ERA Interim) and (D) the normalised difference between the two climatologies ((Ensemble mean – ERA Interim) / ERA Interim). E shows the cumulative-probability distribution function for the climatological-mean in the Seasonal minimum of the PBL depth given in fraction of land covered for each of
the individual models (grey), the ensemble mean value (black), and the ERA Interim reanalysis (red).
Supplementary Figure 8. The climatological-mean in the Seasonal maximum of the PBL depth from (A) the ensemble-mean of the models and (B) ERA-Interim with (C) the difference between the two climatologies (Ensemble mean – ERA Interim) and (D) the normalised difference between the two climatologies ((Ensemble mean – ERA Interim) / ERA Interim). E shows the cumulative-probability distribution function for the climatological-mean in the Seasonal maximum of the PBL depth given in fraction of land covered for each of
the individual models (grey), the ensemble mean value (black), and the ERA Interim reanalysis (red).