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A Comparison Between UARS and Operational Global Analyses

by

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Abstract

A comparison is made between the global (mostly tropospheric) analyses produced by the UARS and operational data assimilation systems during July and December of 1993, revealing substantial differences for dynamic precipitation and low cloud. Experiments suggest that, to a large extent, these are due directly to differences between the underlying model climatologies, the differing low cloud climatologies probably being due mainly to a timestep dependency. However, differences between the large amounts of spin-up displayed for these fields are also contributing to the analysis differences. Generally speaking, the moisture spin-up associated with the UARS system is worse than that associated with the operational system. In the light of these results, we consider current plans to develop a system for assimilating data into the climate configuration of the unified model.

Note: This report is also available to Met.Office personnel as a hypertext document containing links to graphics not included here. It's URL is //fr0600/~frca/public_html/UARS/UARS_tech.html.

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1. Introduction

In recent years, an interest has developed in using data assimilation systems for climate research. Systems designed for this purpose are called *climate data assimilation systems*. The future research plans of the Analysis and Assimilation Group identify a number of uses that might be found for a climate data assimilation system based on the climate configuration of the unified model. In particular, there are tentative plans at present to use such a system to reanalyse historical data (though perhaps only as correlative input to more extensive reanalysis projects elsewhere), and to perform climate model validation exercises (see Appendix 1). At present, it is possible to assimilate data into the climate model using standard programs. However, the characteristics of this system are not well-known, so if we decide to use it for a specific purpose, such as one of those mentioned above, we will need to assess its performance and decide what modifications are needed. A detailed study would involve running a number of extended assimilation experiments, and would inevitably consume a large amount of time and effort. We are fortunate, then, that, for some time now, the Middle Atmosphere Group of the Hadley Center has been running an assimilation system - the 'UARS' system (Swinbank (1993), Swinbank and O'Neill (1993)) - which in a number of key respects is identical to our current system (in particular, the horizontal resolutions are the same), thus providing a relatively cheap means of beginning an assessment.

In this technical report, we present a comparison between some of the analysed fields produced by the UARS and operational global assimilation systems during July and December of 1993. We hope that by identifying reasons for any differences, we will gain insights which will help us decide (a) which areas of the climate data assimilation work might be worth pursuing, and (b) what problems we are likely to encounter along the way. In addition we hope to point out some more general results concerning the two model configurations involved in the comparison. The plan is as follows. In section 2, we briefly introduce the UARS data assimilation system, explaining in particular how it differs from the operational system. In sections 3 and 4, we explain our choice of fields and our comparison methods. Our results are presented in section 5, where we also attempt to explain some of the differences we have noticed. Finally, in section 6, we summarise and offer some concluding remarks.

2. The UARS Data Assimilation System

The UARS data assimilation system was set up in September 1991, mainly to provide verifying analyses for the data gathered by the Upper-Air Research Satellite (hence 'UARS'). The principal difference between the UARS system and the operational global assimilation system is the configuration of the unified model (UM) into which the data is assimilated. Any other differences are minor by comparison; for example, both systems use the analysis-correction assimilation scheme and, as far as possible, the same observation processing programs.

The main concern of the Upper Atmosphere group is to provide stratospheric analyses, and therefore the UARS UM configuration has many more model levels in this region than the operational global model. However, in the troposphere the model levels are the same, and the only major differences are between the horizontal resolutions (the UARS system having climate resolution), the timesteps used (the UARS system having a 20-minute timestep), and the horizontal diffusion parameters; the physical parameterisations used are the same. For a more detailed list of differences, see Appendix 2.

To cut down on computer costs, the UARS system is run overnight, and with a modified assimilation cycle in which background fields for a complete 24-hour period are generated by a single run of the model. This has two minor consequences. Firstly, since the UARS system is run *after* the operational system, it is able to utilise some of the observations that arrived after the operational cut-off time. Secondly, the modified assimilation cycle can lead to differences between observation rejections during quality control.

Finally, there are minor differences between the observation types assimilated; the UARS system does *not* assimilate LASS temperature data or any bogus observations.

3. Choice of Fields

Given their central importance in climate studies, we chose to bias our comparison heavily towards moisture fields, and those fields that are directly related to them. Further, we chose to compare monthly mean fields to obtain statistically significant results and eliminate 'bullseyes'. The UARS fields were reconstructed from 12Z model dumps, which are archived daily. To cut down on computational costs, we limited our scope to fields which could be compared with counterparts in the operational archives.

To get some idea of seasonal dependencies, we chose to compare fields for a summer month, July 1993, and a winter month, December 1993. We ensured that during these periods the operational and UARS systems were running the same UM build. For both months, we chose to compare the following 12Z analyses:

- relative humidity (950,850,700,500,400,300hPa)
- temperature (950,850,700,500,400,300,250,200,150,100hPa)
- low cloud amount
- medium cloud amount
- high cloud amount
- convective cloud amount

and the following averages and accumulations

- net downward LW radiation flux at surface, averaged over values at 12, 15 and 18Z
- net downward SW radiation flux at surface, averaged over values at 12, 15 and 18Z
- 12Z-18Z accumulated evaporation
- 12Z-18Z accumulated dynamic rain
- 12Z-18Z accumulated convective rain
- 12Z-18Z accumulated dynamic snow
- 12Z-18Z accumulated convective snow

For December, we also chose to compare temperature analyses at 70, 50 and 30hPa (to examine their sensitivity to the choice of vertical levels near the top of the atmosphere). The STASH definitions for the UARS fields can be found in Appendix 3.

It should be noted that the UARS low, high and medium cloud fields actually have a validity time of 12:20Z, rather than 12Z, since it was necessary to run a physics timestep to retrieve them from the model dumps. The UARS averaged/accumulated fields were produced by running 6-hour forecasts from the analysis dumps. To retrieve the operational accumulated fields from the archive, it was necessary to subtract the 12Z analyzed fields, which are 6Z to 12Z accumulations, from the 18Z background fields, which are 6Z to 18Z accumulations. As a result, the operational accumulations correspond essentially to *forecast* periods, and are therefore comparable with the UARS accumulations.

4. Comparison Methods

Having obtained the relevant UARS and operational fields, we proceeded as follows. First of all, to save on memory usage and ensure compatibility between the two sets of fields, we 'interpolated' the operational fields onto a climate resolution grid using the PP-package program 'INTERP', which performs bilinear interpolation. This re-gridding process does, of course, smooth the fields to some extent, but, more importantly, it can alter their average values in a biased way. By comparing averages before and after this process, we concluded that in most cases they were not significantly altered. However, for fields where there is a large degree of variation over small distances, the differences can be significant. For example, we noted that a re-gridding of the dynamic rain fields can lead to a reduction in the area-weighted global mean of as much as 9%, though on average the reduction is much less.

Having produced these climate resolution fields, we transferred them to the FR HP system and used them to create monthly means by summing and dividing by 31. If we had re-gridded the operational fields *after* we had created the monthly means, we would have ended up with different results. However, a test confirmed that the differences would have been very small.

5. Results and Analysis

In this section, we present the main results of our comparison and try to explain some of the differences we have noticed. Because they are so closely related to the cloud fields, we have chosen not to include here a discussion of the radiation and relative humidity fields. Readers who would like to study these should refer to Appendix 4.

5.1 Precipitation and Evaporation

The development of climate data assimilation systems should provide us with a means of obtaining improved estimates of the atmospheric components of the hydrological cycle. In particular, the dynamical coupling between model components ensures a spread of information from relatively well observed quantities, such as surface pressure, to poorly observed or non-assimilated quantities like precipitation rates. However, for a data assimilation system to be of any use in this regard it is vital that (a) the underlying numerical model has a good representation of hydrological processes, and (b) that there is no major spin-up (or spin-down) associated with the moisture fields.

Spin-up (spin-down) is a systematic negative (positive) bias, with respect to model forecast fields, introduced by the process of data assimilation. Spin-up in the hydrological cycle is a common problem which can degrade significantly the quality of a forecast in the hours following the analysis, as the model adjusts back towards a balanced state (ie. towards its attractor). The spin-up of precipitation and evaporation in the operational global forecast system from January 1992 to May 1994 has been documented by Milton and Van der Wal (1994). They note that, throughout this period, there has been a marked spin-up of precipitation, particularly its dynamic component. As a result, average daily values of evaporation during assimilation are significantly greater than those for precipitation - quantities that in the real atmosphere are, of course, very close.

We can make a preliminary assessment of the amount of moisture spin-up in the UARS system by comparing the monthly average 12Z-18Z accumulations of precipitation and evaporation (which we recall correspond to forecast periods immediately following analyses) with those of the operational system, whose spin-up characteristics are well known. The average accumulations are as follows:

		Operational system	UARS system
JULY 93	Total ppt.	0.660 kg/m^2	0.565 kg/m^2
	Total evap.	0.740 kg/m^2	0.699 kg/m^2
DECEMBER 93	Total ppt.	0.645 kg/m^2	0.548 kg/m^2
	Total evap.	0.682 kg/m^2	0.631 kg/m^2

The spin-up of precipitation in the UARS system is thus likely to be far worse. We will return to this problem throughout the remainder of this section.

We have compared four separate components of the total precipitation field; the 12Z to 18Z accumulations of dynamic rain, dynamic snow, convective rain and convective snow. Recall that our re-gridding of the operational fields onto a climate grid has reduced the global averages by a small fraction. The outstanding difference here is a relative lack of dynamic precipitation in the UARS fields. For example, figure 1 shows the operational and UARS dynamic rain fields for July 1993. From the area-weighted global averages, we see that there is approximately 60% more dynamic rain in the operational fields. For December, the difference is slightly less: 50%. The differences for dynamic snow are less pronounced, but still substantial - the operational accumulations being approximately 35% greater for July, and 20% greater for December. Presumably, the differences for dynamic snow and dynamic rain are related, so we will concentrate on the latter. A priori, the differences between the dynamic rain fields may be due to (a) differences between the observations assimilated, (b) differing model characteristics (eg. climatologies, transient responses, etc.), (c) the differing assimilation algorithms (which are dependent, for example, on the underlying model resolutions and timesteps), or to some combination of the three. As we noted above, the UARS system assimilates the same observations as the operational system except (i) it does not utilise bogus data, (ii) it has a later data cut-off time, (iii) there are differences due to quality control, and (iv) it does not utilise LASS data. Neither of these is likely to be a major factor - the first three are unlikely to produce the large systematic differences we are looking for, and LASS data only influences an area local to the UK, whereas the differences we see are clearly of a global nature. We deduce, therefore, that the differences we see are due mainly to a combination of factors (b) and (c) (whose relative contributions, incidentally, are in general rather difficult to disentangle).

To analyse matters further we examined, in both systems, the evolution of dynamic rain averages in the forecast periods following analyses. Our aim here was (a) to estimate the likelihood of there being different climatological values for this quantity, and (b) to study the spin-up characteristics for each system. To eliminate natural variability on short timescales, we averaged results from a series of runs. For the UARS system, we ran 7 150-hour forecasts running from the analyses for 12Z on 1st, 6th, 11th, 16th, 21st, 26th and 31st of December 1993. Figure 2 shows the evolution of dynamic rain rate averages for a number of different domains. We see that there is a high degree of spin-up for all domains, the global average increasing by approximately 40% in the first 4 hours, and by 70% by the end of the run.

The spin-up of dynamic rain in the operational system during the same period can be determined to some extent from data stored in the operational archives. The dynamic rainfall rates averaged over the whole globe, all the forecasts running from 12Z analyses during December 93, and the specified time intervals are as follows:

T-6 to T+0:	6.04e-6 mm/s
T+0 to T+6:	6.23e-6 mm/s
T+6 to T+12:	6.66e-6 mm/s
T+12 to T+24:	7.27e-6 mm/s
T+24 to T+48:	7.51e-6 mm/s
T+48 to T+72:	7.71e-6 mm/s

Unfortunately, these figures don't tell us a great deal about the evolution of dynamic rain averages *immediately* after the analysis. For comparison, we have estimated from our graph the corresponding figures for the UARS system:

T-6 to T+0:	not available
T+0 to T+6:	4.3e-6 mm/s
T+6 to T+12:	4.6e-6 mm/s
T+12 to T+24:	4.9e-6 mm/s
T+24 to T+48:	5.2e-6 mm/s
T+48 to T+72:	5.3e-6 mm/s

(T+150: 6.0e-06 mm/s)

Both systems thus display a high degree of spin-up in dynamic rain. However, it seems likely that there is also a substantial difference between the climatological values of dynamic rain in the two systems.

Following this observation, we investigated some possible reasons for the different climatologies. First, we tested the sensitivity of dynamic rainfall to a change in the UARS horizontal diffusion parameters. At present, the UARS parameters are K=.800E+09 and N=3 (for use in the expression $K.\nabla^{2N}$). Following an investigation by Hall and Stratton (1994), however, it has become standard to choose a smaller value for K, namely .436E+09. Thus we ran two forecasts from the UARS analysis for 12Z on 1/12/93; one with the standard UARS configuration, and a second with K equal to .436E+09. Figure 3(a) shows the evolution of the dynamic rain differences between the two runs. We see that the change generally leads to an increase in dynamic rain rates of around 0.5e-6 mm/s.

In the same way, we studied the sensitivity of dynamic rainfall to a change in the UARS timestep from 20 minutes to 10 minutes (as in the operational system). The evolution of the dynamic rain differences between the two runs is shown in figure 3(b). We see an increase in dynamic rain rates of around 0.3e-6 mm/s (which is in accordance with the results reported by Stratton (1994, especially fig.11(d)) on sensitivity to timestep in the climate model). Both of our changes, then, lead to an increase in dynamic rain averages, but it is unlikely that together they account for all the major differences between the two climatologies. It may be, for example, that the differing model resolutions are also playing a part.

We turn now to the convective components of precipitation. For convective snow, there is approximately 17% more in the UARS fields in December but 7% less in July; we won't analyse this further however. The convective rain averages are as follows:

	Operational system	UARS system
JULY 93	0.480 mm	0.448 mm
DECEMBER 93	0.457 mm	0.411 mm

We see that there is approximately 10% more in the operational system for both months. As with dynamic rain, there is some spin-up of convective rain in the operational system (see Milton and Van der Wal (1994)), but not to the same degree. The convective rainfall rates averaged over the whole globe, all the forecasts running from 12Z analyses during December 93, and the specified time intervals are as follows:

T-6 to T+0:	1.89e-5 mm/s
T+0 to T+6:	2.15e-5 mm/s
T+6 to T+12:	1.93e-5 mm/s
T+12 to T+24:	1.90e-5 mm/s
T+24 to T+48:	2.01e-5 mm/s
T+48 to T+72:	2.07e-5 mm/s

The corresponding results for the UARS system, estimated from the seven December forecast runs we referred to earlier, are as follows:

T-6 to T+0:	not available
T+0 to T+6:	1.87e-5 mm/s
T+6 to T+12:	1.79e-5 mm/s
T+12 to T+24:	1.78e-5 mm/s
T+24 to T+48:	1.95e-5 mm/s
T+48 to T+72:	1.99e-5 mm/s

The thing to note here, is that in the relevant period (T+0 to T+6), there is substantially more convective rain in the operational system than in the UARS system, but that the differences are much smaller for the last two periods. It seems, then, that the differences we see in our accumulations are due mainly to differing spin-up characteristics.

Finally, we remark that the evaporation fields are broadly similar (the globally averaged accumulations were given earlier in this section) and show a small degree of spin-up in both systems. However, this spin-up is much smaller than that associated with the precipitation fields, and is due mainly to the spin-up of cloud which is commented on in the next section.

5.2 Cloud

The study of cloud processes and feedbacks is one of the most important areas of climate research, so any deficiencies in the cloud analyses produced by climate data assimilation systems need to be well understood. Comparing those produced by the operational and UARS systems, we note that by far the most significant difference is the disparity between monthly mean low cloud averages (see figure 4). In particular, the UARS analysis has much less low cloud west of South America, Southern Africa and Australia. Looking at a breakdown of the averages (figure 5), we see a 40% difference in low cloud amounts over the sea as a whole. Surprisingly, over the land, the UARS analysis has as much low cloud in July, and *more* in December.

To enable us to estimate how much of these differences are due to spin-up, and how much directly to the model climatologies, we ran a 150 hour forecast with the operational configuration of the UM from the operational analysis for 12Z on 1/12/93. The evolution of low cloud averages for this run, together with results from a corresponding UARS forecast run, are shown in figure 6. The difference between low cloud amounts over southern sea points is clearly substantial throughout the runs. However, the initially large difference for this domain is approximately halved by the end of the run. Further investigation reveals that the increased difference at the start of the run is due to an especially large degree of spin-up over this domain in the UARS system (as can be seen from figure 7, which shows the evolution of low cloud averages averaged over the seven December runs previously mentioned). We also note, however, that by the end of the run, the UARS forecast still has less low cloud over the sea but more over land. It seems likely, then, that a large component of the differences we see between the low cloud analyses is due directly to the differing model climatologies. However, there is also a contribution from the differing spin-up characteristics.

To try and find reasons for the different climatologies, we examined the low cloud results from the two UARS sensitivity experiments we mentioned in the previous section. Looking at a difference graph (figure 8(a)), we see that reducing horizontal diffusion tends to increase low cloud amounts, but by a similar amount over all our chosen domains. The results from the 10 minute timestep run are much more encouraging. This time, the difference graph (figure 8(b)), shows a substantial increase in low cloud over sea points, and a decrease over land points by the end of the run, which is just the signal we were looking for. Moreover, the change also brings the other cloud fields more into line with what is produced by the operational system. It seems likely, then, that the different climatologies of low cloud are due mainly to the different choices of timestep. For comparison, it is worth noting that reducing the timestep from 30 minutes to 10 minutes in the standard version of the climate model (see Stratton (1994)) tends also to reduce low cloud amounts over the land, but the increase over the sea is not nearly as well marked as it is here. Similarly, a recent increase in physics timestep for the operational global model has not produced the large low cloud changes seen here.

Compared with the major differences we see between the low cloud analyses, the medium cloud averages differ very little, the only significant differences occurring near the Andes in December, where there is more cloud in the UARS analysis. Presumably this is due to differences between orographic forcing in this region.

Between the high cloud averages, there are more substantial differences, but again they are not nearly as well marked as those we see for low cloud. Again, there is more cloud in the UARS analysis near the Andes, this time in both months. There are also significant differences over the tropics. However, these can be attributed mainly to differing degrees of convection, and hence upward moisture transport. For example, Figure 9 shows the July 1993 operational minus UARS fields for high cloud and accumulated convective rain. Over the tropics, wherever there is more (less) high cloud in the operational field, we generally see more (less) convective rain, and vice versa.

Finally, we turn to the convective cloud averages. As with low cloud, there is more convective cloud over the sea in the operational analysis, but less over land (see figure 10). However, the differences aren't as well marked. In this case, our spin-up experiments do not establish conclusively a difference between the model climatologies.

5.3 Temperature

Most of the differences between the UARS and operational temperature analyses can be attributed either to differing boundary effects (caused by differing orographies, surface characteristics, and so on), or to differences between the cloud analyses. For example, Figures 11 and 13 show the operational minus UARS analyses of 12Z temperature at respectively 950 and 700hPa, averaged for July 1993. Clearly, differences over the land are greater in the former, and occur in the latter mainly near mountainous regions, such as the Himalayas and the Andes. On the other hand, differences over the sea in the 950hPa analyses are strongly correlated with the low cloud differences (figure 12) - where there is more low cloud in the operational analysis, the temperature tends to be lower.

Generally speaking, as we go higher in the atmosphere, temperature differences decrease as the influence of the lower boundaries decreases. However, as we approach the top layers of the atmosphere, we begin to see the influence of the different model layer densities. Figures 14-16 show the differences between the mean 12Z temperature analyses at 70, 50 and 30hPa for December 93 (note that the corresponding fields for July were *not* retrieved). At all three levels, we see clear systematic differences of around 2-3K. At 50 and 30hPa, the operational analysis is cooler almost everywhere. However, at 70hPa the operational analysis is clearly warmer in the tropics but colder elsewhere. If you would like to study the temperature analyses further, please refer to Appendix 4.

6. Summary and Concluding Remarks

Our comparison between UARS and operational analyses has revealed a number of systematic differences. In particular, the UARS analyses have much less dynamic precipitation and low cloud. Experiments suggest that, to a large extent, these latter differences are due directly to differences between the underlying model climatologies, the differing low cloud climatologies probably being due mainly to a timestep dependency. However, differences between the large degrees of spin-up displayed for these fields are also contributing to the analysis differences. On the whole, moisture spin-up is more pronounced in the UARS system.

The presence of appreciable degrees of spin-up in a data assimilation system is always a cause for concern as it is indicative of either (a) observational or model biases, or (b) a less than satisfactory assimilation scheme. In NWP systems, spin-up, whilst being undesirable, is not necessarily a great problem, as we may be interested only in the quality of forecasts some time after the analysis, where the effects of spin-up might not be as evident. However, the primary purpose of climate data assimilation systems is to produce good *analyses*, so it is vital that any spin-up they display is eradicated as far as possible. At the start of section 5.1, we stated that the development of climate data assimilation systems should eventually lead to improved estimates of the atmospheric components of the hydrological cycle, such as rainfall rates, cloud fractions, and so on. The basis of this statement is the dynamical coupling between different quantities in the atmosphere - for example, the pressure field provides information about the cloud field. A climate data assimilation system that has a good representation of atmospheric processes, and is able to spread observational information correctly, should therefore be capable of producing field estimates that are better than those that could be obtained from the climatology of the underlying model, particularly for quantities that are not directly observed or assimilated. In designing a system for this purpose, however, particular care must be taken to ensure that data assimilation never has a bad influence on any of the fields we are interesting in estimating. In particular, large degrees of spin-up must be eradicated. Where it remains, we must be sure that it indicates an improvement over model estimates.

Clearly, because of the large amounts of spin-up in the operational and UARS data assimilation systems during July and December of 1993, we could have little confidence that the moisture analyses they produced during these periods are good estimates of reality. Indeed, the monthly climatologies obtained from operational *forecasts* during these periods are closer to the Jeager climatology than those based on the operational *analyses* (see Milton and Van der Wal (1994), figure 3(a)). Recently, an effort has been made to reduce spin-up in the operational forecasting system by correcting suspected observation biases and making changes to some of the assimilation algorithms (Bell (1994a), Bell (1994b)). The results of this work have so far been very encouraging, spin-up having been reduced substantially. We would expect, therefore, that the currently available data assimilation system based on the climate configuration of the unified model is much better than the UARS system was in the periods we studied. Not only does it use improved assimilation algorithms, but it is also likely to have a better underlying numerical model.

We end with two points. First, it would seem to be a good idea to change the diffusion parameters in the UARS system (which has recently become operational) so that they are in accordance with those used in standard climate runs. As well as bringing the system into line with other climate work, the change should also have a beneficial impact on at least the tropospheric analyses (see Hall and Stratton (1994)). Finally, we note that the development of an assimilation system based on the climate model would provide an important tool not only for studies of atmospheric phenomena, but also for validation of the model itself.

Appendix 1: Climate Data Assimilation

The aim of modern data assimilation systems is to combine, in an optimal way, a heterogeneous set of observations, distributed irregularly in space and time, with prior information, and the dynamical knowledge encompassed by a numerical model, to produce a complete and consistent estimate of the atmosphere's state. At present, most data assimilation systems are designed for use within NWP to provide initial conditions for a forecast model. However, in recent years, an interest has developed in their wider use for studies of climate (see, for example, the 1991 report of the National Research Council). Systems designed for this purpose are called *climate data assimilation systems.* In this appendix, we present a brief discussion of two important applications; reanalysis, and climate model validation.

Reanalysis

Much of our current understanding of dynamical and physical processes in the atmosphere is based on the analyses produced daily at NWP centers, and archived to create general circulation datasets. However, since data assimilation systems are constantly being improved, there are benefits to be gained by *reanalysing* historical data using more modern systems. Additionally, by reanalysing long periods of data using a *fixed* assimilation system, we can remove the temporal inhomogeneities caused by upgrades to the operational system, thus creating datasets that are more appropriate for studies of long-term climate variability (see, for example, Bengtsson and Shukla (1988)). To cut down on computational costs, systems designed for this purpose are usually based on low resolution climate models.

An extensive reanalysis project is already well in progress at NASA's Goddard Space Flight Centre (Schubert et al (1993)), and similar projects are in their early stages at NMC and ECMWF. Whilst the Met.Office has no immediate plans to duplicate this work using a system of its own, there may be some value in producing a few month's data as a validation exercise.

Climate Model Validation

Precise validation of a climate model field, such as cloud cover, requires a long model run, and a long period of data, in order to reduce differences due to the atmosphere's natural variability. However, one can get around this problem to some extent by carefully assimilating data into the model during the run. For example, by assimilating observations of the primary model variables (such as pressure, temperature, and wind), one can restrain the model's flow pattern to closely match that of the atmosphere's. Variables which are generated within the model, rather than being assimilated directly, can then be validated against independent observations. Because the model and the atmosphere follow almost the same synoptic evolution, variability does not significantly affect the validation, and significant results can be obtained with only a few weeks of data. Because some model fields are constrained to fit the data, only the model components which generate the diagnosed variables are validated, rather than the entire model. By changing the observations used, we can focus on different model components: the example above would validate the entire moisture budget, while additionally assimilating humidity data focuses on the cloud and rainfall processes.

Appendix 2: Differences Between the Operational and UARS UM Configurations

1. Horizontal resolution

Op: 288*217, UARS: 96*73

2. Vertical levels

Operational:

19 levels. Sigma coords for first 5 half-levels, pressure coords starting at half-level 17.

HALF-LEVEL	ETA VALUE
1	===> 1.00000
2	===> 0.994000
3	===> 0.956000
4	===> 0.905000
5	===> 0.835000
6	===> 0.750000
7	===> 0.650000
8	===> 0.550000
9	===> 0.460000
10	===> 0.385000
11	===> 0.325000
12	===> 0.275000
13	===> 0.225000
14	===> 0.175000
15	===> 0.125000
16	===> 0.750000E-01
17	===> 0.400000E-01
18	===> 0.200000E-01
19	===> 0.100000E-01
20	===> 0.500000E-03

UARS:

42 levels. Sigma coords for first 5 half-levels, pressure coords starting at half-level 20.

HALF-LEVEL	ETA VALUE
1	===> 1.00000
2	===> 0.994000
3	===> 0.956000
4	===> 0.905000
5	===> 0.835000
6	===> 0.750000
7	===> 0.650000
8	===> 0.550000
9	===> 0.460000
10	===> 0.385000
11	===> 0.325000
12	===> 0.275000
13	===> 0.235000
14	===> 0.196000
15	===> 0.157000
16	===> 0.125500
17	===> 0.100000
18	===> 0.794328E-01
19	===> 0.630957E-01
20	===> 0.501187E-01

21	===> 0.398107E-01
22	===> 0.316228E-01
23	===> 0.251189E-01
24	===> 0.199526E-01
25	===> 0.158489E-01
28	===> 0.794328E-02
29	===> 0.630957E-02
30	===> 0.501187E-02
31	===> 0.398107E-02
32	===> 0.316228E-02
33	===> 0.251189E-02
34	===> 0.199526E-02
35	===> 0.158489E-02
36	===> 0.125893E-02
37	===> 0.100000E-02
38	===> 0.794328E-03
39	===> 0.630957E-03
40	===> 0.501187E-03
41	===> 0.398107E-03
42	===> 0.316228E-03
43	===> 0.251189E-03

3. Vertical Diffusion

Operational: Vertical diffusion included from level 8 to level 14.
Reference coefficient: 0.10E+03

UARS: Vertical diffusion included from level 10 to level 42.
Reference coefficient: 0.10E+07

4. Horizontal Diffusion

Coefficients and exponents for use in the diffusion operator $K.\nabla^{2N}$ for u, v, Θ and humidity:

Operational: K=0.4E+08, N=2

UARS: K=0.8E+09, N=3

Note: top two levels ignored here.

5. Divergence Damping Coefficients for Assimilation

Operational: 0.10E+07
UARS: 0.30E+07.

Appendix 3: STASH Definitions of Fields

Diagnostic	Time Domain
RELATIVE HUMIDITY ON PRESSURE LEVELS	TIMM
TEMPERATURE ON PRESSURE LEVELS	TIMM
LOW CLOUD AMOUNT	TIMMCL
MEDIUM CLOUD AMOUNT	TIMMCL
HIGH CLOUD AMOUNT	TIMMCL
CONVECTIVE CLOUD AMOUNT	TIMM
NET DOWN SURFACE LW RAD FLUX	TRAD
NET DOWN SURFACE SW FLUX: SW TS ONLY	TRAD
TOTAL SURFACE MOIST FLUX PER TIMESTEP	TPPEV
LARGE SCALE RAIN AMOUNT KG/M2/TS	TPPEV
CONVECTIVE RAIN AMOUNT KG/M2/TS	TPPEV
LARGE SCALE SNOW AMOUNT KG/M2/TS	TPPEV
CONVECTIVE SNOW AMOUNT KG/M2/TS	TPPEV

Time Domains

TIMM
Single time field.
Output at regular intervals:
STARTING 0 ENDING 0 FREQUENCY 1 UNITS H

TIMMCL
Single time field.
Output at regular intervals:
STARTING 1 ENDING 1 FREQUENCY 1 UNITS T

TRAD
Time mean: Meaning interval 6H
Values every 3H.
Output at regular intervals:
STARTING 0 ENDING 6 FREQUENCY 6 UNITS H

TPPEV
Accumulation: Accumulating interval 1T
Accumulating every 1T
Output at regular intervals:
STARTING 0 ENDING 1 FREQUENCY 6 UNITS H

Appendix 4: Location of Data

The pp-files containing the monthly mean UARS and operational analyses, and the mean difference and standard deviation of difference fields, are stored on the FR HP system in the directory /data/string06/longterm/frca/UARS. The contents of each file should be clear from the filename.

The daily pp-files taken or reconstructed from the UARS model dumps are stored on cartridge number 015441 as IBM datasets. The dataset names are of the form MS12.CAUARSPP.DDDMMYY, where DDMMYY is the relevant date.

Also available is a PV-Wave program which was written to help us view the monthly mean fields. It is called 'lookat', and is on the FR HP system in file /users/string06/frca/wave/progs/lookat.pro. The instructions for use are included at the beginning of the file. If you need any help with it, please don't hesitate to contact me.

Acknowledgements

We would like to thank Richard Swinbank, Darren Podd, and Penny Connew of the Middle Atmosphere Group, and Anette Van der Wal (Unified Model Development) for their help during this work. Thanks also go to Stuart Bell and Andrew Lorenc of the Analysis and Assimilation Group for guidance throughout the project.

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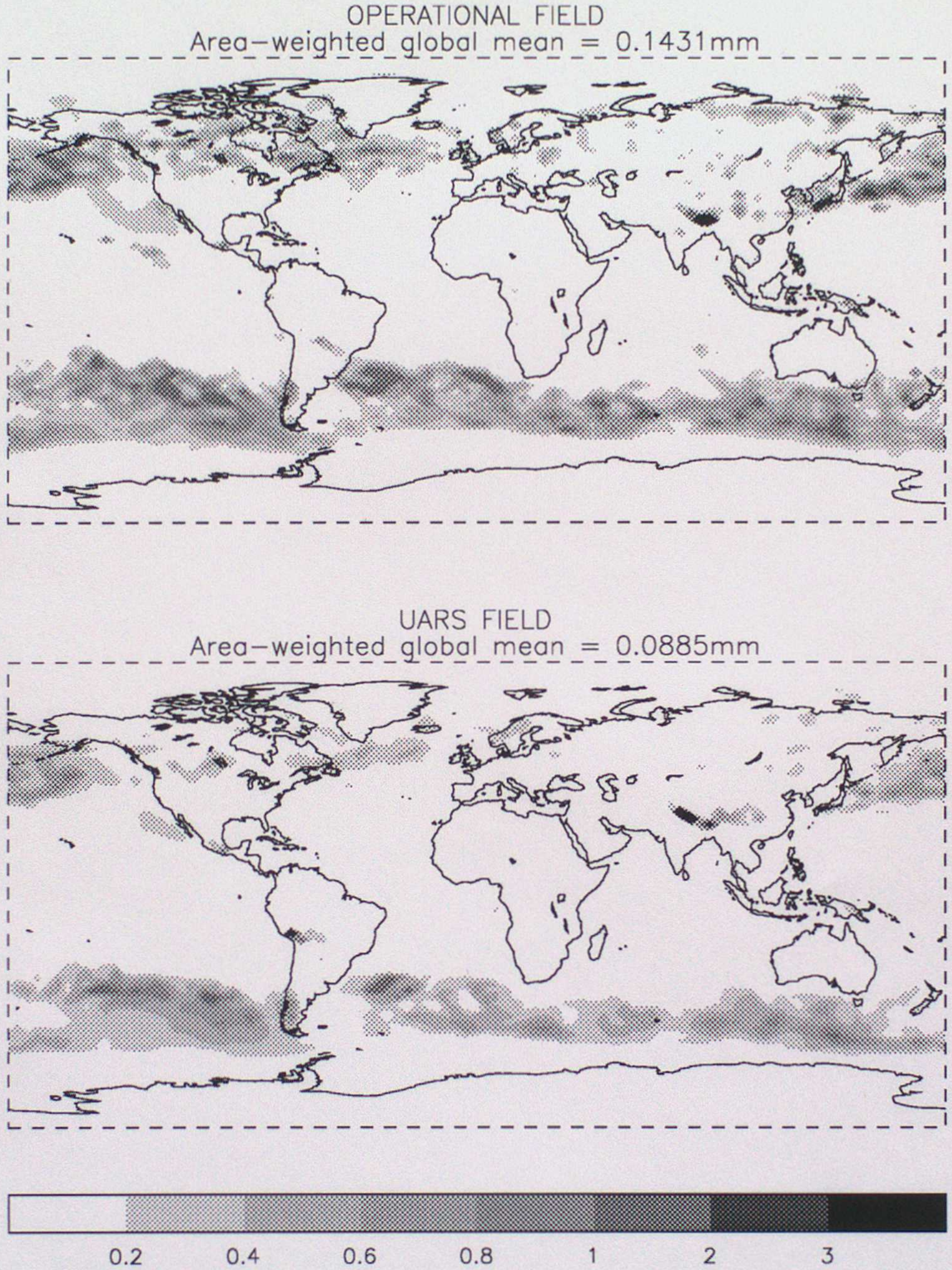


Figure 1: Operational and UARS 12Z-18Z accumulated dynamic rain averages for July 1993. Units: mm (= kg/m^2).

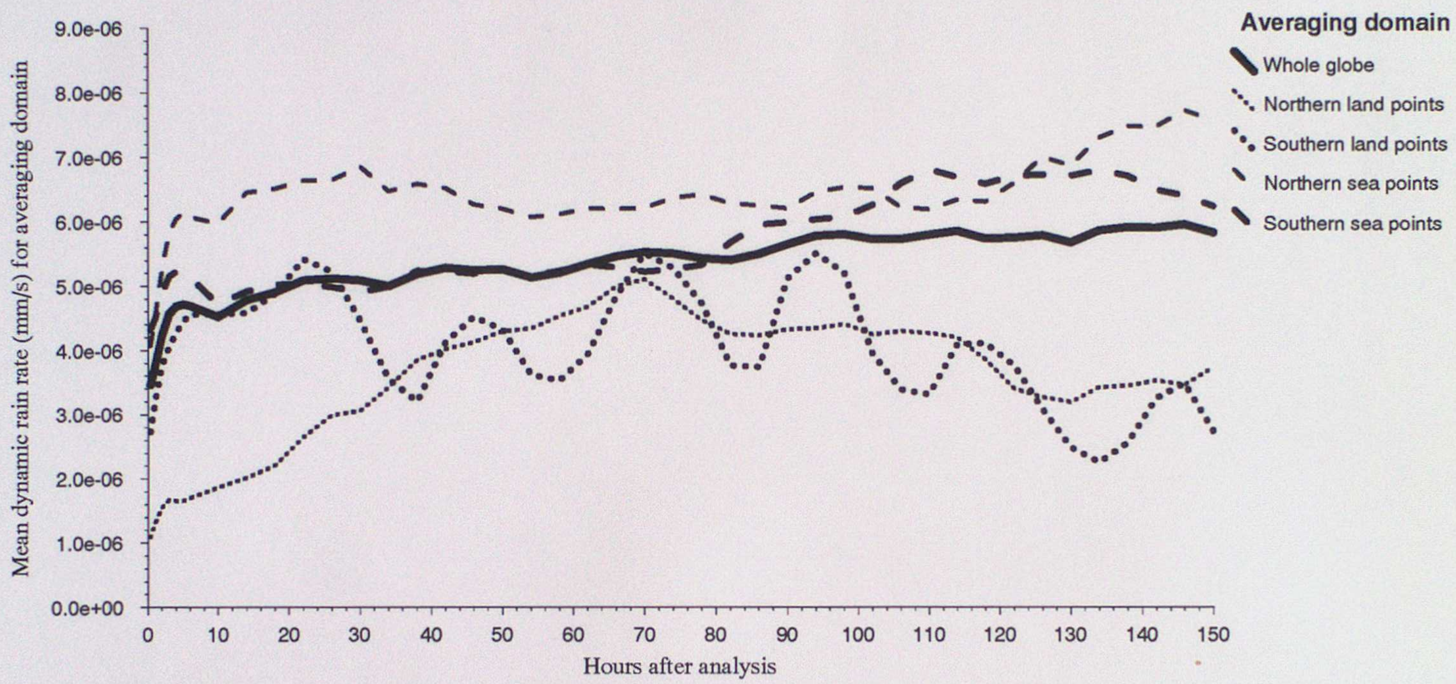
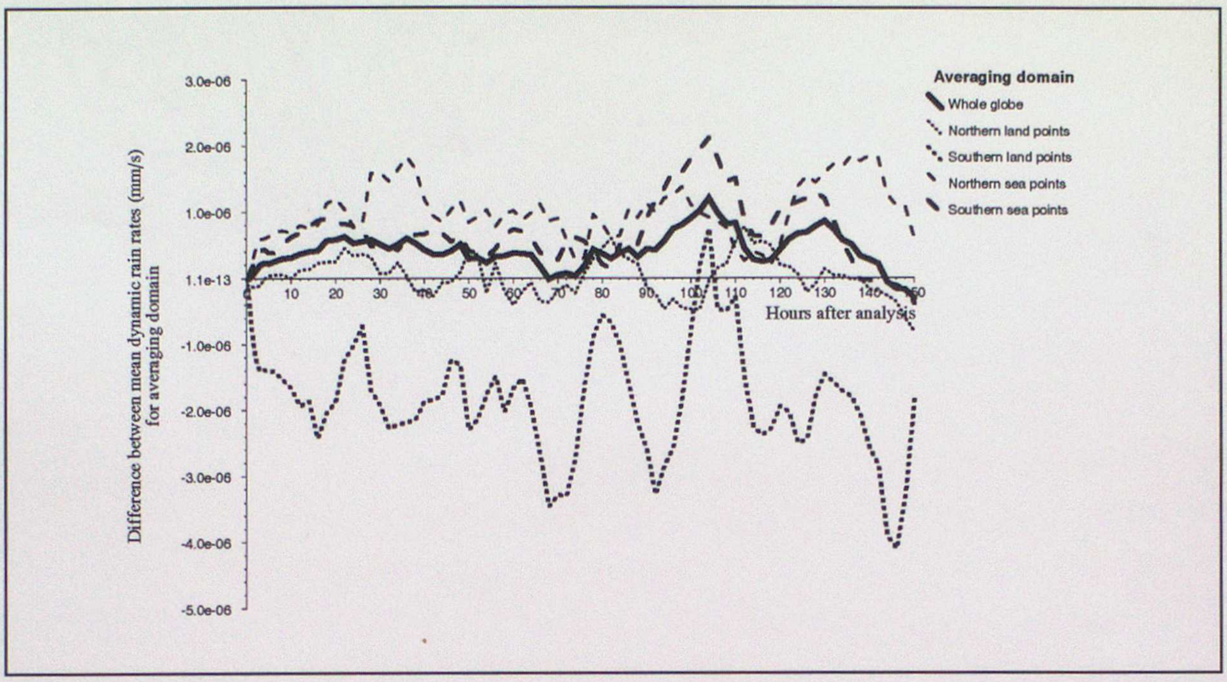


Figure 2: The evolution of UARS dynamic rain rate averages in the hours following the analysis. Results obtained by averaging over 7 forcast runs. Analyses valid at 12Z on 1st, 6th, 11th, 16th, 21st, 26th and 31st December 1993.

(a)



(b)

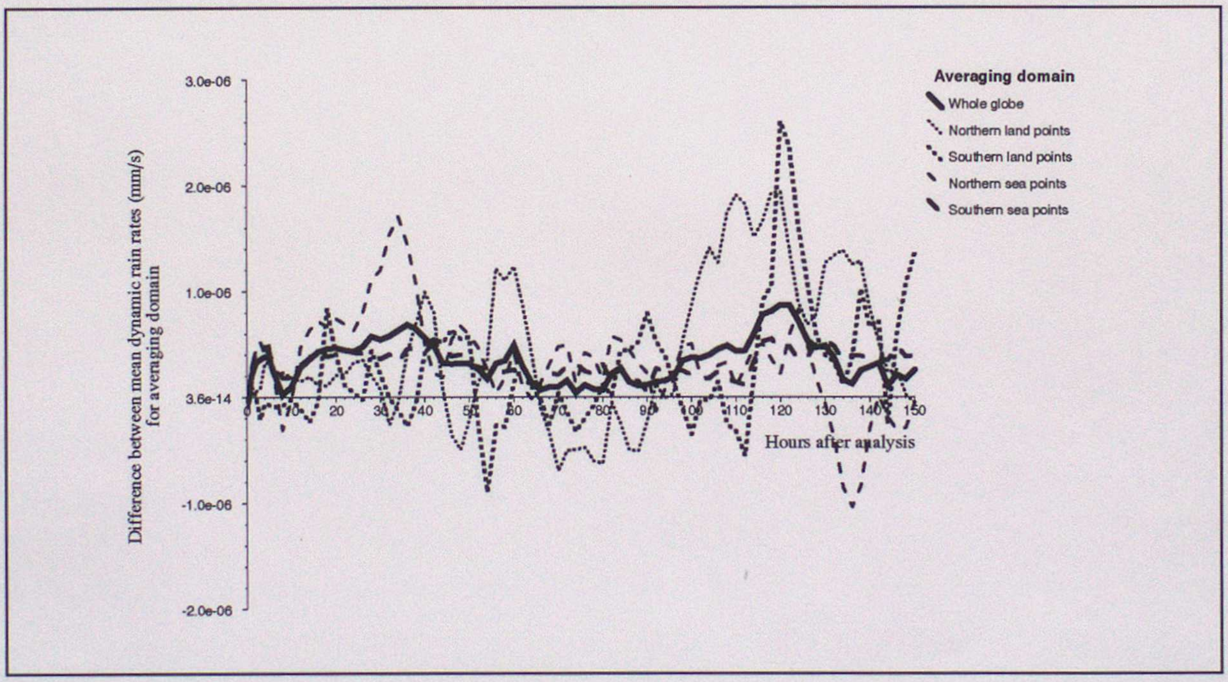


Figure 3: The sensitivity of UARS dynamic rainfall rates (a) to a change in the diffusion parameter K from 0.800e+9 to 0.436e+9, and (b) to a change in the timestep from 20mins to 10mins. Graphs show experiment minus control (standard UARS) values obtained from forecast runs starting from the UARS analysis for 12Z on 1/12/93.

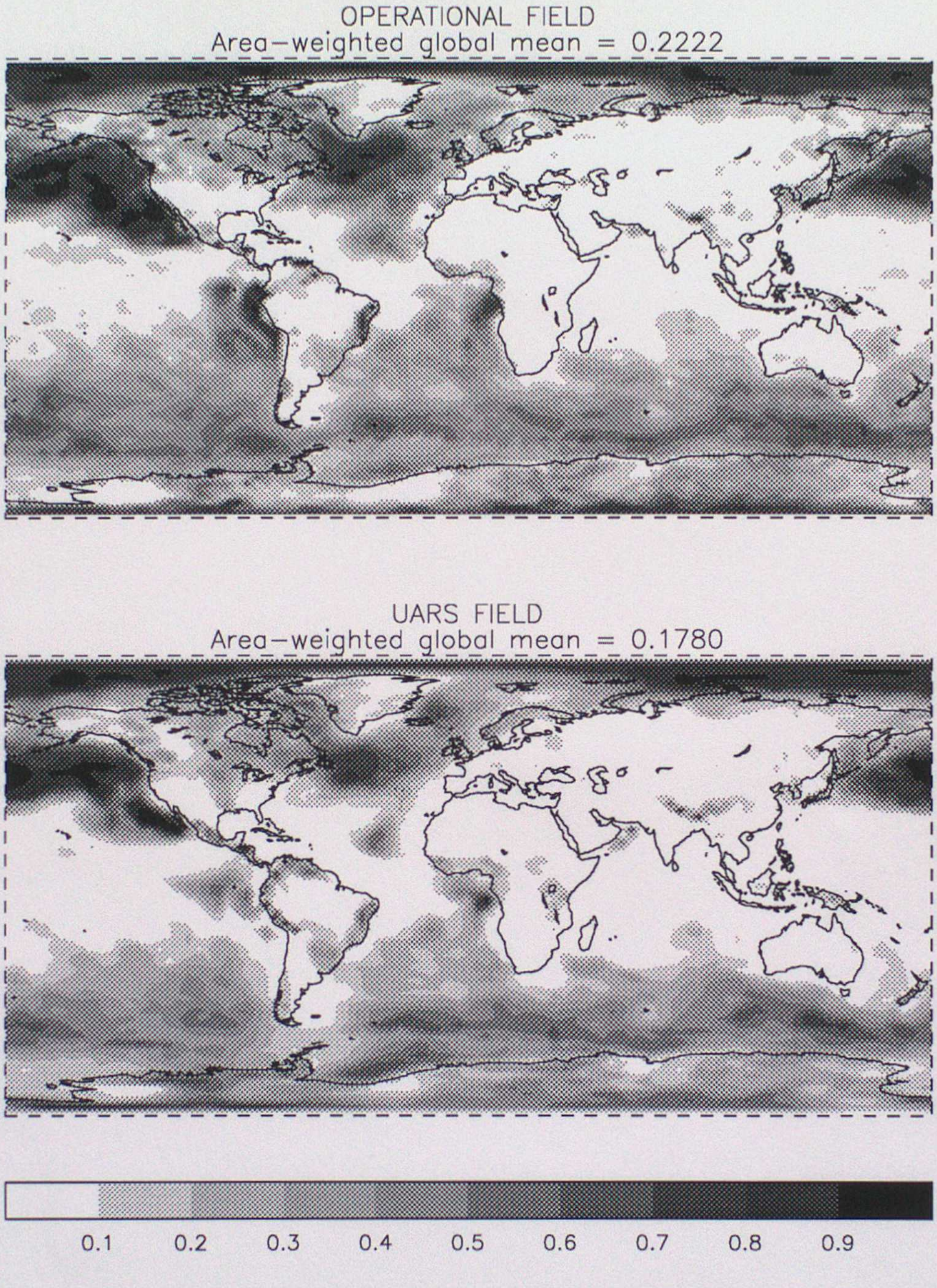


Figure 4: Operational and UARS low cloud fraction averages for July 1993 (12Z for operational field, 12:20Z for UARS field).

July 1993

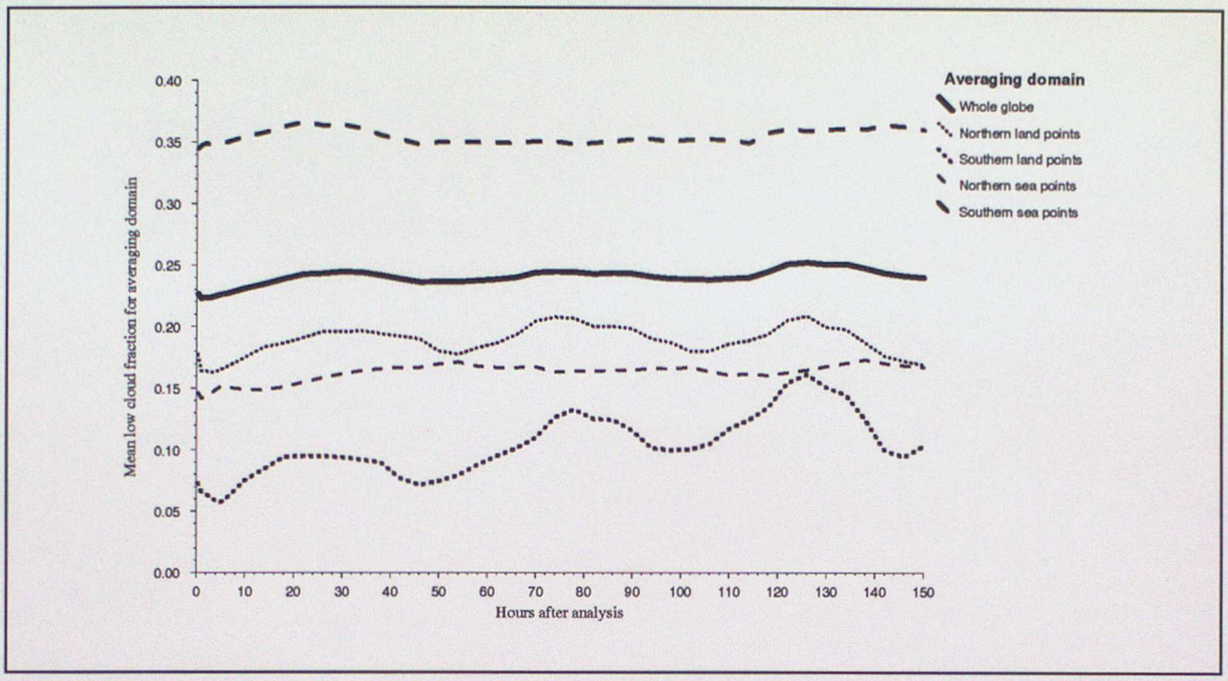
Averaging domain	UARS area-weighted mean	Operational area-weighted mean
Whole globe	0.1780	0.2222
Northern hemisphere	0.1654	0.2040
Southern hemisphere	0.1906	0.2404
Land points	0.1090	0.1088
Sea points	0.2061	0.2684
Northern land points	0.0937	0.0961
Southern land points	0.1416	0.1359
Northern sea points	0.2120	0.2741
Southern sea points	0.2017	0.2642

December 1993

Averaging domain	UARS area-weighted mean	Operational area-weighted mean
Whole globe	0.1835	0.2282
Northern hemisphere	0.1491	0.1635
Southern hemisphere	0.2179	0.2929
Land points	0.1571	0.1436
Sea points	0.1943	0.2627
Northern land points	0.1611	0.1629
Southern land points	0.1485	0.1025
Northern sea points	0.1414	0.1640
Southern sea points	0.2336	0.3362

Figure 5: A breakdown of the low cloud fraction averages.

(a)



(b)

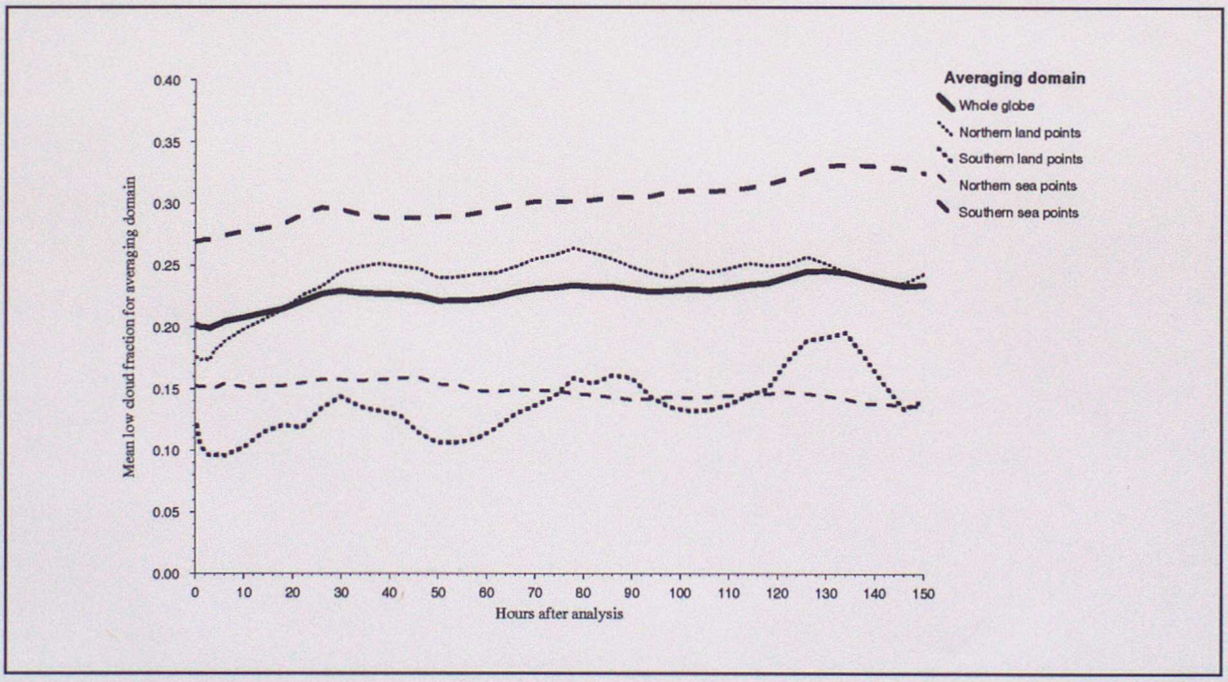


Figure 6: The spin-up of low cloud in (a) the operational system, and (b) the UARS system, following the analyses for 12Z on 1/12/93.

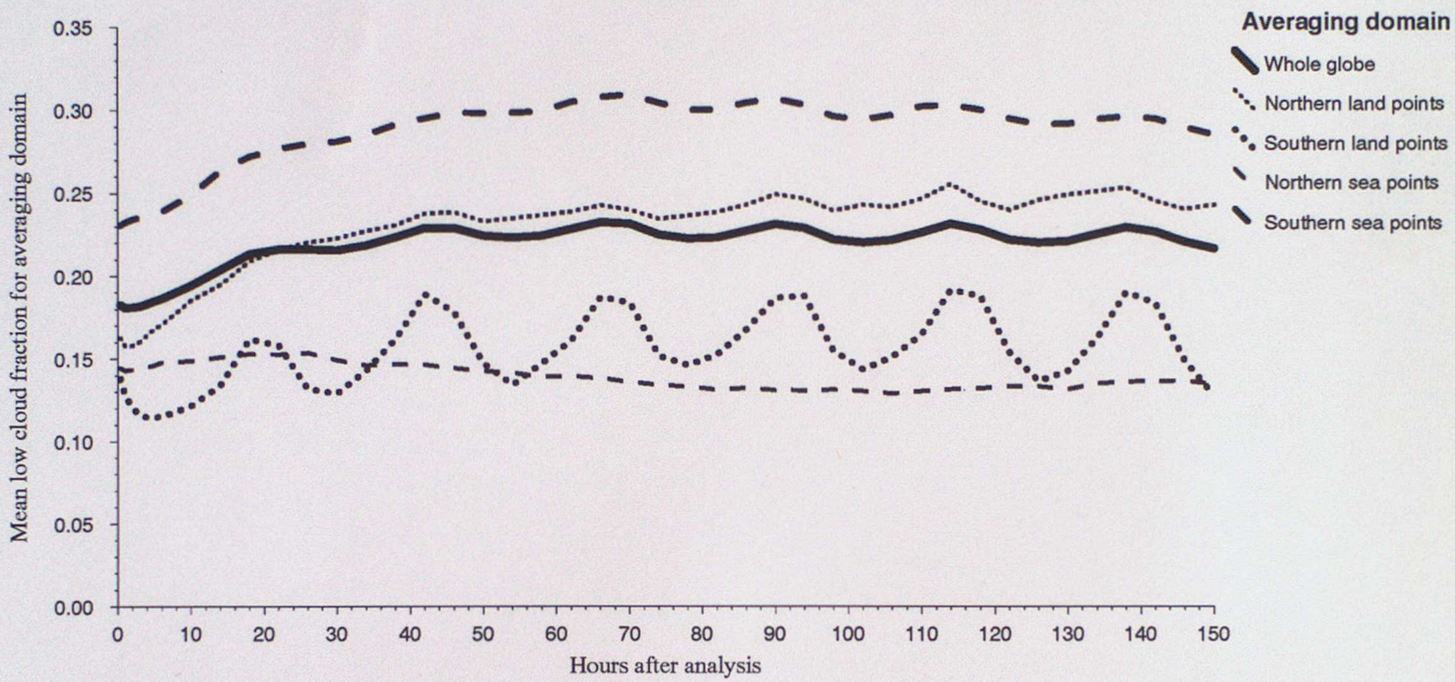
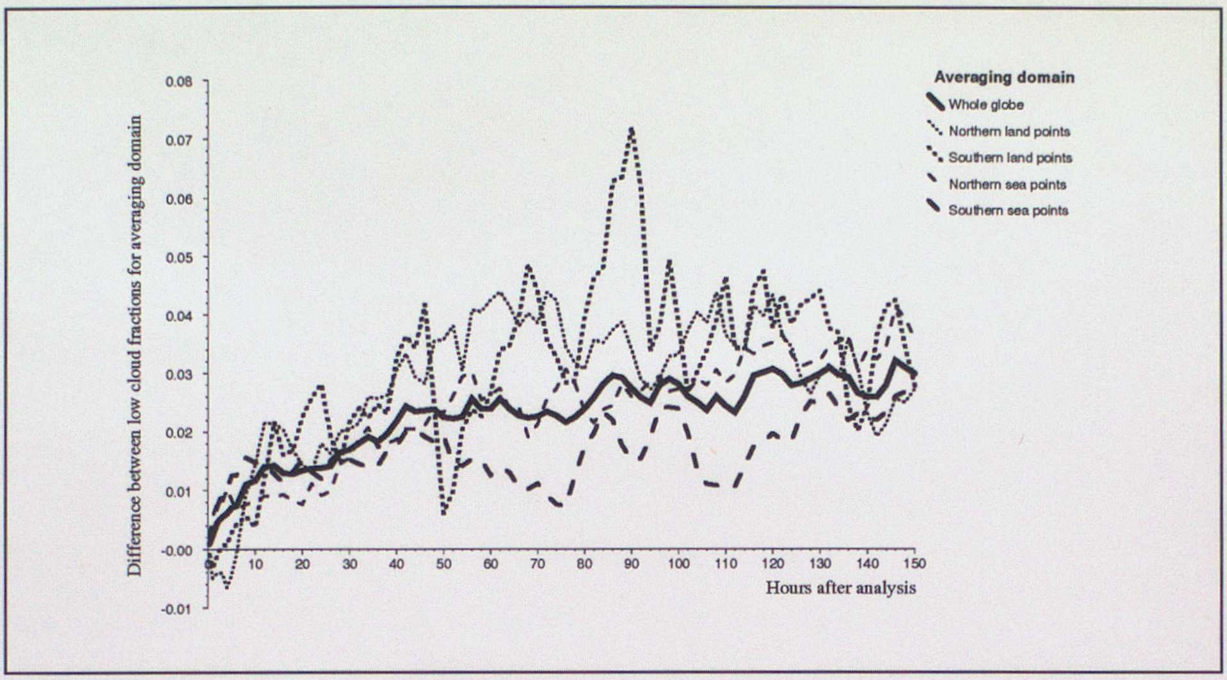


Figure 7: The evolution of UARS low cloud fraction averages in the hours following the analysis. Results obtained by averaging over 7 forcast runs. Analyses valid at 12Z on 1st, 6th, 11th, 16th, 21st, 26th and 31st December 1993.

(a)



(b)

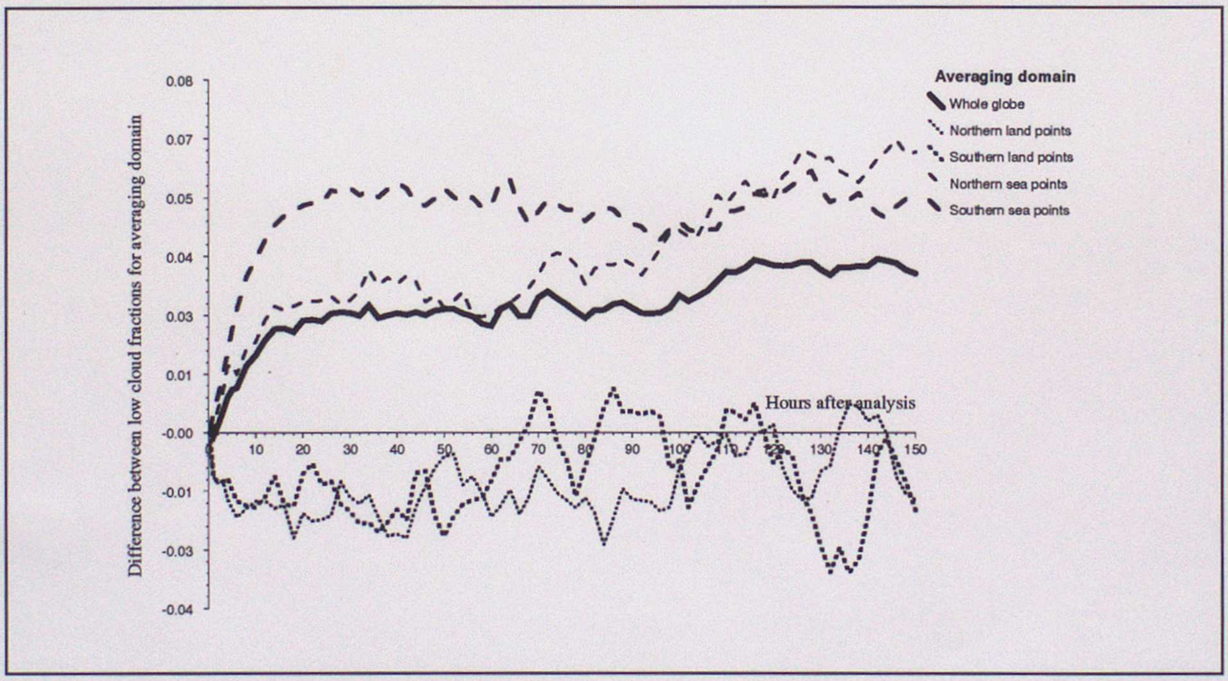


Figure 8: The sensitivity of UARS low cloud fraction (a) to a change in the diffusion parameter K from 0.800e+9 to 0.436e+9, and (b) to a change in the timestep from 20mins to 10mins. Graphs show experiment minus control (standard UARS) values obtained from forecast runs starting from the UARS analysis for 12Z on 1/12/93.

(a) (b)

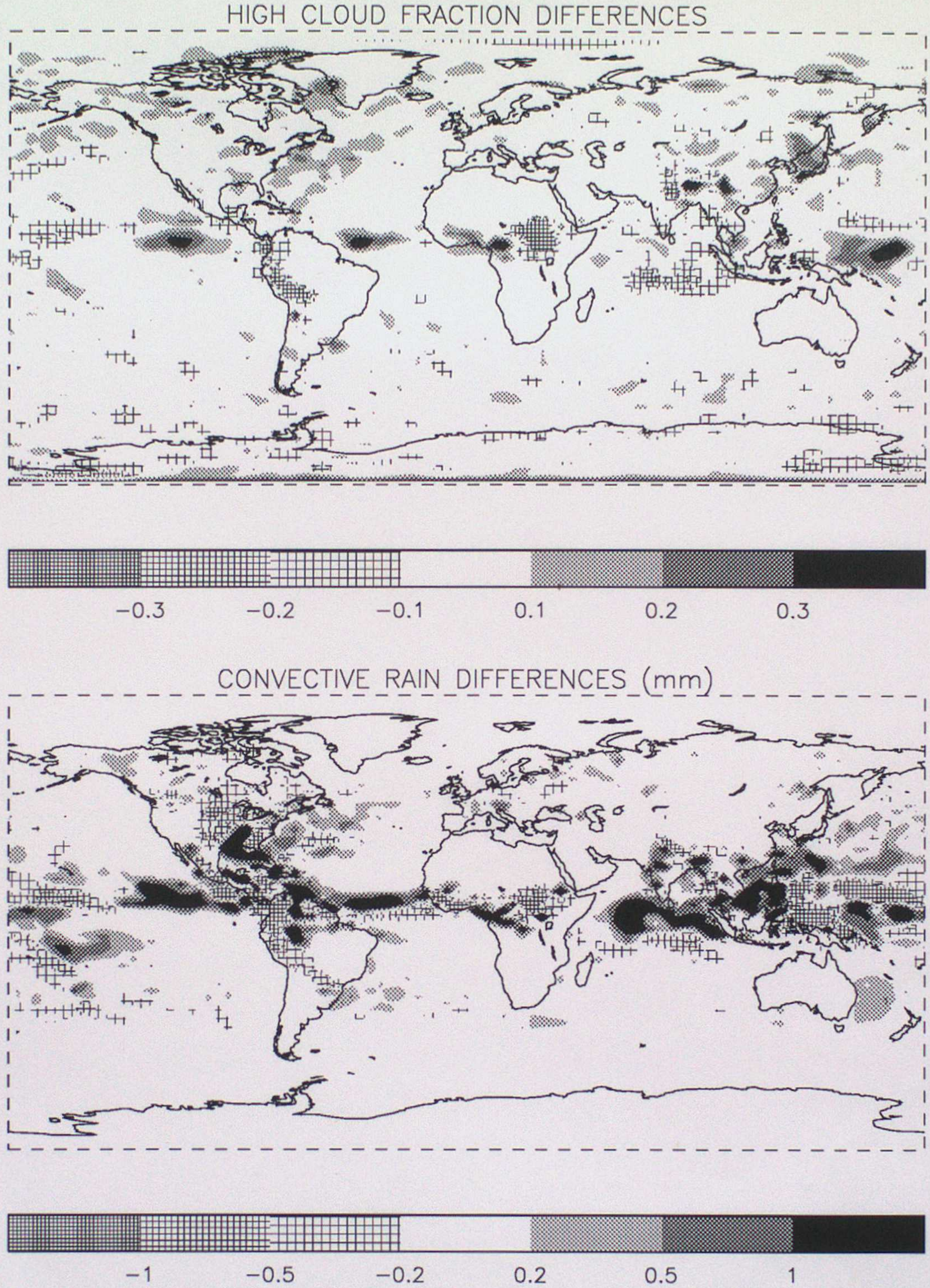
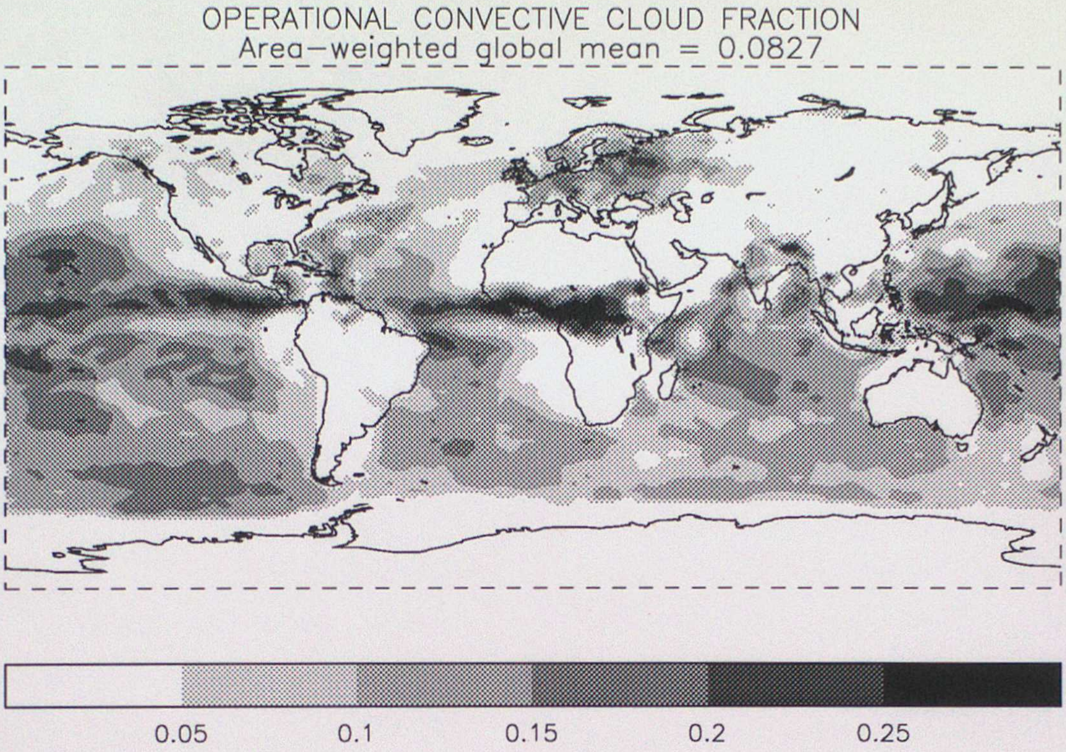


Figure 9: Average July 1993 operational minus UARS fields for (a) high cloud fraction (12Z for operational field, 12:20Z for UARS field), and (b) 12Z-18Z accumulated convective rain (mm).

(a)



(b)

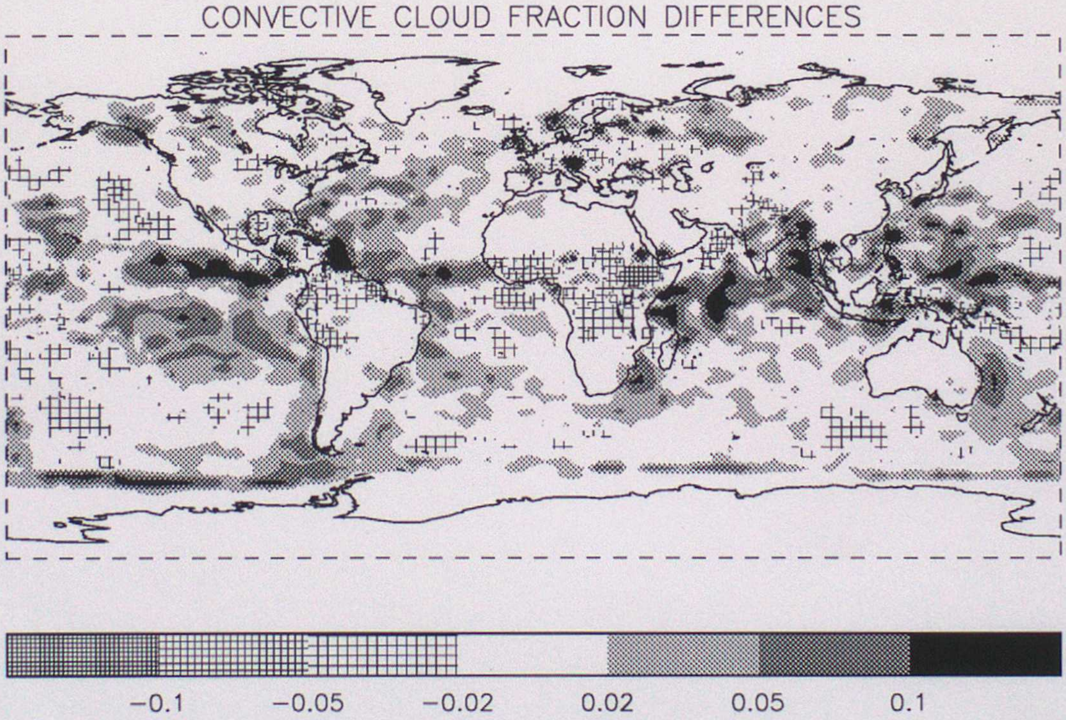


Figure 10: (a) operational, and (b) operational minus UARS 12Z convective cloud averages for July 1993.

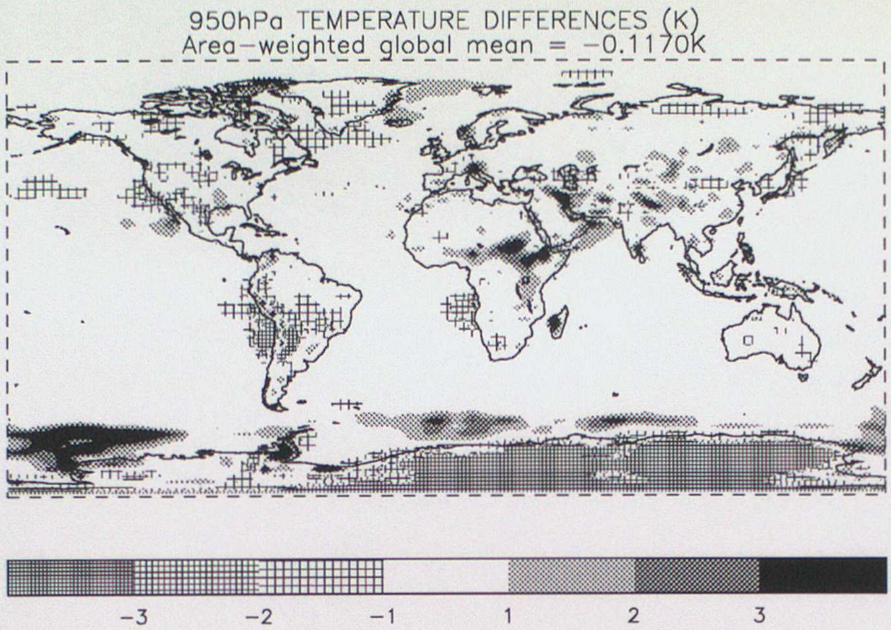


Figure 11: Operational minus UARS 12Z 950hPa temperature averages for July 1993.

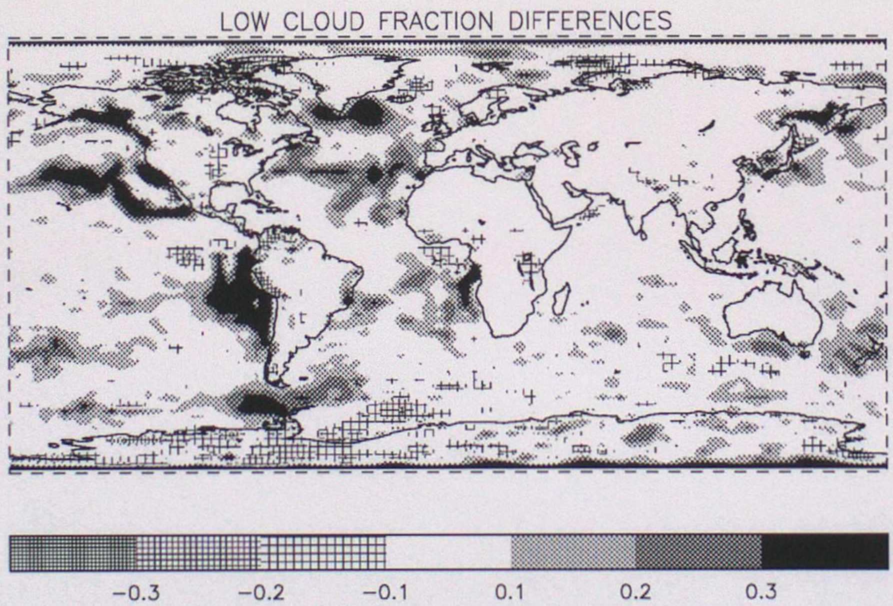


Figure 12: Operational minus UARS low cloud averages for July 1993.

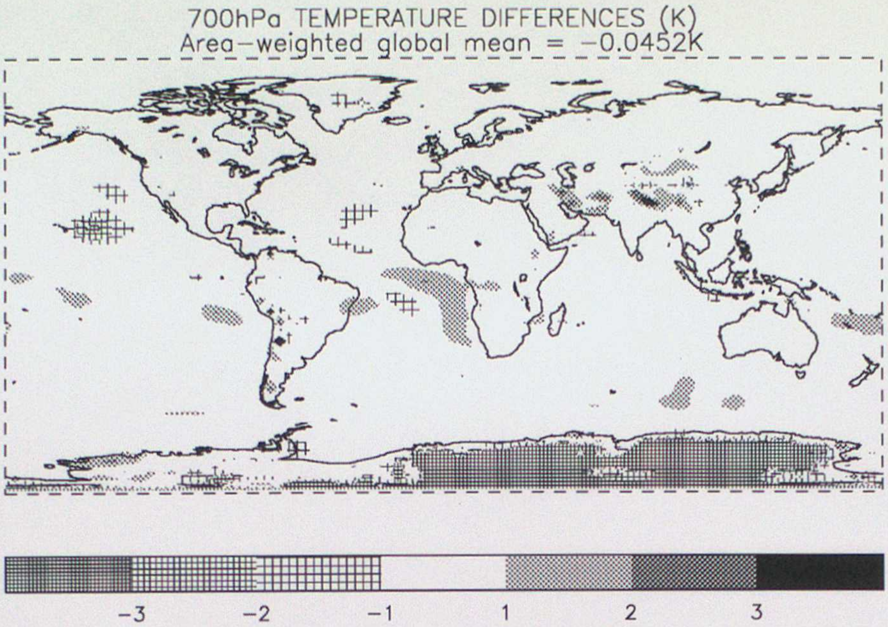


Figure 13: Operational minus UARS 12Z 700hPa temperature averages for July 1993.

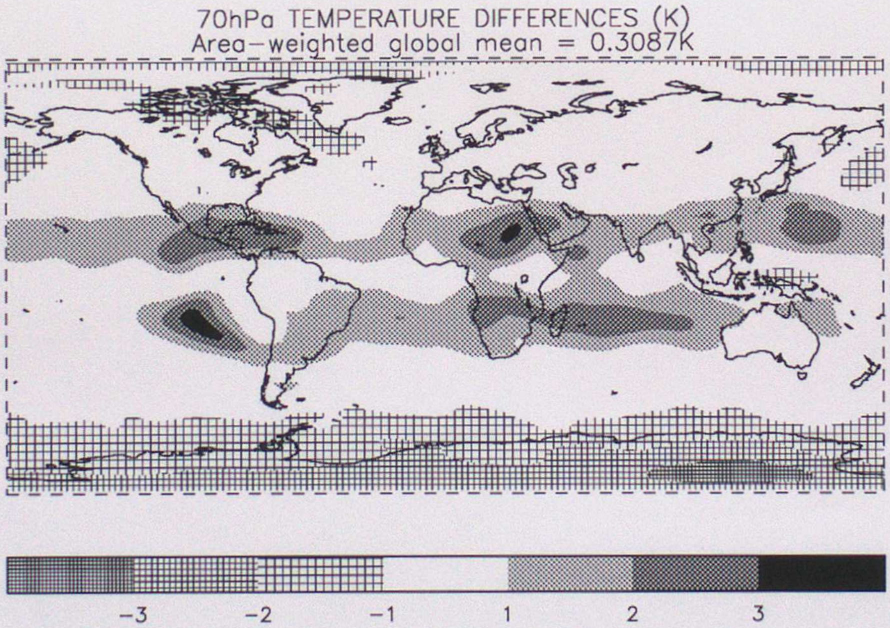


Figure 14: Operational minus UARS 12Z 70hPa temperature averages for December 1993.

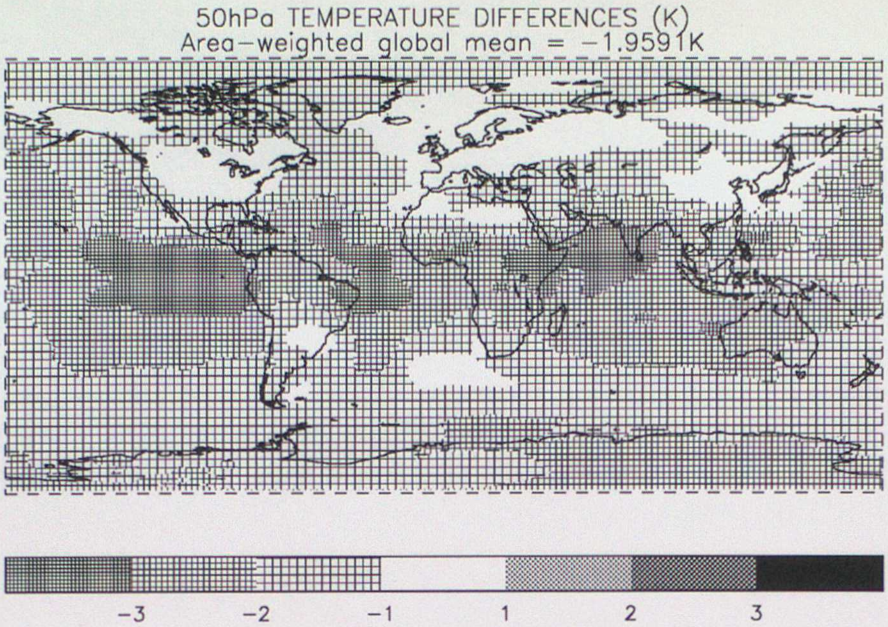


Figure 15: Operational minus UARS 12Z 50hPa temperature averages for December 1993.

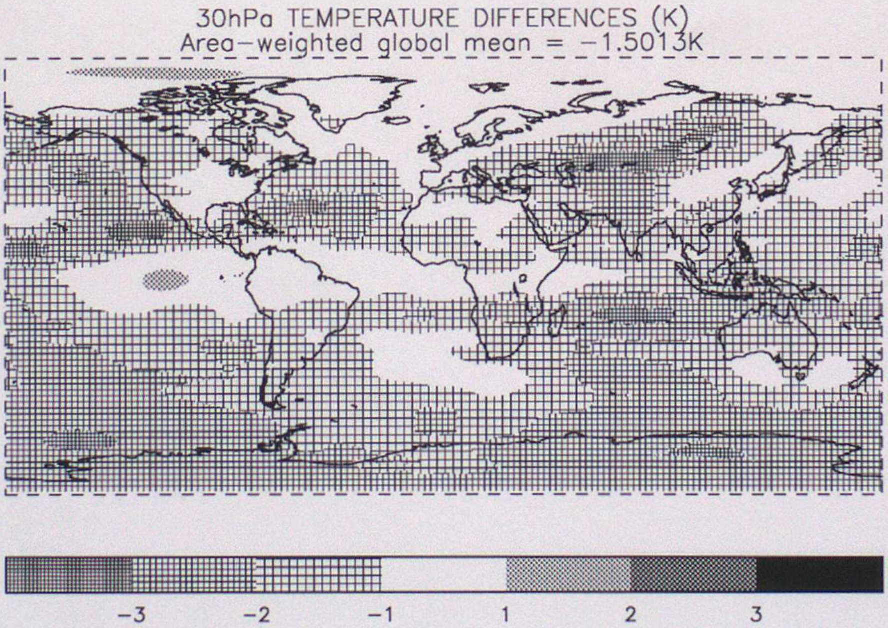


Figure 16: Operational minus UARS 12Z 30hPa temperature averages for December 1993.