Problem Set #9

These answers are based on text provided by Rachel Stanley, edited by the instructors.

Examining The Seasonal Model Performance

The m-file `ps09.m` will run the model climatology comparison calculations and make the required graphics. The EPS plots are made with the following commands:

```
orient tall
print -depsc2 fig09_fig01.eps
```

Note that the `colormap anom64cmap.mat` was used for the difference plots. This `colormap`, provided with the answers, makes the sign of the difference of the model from the climatology immediately apparent. If the plot is reddish, then the model run is warmer than the climatology; if the plot is blueish, then the model run is cooler than the climatology. It is often better to dislay anomalies in this fashion than to use a default `colormap` (*i.e.*, `jet`), which can actually obscure the differences you are looking for.

a) Compare the model run to the climatology

There is a general pattern of the modeled data being too warm at the surface in summer and too cold at the surface in autumn and winter. The largest differences between the data and model occur at the surface. This is largely because the surface temperature is sensitive to mixed layer depth since a thinner mixed layer traps more heat and thus is warmer. So any problem the model has in getting the mixed layer depth correct leads to a problem in predicting the surface temperature. The discrepancy between the model and the data at the surface is also because the surface temperature is dependent on how heat is transported out of the surface. Some of the mixing is modeled explicitly and some is modeled through the mixing parameter K_z. But using K_z is a somewhat simplified way of taking into account many processes that are occurring. The differences between model and data gradually decrease until approximately 100–125 m depth where the model matches the data fairly well (the zero contour). Then, the model starts to break down again with the model being too warm in the spring and summer at about 150 m depth. This difference between the model and data at 150 m may be due to problems with the bottom boundary conditions or model assumptions (such as no lateral transport).

The choice of K_z greatly affects the surface temperature in the summer. If K_z is very low, not much heat is vertically transported and thus the heat remains in the mixed layer, heating it considerably. When K_z is higher, more heat is transported out of the mixed layer and thus the summer surface temp is smaller. Hence, the runs with low K_z have warmer summer surface temperatures than runs with higher K_z. For example, when $K_z = 0.50 \times 10^{-4}$ m^2/s, the difference between model and Levitus data is as high as +3 °C in the summer surface waters whereas when $K_z = 1.5 \times 10^{-4}$ m^2/s, the difference is only around +0.5 °C in the summer surface waters. Runs with very low K_z have temperatures too cold below 50 m because not enough heat is transported from the surface downwards. Additionally, runs with large K_z have the autumn and winter surface being too cold whereas runs with the lowest K_z show good agreement between data and model in autumn and winter. This occurs because a very large K_z transports too much heat out of the surface. All runs predict too warm a temperature at approximately 150 m. As K_z gets larger, this discrepancy is smaller — *i.e.*, the runs with larger K_z fit the data better at around 100-200 m. Thus the warm spot at 100-200 m may have to do with the model not accurately portraying all the mixing processes that are occuring. Changing K_z changes these unresolved mixing processes and thus can diminish the discrepancy at 150 m.

As more stochastic wind forcing is added, the offset between the model and the data in the summer mixed layer decreases. With more stochastic winds, the model predicts a cooler summer mixed layer and thus there is better agreeement between the model and the data (though the model still predicts warmer temperatures than are observed in all but the case with the $K_z = 1.50 \times 10^{-4}$ m^2/s with double stochastic forcing). More stochastic winds lead to lower summer mixed layer temperature because the stochastic wind events have the effect of increasing mixing and thus transporting heat out of the mixed layer.

Additionally, increasing stochastic winds has only the tiniest effect on the model–climatology mismatch at 150 m. Winds that are more stochastic decrease the problem of too warm temperatures at around 150 m by an almost imperceptible amount – the 0.5 degree difference contour encircles slightly less area in the case of double stochastic winds than in the case of completely smooth winds. Again the nature of the winds – smooth or stochastic – effects how the water column is mixed since large storms can mix up the water column. So changing the wind forcing changes the mixing and thus affects the 150 m warm spot.

b) Compute the two most important "global diagnostics" of the model–data differences

The contour plot of average difference suggests that a larger K_z fits the data better than does a smaller one. For the case of smooth winds, the optimal K_z is about 1.4×10^{-4}m^2/s. For double stochastic forcing, the optimal K_z is around 1.25×10^{-4} m^2/s. As the stochastic forcing increases, a smaller K_z is neccesary to match the data – note that the contour lines have a negative slope. This can be rationalized by storms deepening the temporary mixed layer below the average mixed layer, causing mixing and transport of heat to lower waters. Thus if the model includes stochastic winds, it can achieve the same amount of total heat transport with a smaller K_z. The contour lines show that changing K_z has a much greater effect on the average difference than does changing the stochastic forcing. This makes sense – K_z is a major parameter for mixing in the model whereas the presence of stochastic or smooth winds is much less important and must affect the model from the surface downwards. Additionally, the slope of the contours changes at a stochastic forcing of 0.5. The solution with very low stochastic forcing is not very different from the case with smooth winds (contour lines are almost vertical). Thus, the stochastic nature has to reach a critical value of sorts before the episodic nature of the winds can change the solution much. Perhaps at very low stochastic forcing, there are not large enough storm events to have much of an effect on the total solution but once the storms become larger, then they can have much more of an effect – *i.e.*, there is a nonlinearity in the response of the solution to the size of the storms probably reflective of the nonlinearity in the relationship between mixing and wind stress.

The contour plot of the average square deviation shows some similar features – again changing

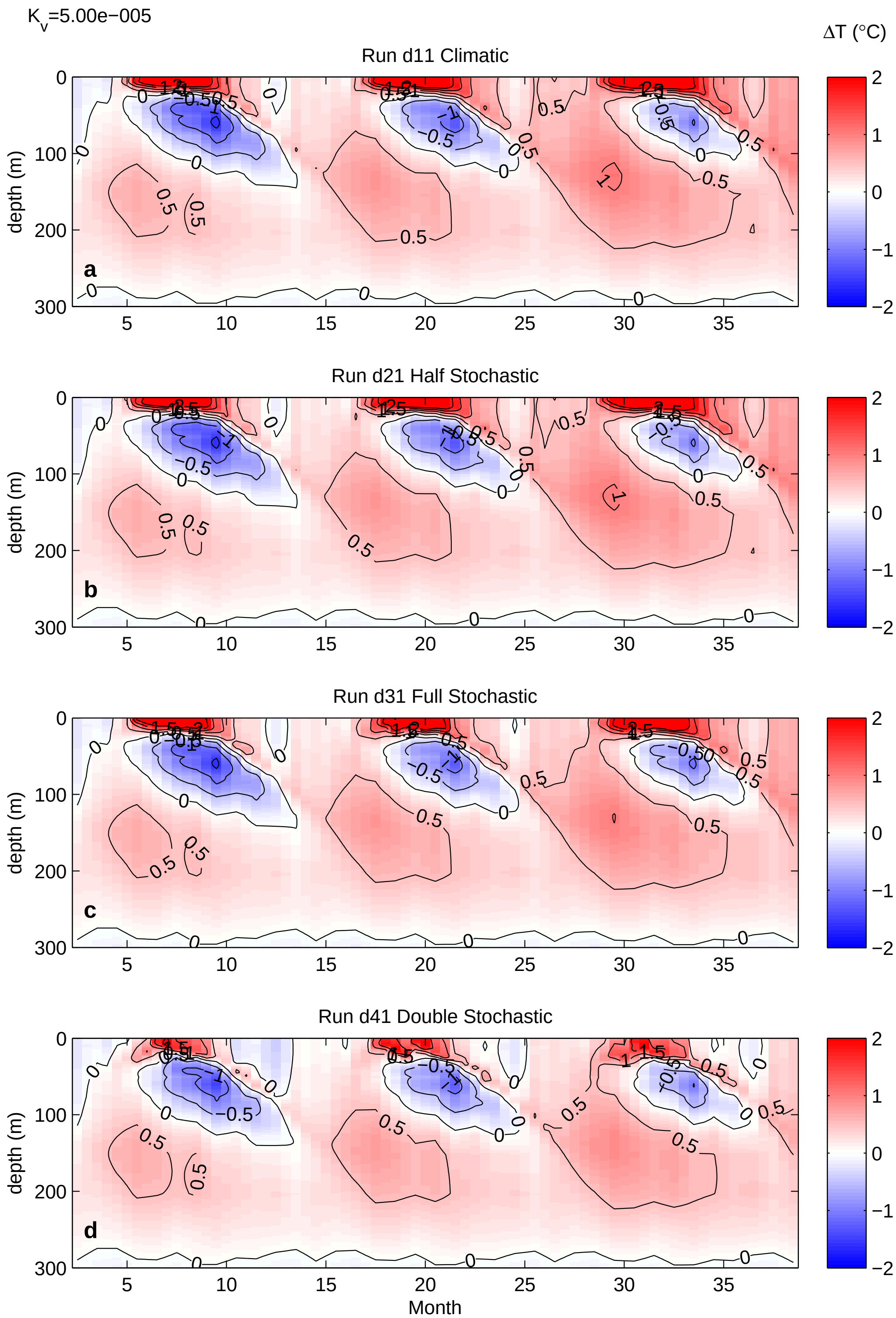

Figure 1: Comparison of the four stochastic runs for a diffusivity of $K_z = 0.50 \times 10^{-4}$ m^2 s^{-1}. a) Climatic winds; b) half stochastic winds; c) full stochastic winds; and d) double stochastic winds.

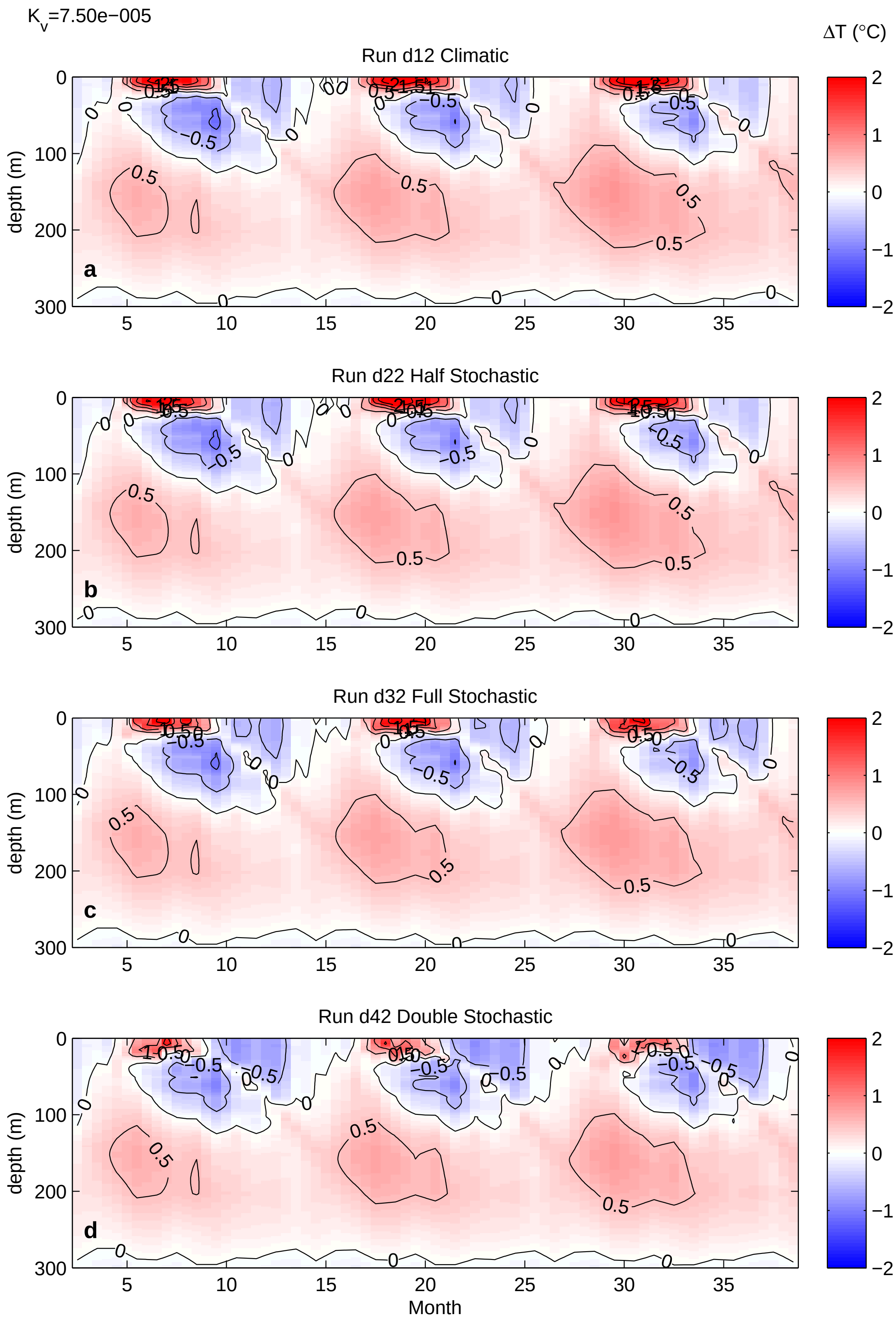

Figure 2: Comparison of the four stochastic runs for a diffusivity of $K_z = 0.75 \times 10^{-4}$ m^2 s^{-1}. a) Climatic winds; b) half stochastic winds; c) full stochastic winds; and d) double stochastic winds.

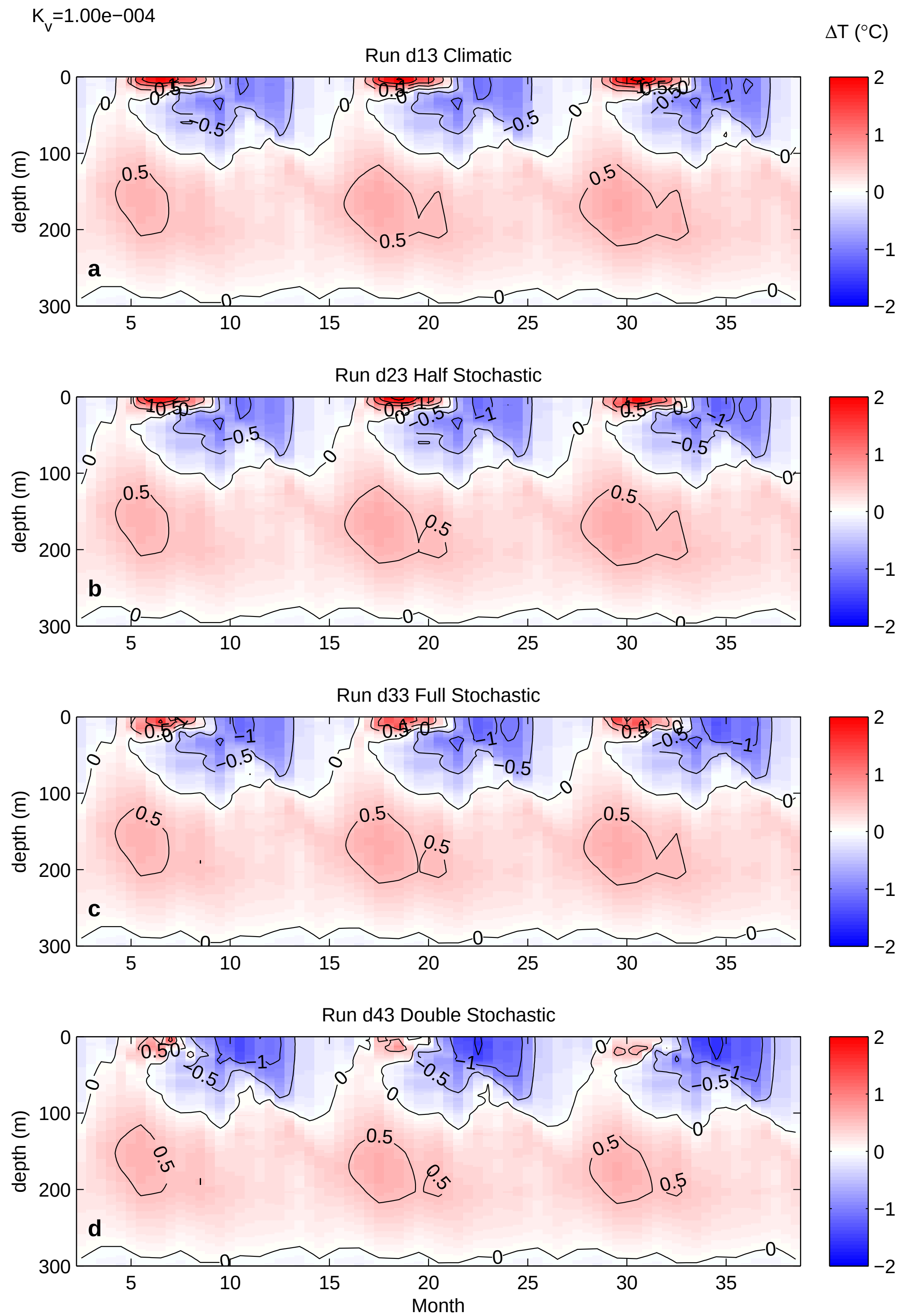

Figure 3: Comparison of the four stochastic runs for a diffusivity of $K_z = 1.00 \times 10^{-4}$ m^2 s^{-1}. a) Climatic winds; b) half stochastic winds; c) full stochastic winds; and d) double stochastic winds.

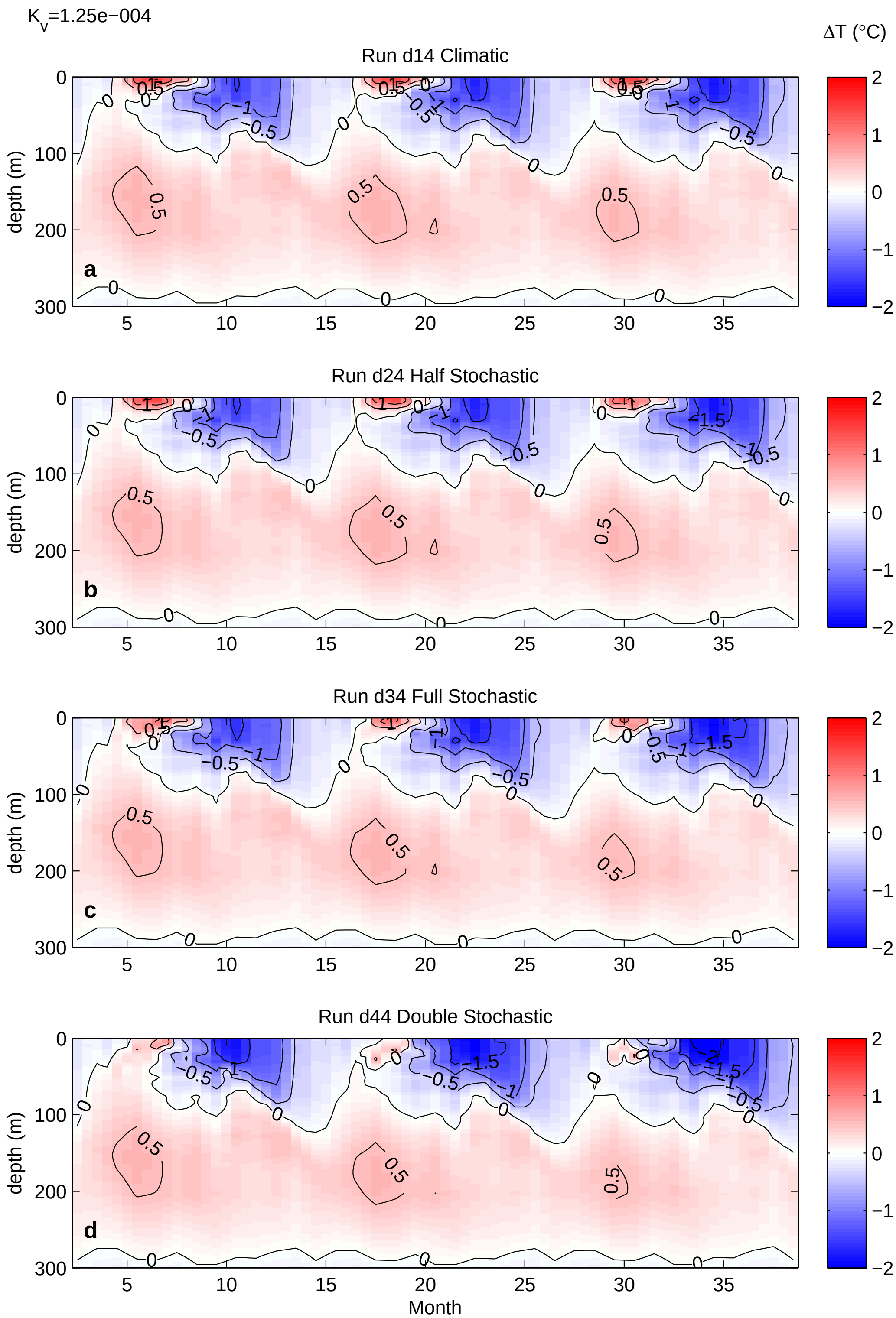

Figure 4: Comparison of the four stochastic runs for a diffusivity of $K_z = 1.25 \times 10^{-4}$ m^2 s^{-1}. a) Climatic winds; b) half stochastic winds; c) full stochastic winds; and d) double stochastic winds.

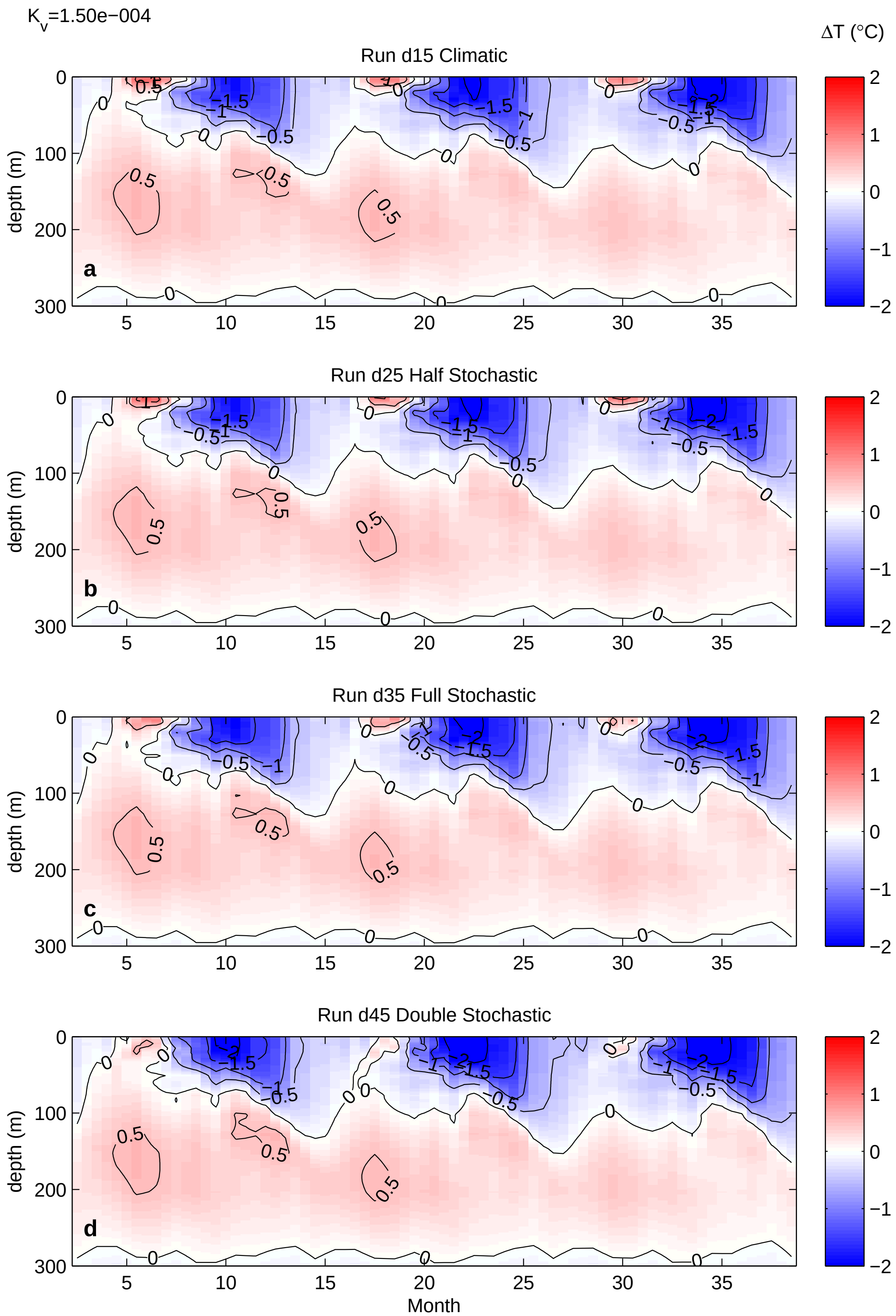

Figure 5: Comparison of the four stochastic runs for a diffusivity of $K_z = 1.50 \times 10^{-4}$ m^2 s^{-1}. a) Climatic winds; b) half stochastic winds; c) full stochastic winds; and d) double stochastic winds.

K_z has a greater effect than changing the stochastic forcing. And again, almost all the contour lines have a negative slope, suggesting that a higher stochastic forcing requires less of a K_z. In the plot of the average square deviation with smooth winds, the optimal K_z (1.0×10^{-4} m^2/s) is smaller than the optimal K_z in the plot of the average difference. In the plot of the average difference, a K_z of 1.4×10^{-4} m^2/s may look great but actually in some places the model may predict too high temperatures whereas in other places it may predict too low temperatures. For example the difference plots in Figure 5 suggest that the model predicts too warm a summer mixed layer and too cool an autumn/winter one. When calculating the average difference, these over and underpredictions cancel each other out and $K_z = 1.4 \times 10^{-4}$ looks like the best fit. But when calculating the average square deviation, they do not cancel each other out and thus a lower K_z seems better. The average square deviation plot shows that nowhere is there a perfect fit – the smallest value is 0.14, corresponding to a RMS offset of 0.2 °C. For the best fit, a stochastic forcing of 2.0 is necessary. It is not surprising to us that some stochastic forcing is necessary to obtain a good fit since mixing caused by storms might be somewhat localized in the mixed layer and upper thermocline whereas mixing caused by K_z is equally felt throughout the water column. Thus the types of mixing are different so one can't just adjust K_z to make up for perfectly smooth winds. It is a bit surprising that a forcing of greater than the variance of the climatological wind stress is needed to achieve the minium error. Perhaps this is because the response to storms is nonlinear – bigger storms have a much bigger effect than smaller ones. If one just included one variance worth of stochastic forcing, then one would not have as many truly big storms as what really occured (since the really big ones are outside one standard deviation). So to get some of the very big storms and thus a good fit between model and data, one needs to include around 2.0 times the variance of stochastic forcing.

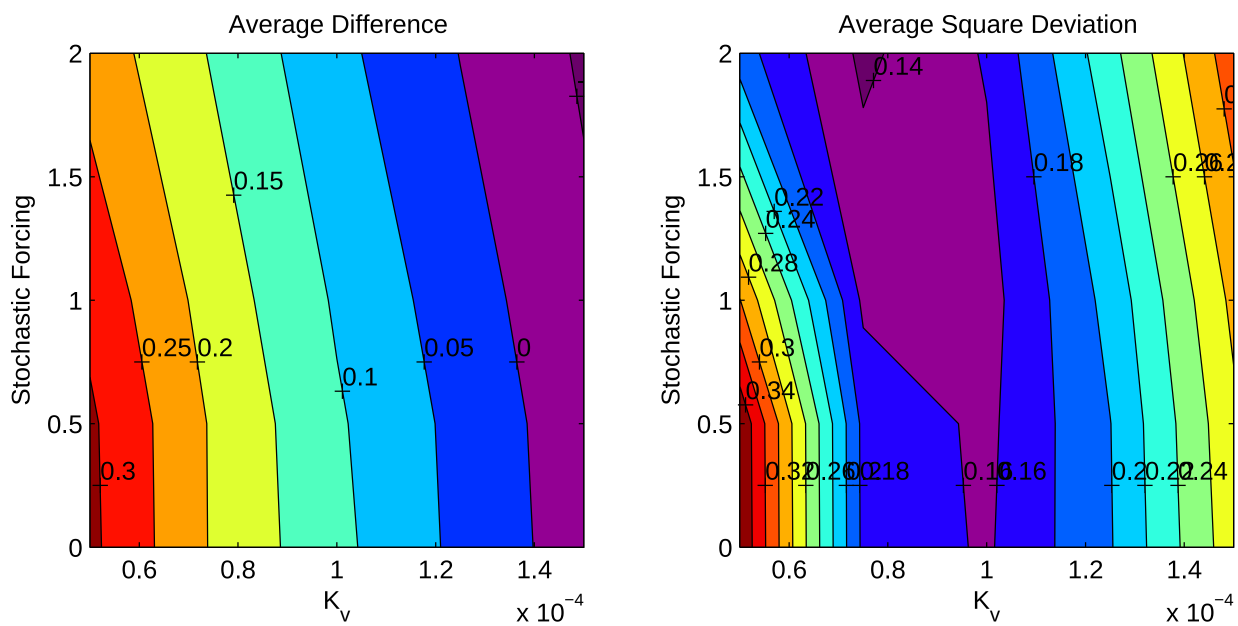

Figure 6: Plots of the average difference (on the left) and the average square difference (on the right) plotted against K_z and the stochastic forcing. The difference referred to is between the model runs and the climatology. These two figures summarize all 20 runs in two figures.