ELSEVIER

Global and Planetary Change 19 (1998) 209–223

GLOBAL AND PLANETARY CHANGE

Comparing the scatter in PILPS off-line experiments with that in AMIP I coupled experiments

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Received 28 August 1997; accepted 9 February 1998

Abstract

In PILPS off-line experiments, quite large discrepancies have been identified among the land-surface schemes in terms of the partitioning of available energy into sensible and latent heat fluxes and the partitioning of precipitation into evaporation and runoff plus drainage. In order to determine whether the extent of such differences found in off-line experiments is replicated in coupled experiments, a direct comparison between the range of scatter in results from PILPS off-line experiments and that from Atmospheric Model Intercomparison Project (AMIP) I coupled experiments is made. The surface response variables are normalized by forcing variables so as to reduce the influences of differences in forcing between the AMIP and off-line simulations. Monthly data of surface variables from 15 AMIP I experiments and from two PILPS off-line experiments (23 simulations from Cabauw and 21 simulations from Valdai) were used for the analysis. The normalized measures of the scatter among land-surface simulations show that the range from the coupled simulations is larger than that from the off-line simulations, on both annual and seasonal time scales. Feedback from the host atmospheric models seems not to have reduced the disagreement among PILPS land-surface parameterization schemes.

Keywords: land-surface processes modelling; surface energy balance; normalization

1. Introduction: differences in results from land-surface simulations

The importance of land-surface processes for climate simulations and weather forecasting has been increasingly recognized by the modelling community over the past twenty years. In order to improve our understanding of the parameterization of land surface processes, the Project for Intercomparison of Land-surface Parameterization Schemes (PILPS) was initiated in 1992 as a joint WGNE/GEWEX project under the auspices of the World Climate Research Programme. The overall goals of PILPS are to improve the performance of land-surface schemes, as they are used in climate and weather prediction models. The progress to date and planned future activities of PILPS are described in detail by Henderson-Sellers et al. (1993, 1995).

One of the PILPS efforts is the joint PILPS–Atmospheric Model Intercomparison Project (AMIP)

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PII: S0921-8181(98)00048-4

project on land-surface processes: AMIP Diagnostic Subproject 12 (Gates, 1992; Phillips, 1994). This paper presents analyses of the surface energy budgets from the 10 years' simulations conducted for the AMIP I experiment and a wide range of results from PILPS Phase 2(a) and 2(d).

In PILPS off-line experiments, quite large differences have been identified among the results from participating land-surface schemes. These have been described in terms of the partitioning of available energy into sensible and latent heat fluxes and the partitioning of precipitation into evaporation and runoff plus drainage (e.g., Shao et al., 1994; Shao and Henderson-Sellers, 1996; Chen et al., 1997; Pitman et al., 1998). For example, the results from Phase 1(c) of PILPS (using forcing data from a GCM representative of a tropical forest and a mid-latitude grassland locations for PILPS schemes run off-line to equilibrium) showed that the annual averages of sensible and latent heat fluxes have ranges across the schemes of 79 and 80 Wm^{-2}, respectively, for tropical forest. In Phase 2(a) of PILPS, observed data from Cabauw, the Netherlands, are used as the atmospheric forcing. The annual averages of sensible and latent heat fluxes produced by the schemes run off-line to equilibrium have ranges across the schemes of 30 and 25 Wm^{-2}, respectively, significantly larger than the uncertainties of the measurements (± 5 Wm^{-2} for sensible heat flux and ± 10 Wm^{-2} for surface net radiation and latent heat flux, e.g., Qu et al., 1998).

These results give cause for concern about the adequacy of land-surface schemes, but since the results were produced decoupled from any host atmospheric model, it is not possible to anticipate the range of results generated from coupled models. It is therefore a priority to determine whether differences among off-line simulations are replicated in coupled model simulations.

As a first step towards answering this question, this paper compares the scatter among two PILPS Phase 2 off-line experiments and that among the coupled experiments from the Atmospheric Model Intercomparison Project (AMIP I) (Gates, 1992; Phillips, 1994) analysed as part of PILPS Phase 3. This paper examines whether the scatter among results from off-line experiments is smaller or larger than that from coupled (AMIP I) simulations. In Section 2, the data used for the analysis will be described. The methods employed for the comparison will be discussed in Section 3. The results will be presented in Section 4 and finally, in Section 5, some conclusions are drawn.

2. PILPS phase 2 and phase 3 (AMIP) data

2.1. PILPS phase 2

Off-line experimental results from PILPS Phase 2(a), Cabauw, and Phase 2(d), Valdai, are used. The Cabauw experiment employed one year of observations from Cabauw, the Netherlands (51°58′N, 4°56′E) (Beljaars and Viterbo, 1994; Beljaars and Bosveld, 1997), as the atmospheric forcing to drive 23 land-surface schemes off-line. All the results are from the final equilibrium simulation. Details about the schemes and experimental results can be found in the works of Chen et al. (1997) and Qu et al. (1998) and will not be repeated here.

The Valdai experiment used 18 years' (1966–1983) observations from Valdai, Russia (57°36′N, 33°6′E) as the atmospheric forcing to drive 21 land-surface schemes. All the results are from 18 years' transient simulation. Details about the schemes and experimental results can be found in the works of Schlosser et al. (1997a,b, 1998) and Vinnikov et al. (1996).

2.2. PILPS phase 3

The coupled experimental results are derived from the simulations from the AMIP I experiments (e.g., Gates, 1992; Henderson-Sellers et al., 1995). Many of the GCMs participating in AMIP use, or have as an alternative, a land-surface scheme which is participating in PILPS (e.g., Henderson-Sellers et al., 1995). These models thus provide an opportunity to assess the performance of the PILPS schemes coupled into their host GCMs. Eleven AMIP models were chosen (Table 1) for the analysis.

Within the framework of AMIP I, some modelling groups have rerun the AMIP experiment with revised GCMs (termed an AMIP 'revisit'). Among those groups, the Bureau of Meteorology Research Centre, Australia (BMRC) and the Laboratoire de

Table 1
Acronyms for AMIP models used for the analysis

BMRC	Bureau of Meteorology Research Centre
CCC	Canadian Centre for Climate Research
CNRM	Centre National de Recherches Météorologiques
CSIRO	Commonwealth Scientific and Industrial Research Organization
ECMWF	European Centre for Medium-Range Weather Forecasts
GLA	Goddard Laboratory for Atmospheres
JMA	Japan Meteorological Agency
LMD	Laboratoire de Météorologie Dynamique
MPI	Max-Plank-Institut für Meteorologie
NMC	National Meteorological Center
UKMO	United Kingdom Meteorological Office

Météorologie Dynamique, France (LMD) undertook a pair of simulations using the same GCM coupled with two different land-surface parameterization schemes. In each case, a standard bucket hydrology (i.e., BMRC + Bucket, LMD + Bucket) and a biophysically based land-surface scheme (i.e., BMRC + BASE, LMD + SECHIBA) were used. These two pairs of simulations are also used in the analysis

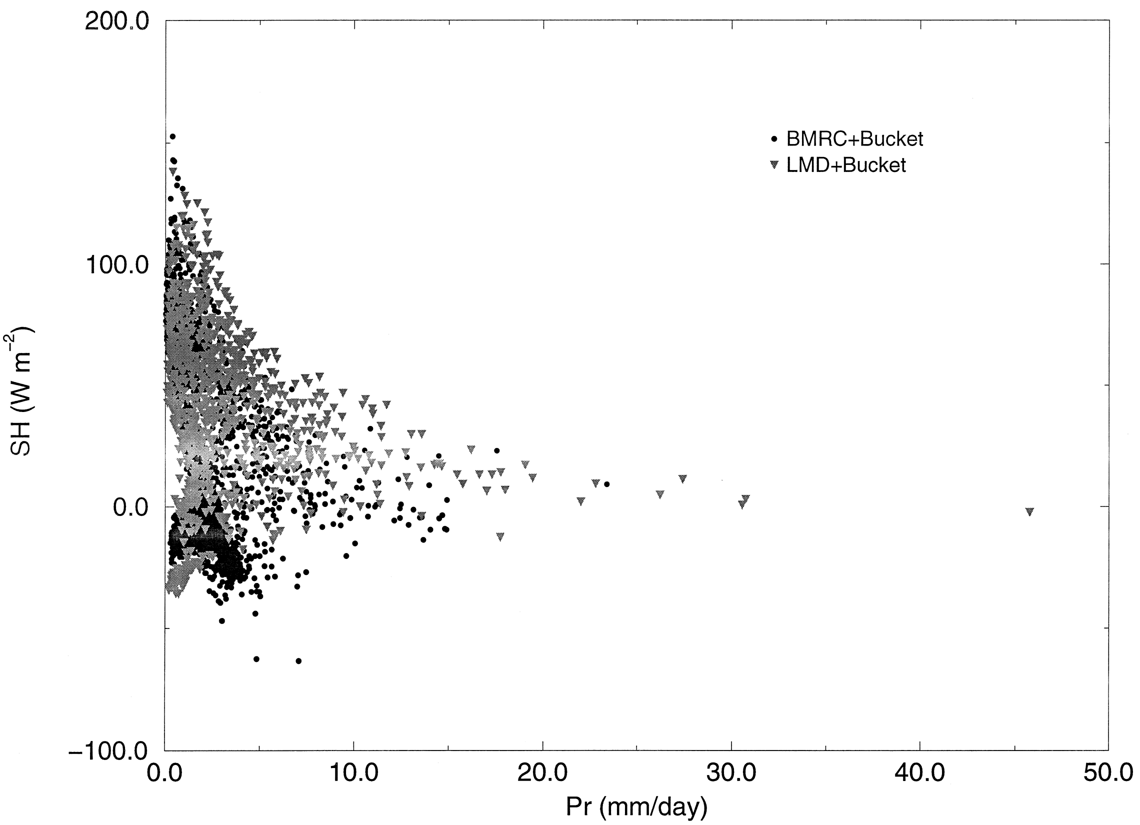


Fig. 1. Annual mean (averaged over the 10 years of the AMIP I period) sensible heat flux (SH) vs. precipitation (Pr) for each grid point over land from two AMIP revisit simulations (BMRC + Bucket and LMD + Bucket).

here. Thus, there is a total of 15 simulations for the coupled analysis. Detailed information about these GCMs can be found in the work of Phillips (1994) and on the AMIP homepage (http://www-pcmdi.llnl.gov).

For both the off-line and coupled simulations, monthly data of surface variables (surface net radiation, latent and sensible heat flux, precipitation, surface air temperature, etc.) are available.

3. Comparing off-line and coupled PILPS results

The available data were not derived to develop an answer to the question ‘do coupled simulations have a smaller or larger scatter due to land-surface processes?’ Care must be taken, therefore, in the analysis and interpretation.

There are three difficulties which make a direct comparison between the scatter among results from PILPS off-line experiments and that among the coupled (AMIP) experiments difficult. Using the data described in Section 2, it must be recognized that different land-surface schemes were used in the off-line and the coupled experiments. Secondly, the number of models differ between the off-line and the coupled experiments and, thirdly, the atmospheric forcings differ between the off-line and the coupled experiments. The very limited set of available data has tempted us to recognize that the first difficulty is insoluble in this analysis. We do, however, try to resolve the second and third difficulties in order to make the comparison and analysis as meaningful as possible.

The different surface forcings between the off-line and the coupled simulations (as well as among the coupled (AMIP) simulations) will cause differences in response variables. In order to reduce the influence of these differences in forcing, we employ normalization. The surface response variables are normalized by the forcing variables to generate new variables which are used as the basis of the analysis presented here.

For energy balance, we concentrate on the latent and sensible heat flux (LH, SH) normalized by the net radiation (R_n), i.e., LH/R_n and SH/R_n, since LH and SH are forced by R_n under the constraint of surface energy conservation. LH and SH are also normalized by precipitation (Pr), i.e., LH/Pr and SH/Pr. LH/Pr can be considered as a component of the water balance, but SH/Pr lacks physical meaning. It may be arguable that on annual time scales there is a relationship between SH and Pr since dry regions have higher sensible heat fluxes than wet regions. Fig. 1 shows an annual averaged Pr vs. SH for each grid-point over land from two AMIP revisit simulations, LMD + Bucket and BMRC + Bucket. It can be seen that on an annual basis, the sensible heat flux tends to decrease with the increase of precipitation for most grid-points except in high latitudes. The sensible heat flux normalized by precipitation on an annual time scale was retained as one element of this analysis.

Some other normalizations are also considered. We normalize the change of soil moisture, dW, with precipitation minus evaporation, Pr $-$ E, i.e., dW/(Pr $-$ E) where dW is calculated as follows:

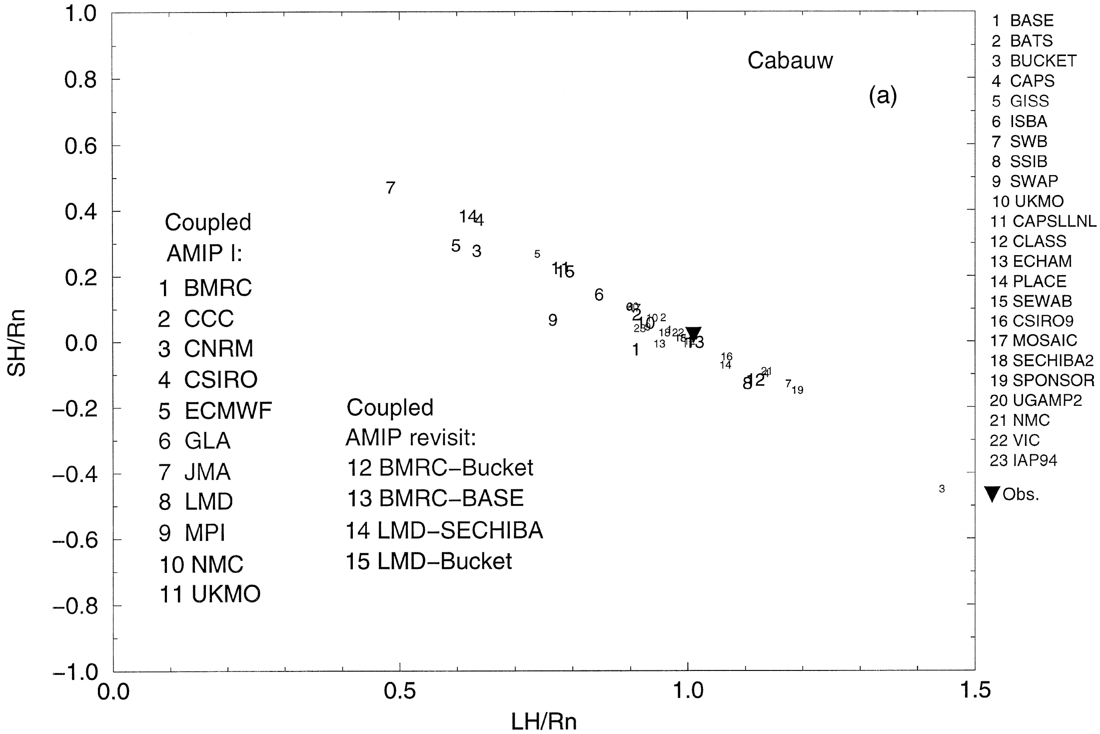
$$\mathrm{d}W = W_{i+1} - W_i \tag{1}$$

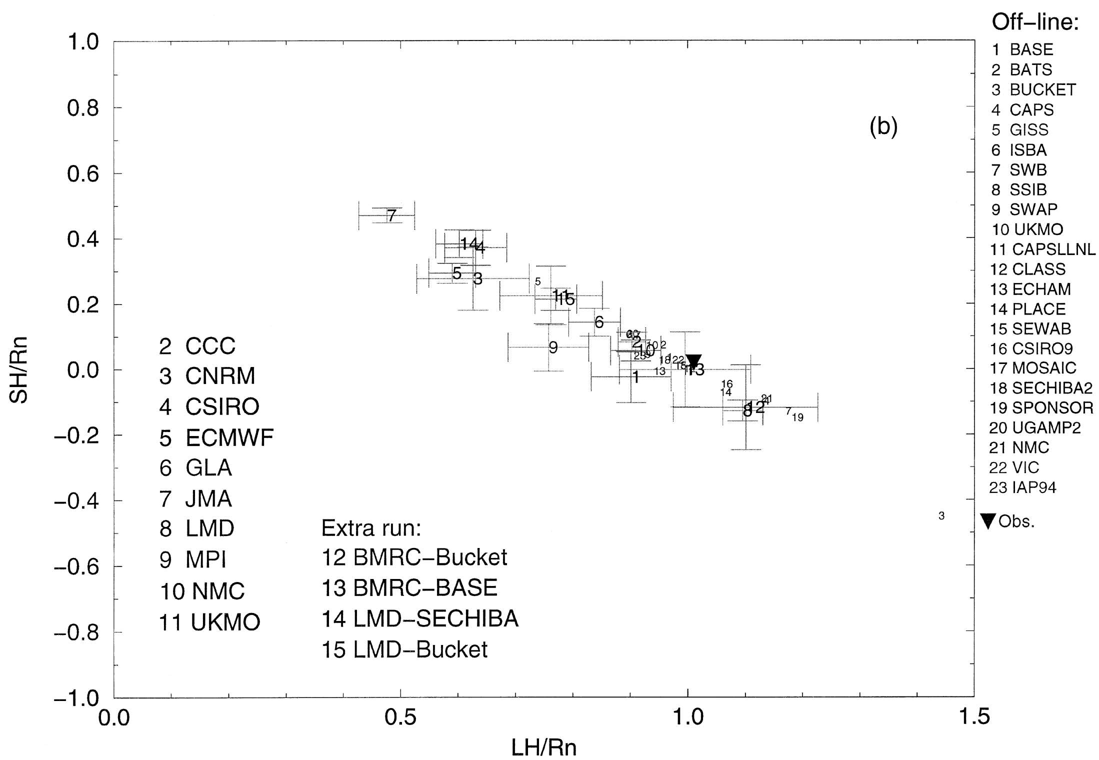
$$\mathrm{d}W = \frac{W_{i+1} - W_{i-1}}{2} \tag{2}$$

$$\mathrm{d}W = W_i - W_{i-1} \tag{3}$$

where W_i is the soil moisture for month i. Eq. (1) is used when $i = 1$ for both coupled and off-line simulations. Eq. (2) is used when $2 < i < 119$ for coupled (AMIP) simulations, $2 < i < 215$ for Valdai, and $2 < i < 11$ for Cabauw. Eq. (3) is used when $i = 120$ for AMIP, $i = 216$ for Valdai, and $i = 12$ for Cabauw. dW/(Pr $-$ E) is constructed by assuming that the change of soil moisture for a given month is driven by the net water input into the soil, which can be measured to a large extent by Pr $-$ E. Ideally, the contribution of the water flux from deeper soil and the lateral water exchange should also be taken into account.

Fig. 2. (a) Annual average of LH/R_n vs. SH/R_n for Cabauw from the off-line simulations (numbers in small font) and the coupled (AMIP I) simulations (numbers in large font); (b) As for (a), but with error bars for coupled (AMIP) simulations shown as are (temporal) standard deviation of the annual averages.


Cabauw
(a)
SH/Rn
LH/Rn
Coupled
AMIP I:
1 BMRC
2 CCC
3 CNRM
4 CSIRO
5 ECMWF
6 GLA
7 JMA
8 LMD
9 MPI
10 NMC
11 UKMO
Coupled
AMIP revisit:
12 BMRC–Bucket
13 BMRC–BASE
14 LMD–SECHIBA
15 LMD–Bucket
1 BASE
2 BATS
3 BUCKET
4 CAPS
5 GISS
6 ISBA
7 SWB
8 SSIB
9 SWAP
10 UKMO
11 CAPSLLNL
12 CLASS
13 ECHAM
14 PLACE
15 SEWAB
16 CSIRO9
17 MOSAIC
18 SECHIBA2
19 SPONSOR
20 UGAMP2
21 NMC
22 VIC
23 IAP94
Obs.


Off–line:
(b)
SH/Rn
LH/Rn
2 CCC
3 CNRM
4 CSIRO
5 ECMWF
6 GLA
7 JMA
8 LMD
9 MPI
10 NMC
11 UKMO
Extra run:
12 BMRC–Bucket
13 BMRC–BASE
14 LMD–SECHIBA
15 LMD–Bucket
1 BASE
2 BATS
3 BUCKET
4 CAPS
5 GISS
6 ISBA
7 SWB
8 SSIB
9 SWAP
10 UKMO
11 CAPSLLNL
12 CLASS
13 ECHAM
14 PLACE
15 SEWAB
16 CSIRO9
17 MOSAIC
18 SECHIBA2
19 SPONSOR
20 UGAMP2
21 NMC
22 VIC
23 IAP94
Obs.

Surface radiative temperature, T_s, can be considered to be forced by incoming radiation. Since incoming radiation is not available in the AMIP standard output, we normalize T_s with the surface air temperature, T_a. These six normalized variables have been calculated for the two off-line experimental sets and from all the coupled simulations.

For analysis on an annual time scale, annual mean values are averages over 10 years (1979–1988) for the coupled (AMIP) simulations and averages over 18 years (1966–1983) for the Valdai off-line experiments. In the case of the Cabauw off-line experiments, each PILPS scheme was run to equilibrium by looping through the 1 year's forcing. The annual means are therefore calculated directly from the monthly data for the equilibrium year. For the analysis on the seasonal time scale, the monthly means for a given month are 10 years' averages of that month for the coupled (AMIP) simulations; and 18 years' averages for the Valdai off-line results and taken from the equilibrium year for Cabauw.

For each AMIP simulation, data from a single grid point which is geographically closest to the location of the off-line experiments were used. Fig. 2bFig. 6b illustrate the error bars for the coupled (AMIP) simulations and also for Valdai simulations generated by considering the temporal standard deviation of the annual averages.

4. Scatter among land-surface scheme results (coupled vs. off-line) on an annual time scale

4.1. Cabauw

Fig. 2 shows the annual mean latent heat flux vs. sensible heat flux, both normalized by net radiation from all the off-line experiments and all the coupled

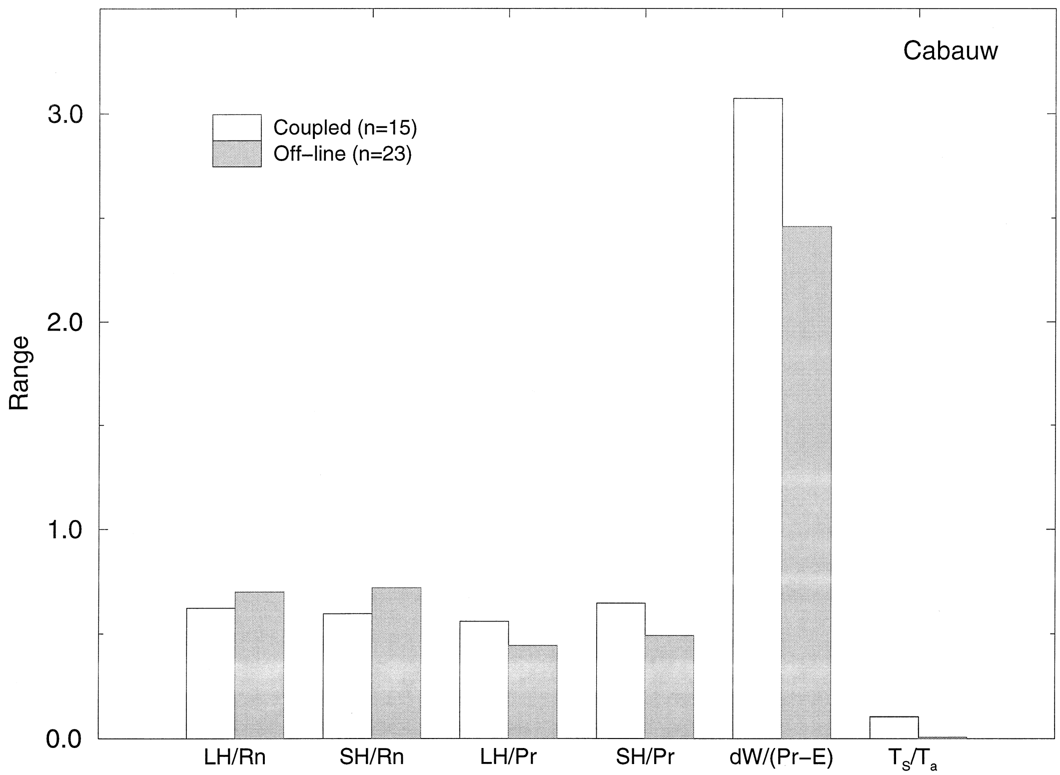


Fig. 3. Range of the annual mean LH/R_n, SH/R_n, LH/Pr, SH/Pr, dW/(Pr − E), and T_s/T_a among the 15 coupled simulations (AMIP) and that among the 23 off-line simulations (Phase 2(a)) for Cabauw.

simulations for the Cabauw location. Most points are located close to the 1:1 line, indicating that most simulations conserve energy (on the annual basis, $LH + SH = R_n$ over a long time period, hence $LH/R_n + SH/R_n = 1$).

There are large differences among the off-line simulations and coupled simulations in terms of the partitioning of net radiation into latent and sensible heat flux. For example, among the 23 off-line simulations, the maximum of LH/R_n is 1.443 (BUCKET) and the minimum is 0.743 (GISS) with a range of 0.700. On the other hand, among the 15 coupled simulations, the maximum of LH/R_n is 1.101 (BMRC + Bucket) and the minimum is 0.476 (JMA) with a range of 0.624. The ranges of other normalized variables calculated in the same way as for LH/R_n are shown in Fig. 3.

Fig. 3 shows that for LH/R_n and SH/R_n the range among the 23 off-line simulations is larger than that among the 15 coupled simulations, but for the other variables examined the range for the off-line simulations is smaller than that for the coupled simulations. In order to reduce the influence of the 'outlier' BUCKET (cf. Chen et al., 1997; Qu et al., 1998), this scheme is removed from the off-line group and the ranges recalculated for the off-line simulations, all the group and the ranges recalculated for the off-line simulations, all the variables having a smaller range for the off-line simulations than that for coupled simulations (Fig. 4).

An alternative method, to compensate for the fact that the number of models differ between the off-line and the coupled experiments, is to calculate the range from the 23 off-line simulations by randomly selecting 15 simulations many times. We repeated this process 80 times in this analysis (by which time convergence had been achieved) and then computed a mean range for each variable. Comparing the mean ranges for the off-line simulations with the range for the coupled simulations, those for the off-line simulations are smaller than those for the coupled simulations (Fig. 5).

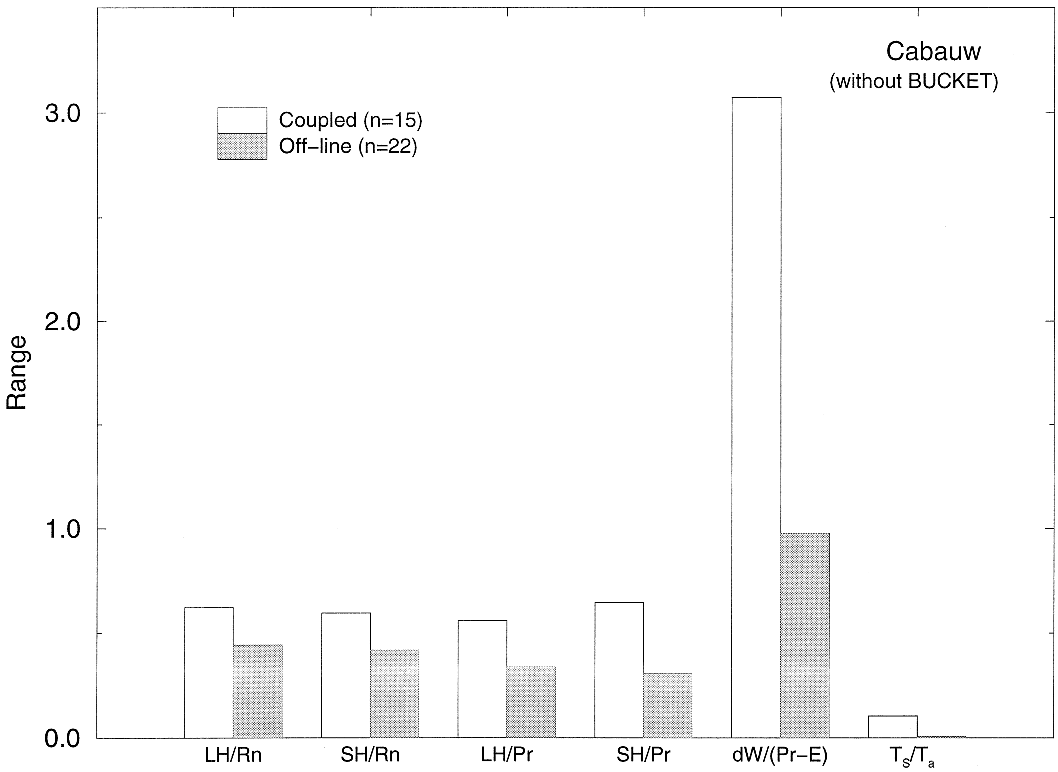


Fig. 4. As for Fig. 3, but the range for the off-line simulations is among 22 off-line simulations excluding BUCKET.

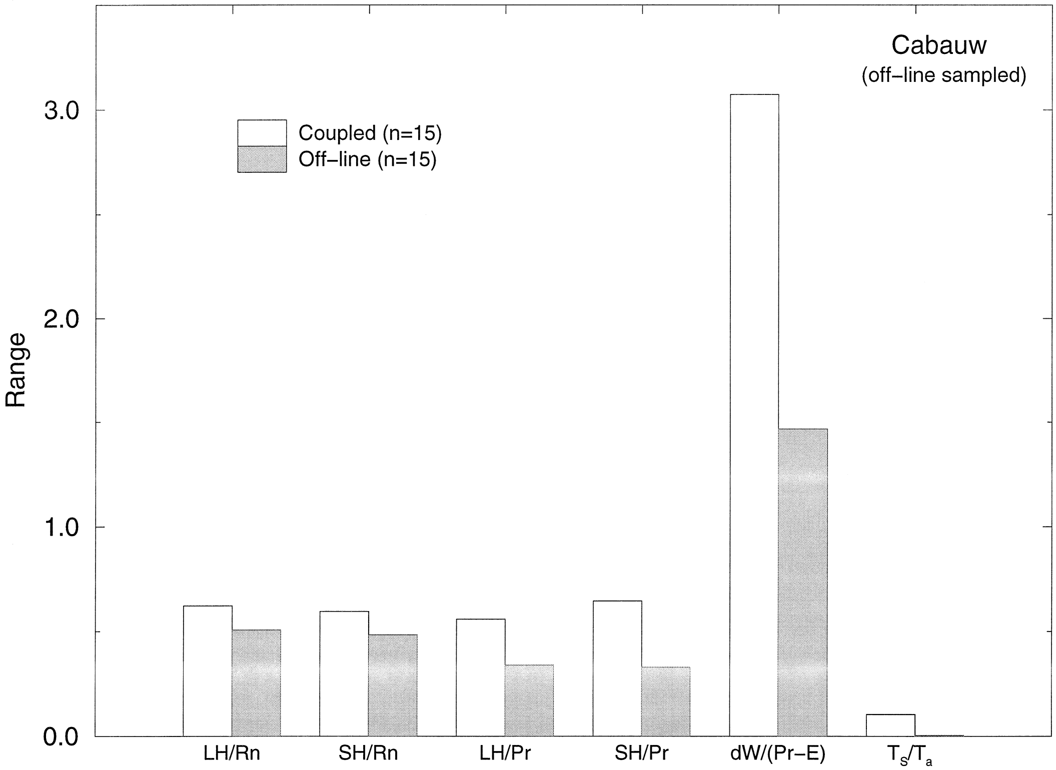


Fig. 5. As for Fig. 3, but the range for the off-line simulations is the average of 80 range-values which are calculated by randomly selecting 15 models 80 times from the 23 available simulations.

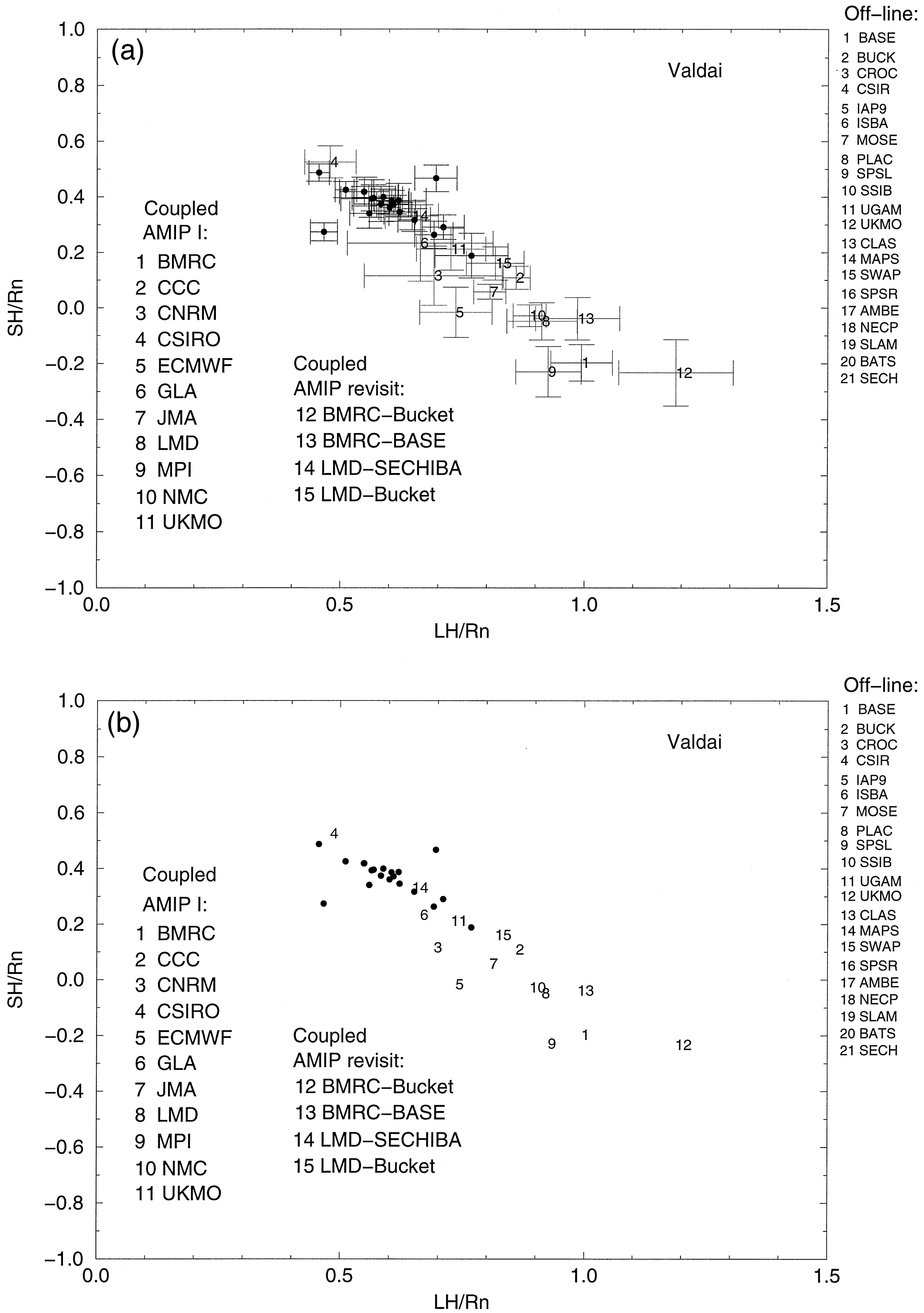
4.2. Valdai

The same analysis has also been undertaken for Valdai. Fig. 6 shows the annual mean of LH/R_n vs. SH/R_n for Valdai from the off-line and coupled simulations. All simulations conserve energy in the sense that the points are located on or close to the 1:1 line. As compared to the Cabauw experiments, the scatter among the off-line (dots) and coupled (numbers) simulations for the Valdai experiments is smaller with most of the off-line simulations clustered between LH/R_n values of 0.5–0.75.

Fig. 7 shows the range of all variables for Valdai for the off-line and the coupled simulations. It can be seen that the range of all six variables for the off-line simulations is smaller than that for the coupled simulations. This result remains the same if the range from the 21 off-line simulations is calculated by randomly selecting 15 simulations, as carried out for Cabauw (Fig. 8).

It might be argued that for off-line simulations LH/Pr is not a 'real' normalization, since there is no feed-back between the response and forcing variable because of using prescribed Pr. Hence, LH/Pr for the coupled simulations is not comparable with LH/Pr for the off-line simulations. If we compare the range of LH/Pr between the coupled and off-line simulations, we actually compare the range of LH/Pr

Fig. 6. (a) Annual average of LH/R_n vs. SH/R_n for Valdai location from Valdai off-line simulations (dots) and AMIP I simulations (numbers in large font); (b) As for (a), but with error bars for coupled (AMIP) and off-line simulations shown as are (temporal) standard deviation of the annual averages.


(a)
Valdai
SH/Rn
LH/Rn
1.0
0.8
0.6
0.4
0.2
0.0
−0.2
−0.4
−0.6
−0.8
−1.0
0.0
0.5
1.0
1.5
Coupled
AMIP I:
1 BMRC
2 CCC
3 CNRM
4 CSIRO
5 ECMWF
6 GLA
7 JMA
8 LMD
9 MPI
10 NMC
11 UKMO
Coupled
AMIP revisit:
12 BMRC−Bucket
13 BMRC−BASE
14 LMD−SECHIBA
15 LMD−Bucket
Off−line:
1 BASE
2 BUCK
3 CROC
4 CSIR
5 IAP9
6 ISBA
7 MOSE
8 PLAC
9 SPSL
10 SSIB
11 UGAM
12 UKMO
13 CLAS
14 MAPS
15 SWAP
16 SPSR
17 AMBE
18 NECP
19 SLAM
20 BATS
21 SECH
(b)
Valdai
SH/Rn
LH/Rn
Coupled
AMIP I:
1 BMRC
2 CCC
3 CNRM
4 CSIRO
5 ECMWF
6 GLA
7 JMA
8 LMD
9 MPI
10 NMC
11 UKMO
Coupled
AMIP revisit:
12 BMRC−Bucket
13 BMRC−BASE
14 LMD−SECHIBA
15 LMD−Bucket
Off−line:
1 BASE
2 BUCK
3 CROC
4 CSIR
5 IAP9
6 ISBA
7 MOSE
8 PLAC
9 SPSL
10 SSIB
11 UGAM
12 UKMO
13 CLAS
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17 AMBE
18 NECP
19 SLAM
20 BATS
21 SECH

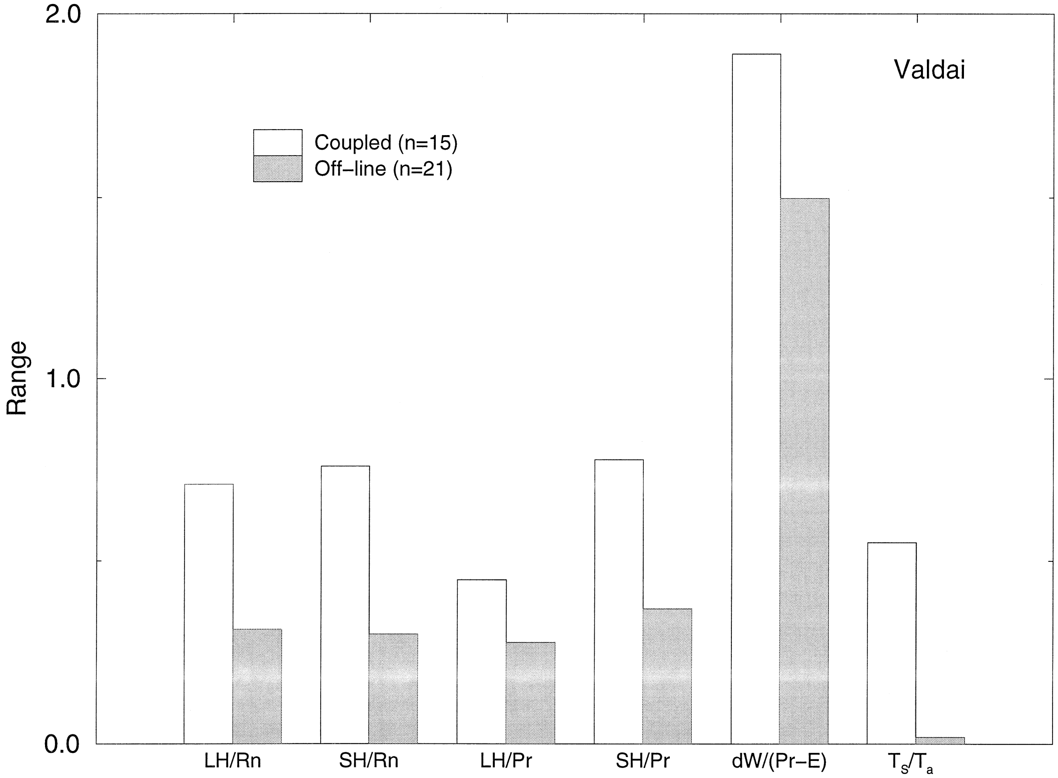

Fig. 7. Range of the annual mean LH/R_n, SH/R_n, LH/Pr, SH/Pr, dW/(Pr − E), and T_s/T_a for Valdai among the 15 coupled (AMIP) simulations and that among the 21 off-line simulations.

for the coupled simulations with the range of LH for off-line simulations, which is multiplied by a constant that is equal to 1/Pr. For LH/R_n, LH as well as R_n are estimated in both the coupled and the off-line simulations, and there is the same link between LH and R_n under the constraint of surface energy conservation. From this point of view, LH/R_n and SH/R_n are probably the most suitable variables with which to compare the range between results from coupled and off-line land-surface simulations.

5. Scatter among land-surface scheme results (coupled vs. off-line) on a seasonal time scale

In Section 4, we compared the range of several normalized surface variables between the off-line and coupled simulations on an annual basis. In this section, we examine the ranges on a monthly time scale. As discussed above, LH/R_n and SH/R_n are considered to be the most useful variables. We therefore evaluate these two variables on a seasonal time scale.

Table 2 shows the range of monthly mean LH/R_n and SH/R_n for the coupled and off-line simulations for each month. For the off-line simulations, 22 simulations excluding BUCKET are used to compute the range for Cabauw, and 21 simulations are used for Valdai. It can be seen from Table 2 that LH/R_n and SH/R_n show very large ranges in the winter months, especially in the coupled simulations. The reason is that in the winter, R_n becomes very small (close to zero). Hence, LH/R_n and SH/R_n become very large (could be infinite), thus limiting the value of the normalization technique on a monthly basis.

Useful normalization can only be achieved in spring, summer and autumn when the forcing variable (here R_n) has the same order of magnitude as the response variables (here LH and SH). Here, the results of the normalizations are considered only for

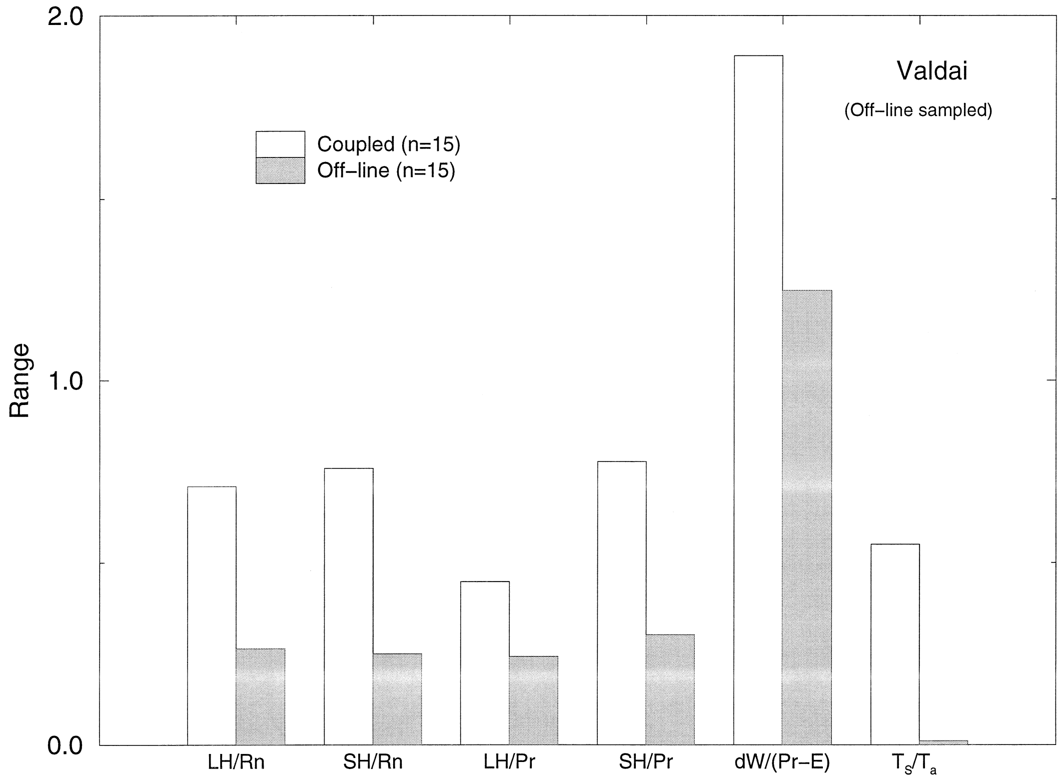

Fig. 8. As for Fig. 7, but the range for the off-line simulations is the average of 80 range-values which are calculated by randomly selecting 15 models 80 times from the 21 available simulations.

Table 2
Range of monthly mean LH/R_n and SH/R_n among the 15 coupled (AMIP) simulations and that among the 22 (the Bucket is excluded) off-line simulations for Cabauw and among the 21 off-line simulations for Valdai

Month	Cabauw				Valdai			
	LH/R_n		SH/R_n		LH/R_n		SH/R_n	
	Coupled	Off-line	Coupled	Off-line	Coupled	Off-line	Coupled	Off-line
1	25.301	1.220	23.877	2.116	1.481	0.758	1.553	1.612
2	1016.724	11.804	1255.221	12.396	10.423	6.267	20.897	6.233
3	1.577	1.610	1.522	1.411	148.998	16.733	248.945	23.061
4	1.182	0.560	0.453	0.367	1.419	1.307	0.657	1.632
5	1.017	0.423	0.330	0.401	0.861	0.310	0.455	0.254
6	0.950	0.427	0.554	0.307	0.744	0.222	0.661	0.164
7	0.923	0.479	0.737	0.468	0.615	0.258	0.634	0.167
8	0.870	0.325	0.788	0.302	0.603	0.246	0.601	0.152
9	0.877	0.398	0.713	0.432	0.976	0.315	0.800	0.299
10	8.691	5.642	3.610	3.326	7.703	1.053	4.021	1.143
11	591.603	4.071	132.201	4.601	2.933	3.416	2.924	3.550
12	6.847	1.282	8.256	1.338	1.288	0.268	1.883	1.176

the months in which LH/R_n and SH/R_n are smaller than 1.5. For most schemes, this occurs between April and September, inclusive, although we allow one off-line value of SH/R_n which slightly exceeds this threshold for Valdai in April. Figs. 9 and 10 show the scatter ranges for the period from April to September, inclusive. The ranges from the off-line simulations are calculated by randomly selecting 15

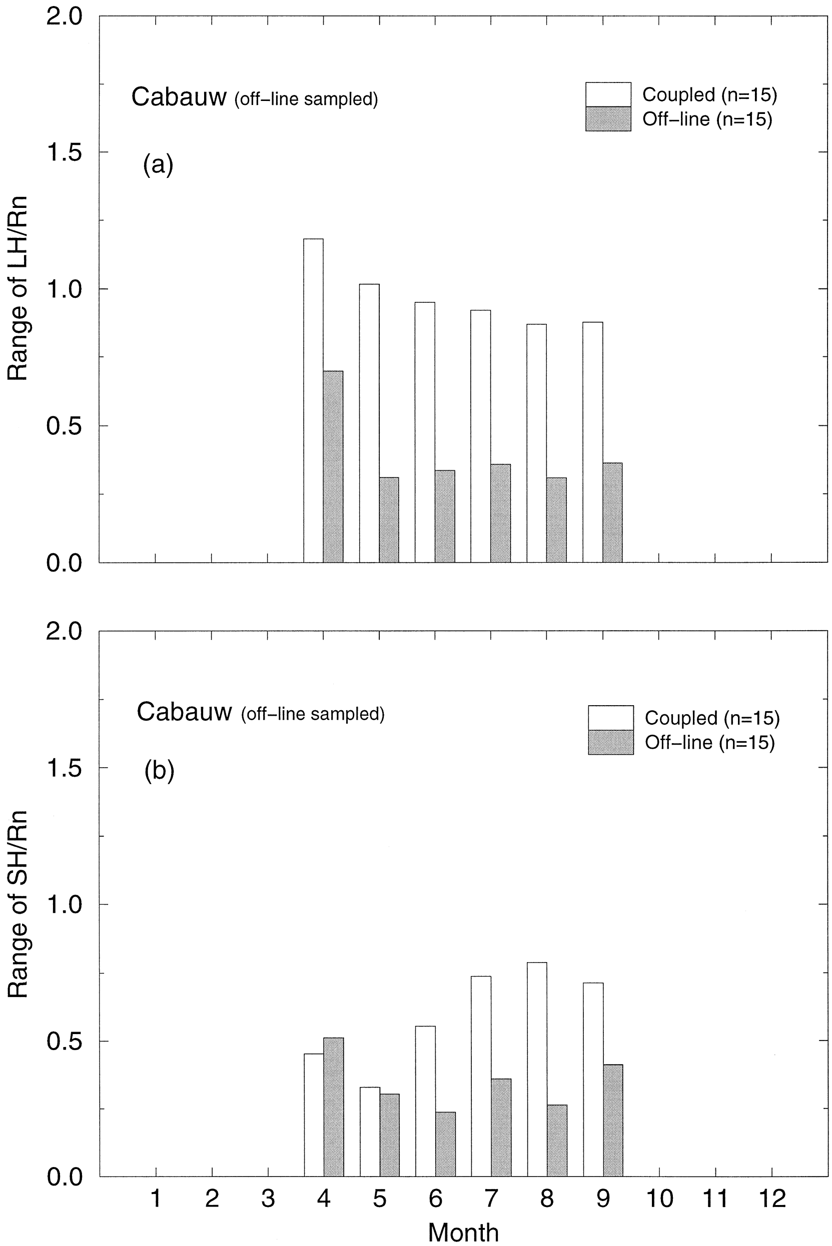

Fig. 9. Range of monthly mean (a) LH/R_n and (b) SH/R_n for Cabauw among the 15 coupled (AMIP) simulations and among the 23 off-line simulations. The range for the off-line simulations is the average of 80 range-values which are calculated by randomly selecting 15 models 80 times from the 23 available simulations.

simulations, as undertaken for the analysis on the annual time scale in Section 4. For every month except April for SH$/R_n$, the ranges for the coupled simulations are larger than those for the off-line simulations. (Note that for Valdai, the April values for SH$/R_n$ for the off-line simulations exceed our cut-off.)

Overall, we can conclude that, on a monthly time scale, the ranges for the coupled simulations are larger than those for the off-line simulations, which

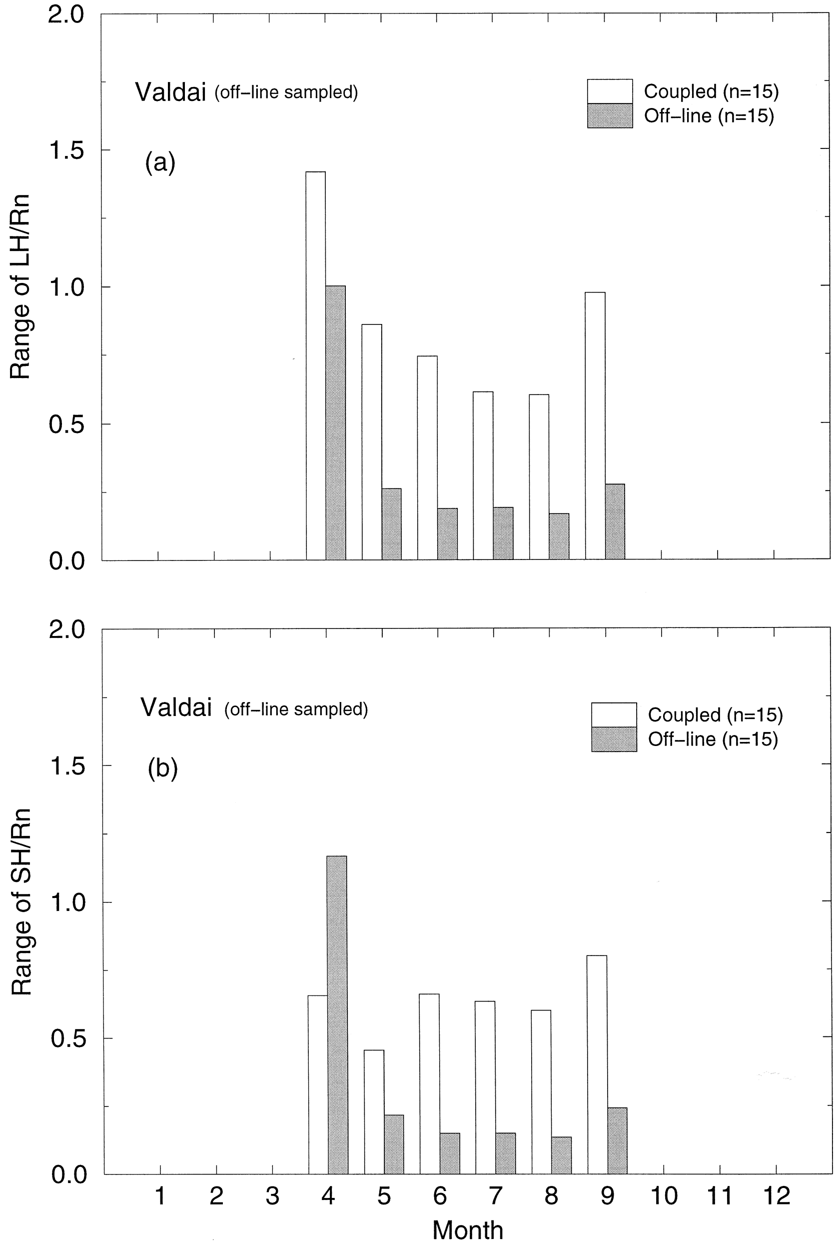

Fig. 10. Range of monthly mean (a) LH$/R_n$ and (b) SH$/R_n$ for Valdai among the 15 coupled (AMIP) simulations and among the 21 off-line simulations. The range for the off-line simulations is the average of 80 range-values which are calculated by randomly selecting 15 models 80 times from the 21 available simulations.

is consistent with the results for the annual time scale.

6. Does coupling land-surface schemes in their host GCMs reduce the range among their results?

We have attempted to answer the question of whether the scatter among the results from PILPS land-surface schemes generated in off-line experiments is smaller or larger than that discovered when land-surface schemes are coupled to their host GCMs. In order to reduce the influence of different forcing between the off-line and coupled simulations, a normalization technique has been used. Six normalized variables, LH/R_n, SH/R_n, LH/Pr, SH/Pr, dW/(Pr $-E$), and T_s/T_a, were analyzed and the range of the scatter of these normalized variable were compared for coupled and off-line simulations.

The analysis shows that LH/R_n and SH/R_n seem to be the most suitable variables for comparison of the range between coupled and off-line simulations. Using these variables as a measure, it is found that the range in the scatter for the coupled simulations is larger than that for the off-line simulations. This is true on both annual and monthly time scales.

This is a surprising result and contrary to our expectations. It had been thought that coupling any land-surface scheme to a host atmospheric model would reduce any tendency to extreme values (e.g., without feedback to a responsive atmosphere a land-surface scheme can dry out or become very wet) and hence, when scatter was considered across a range of land-surface scheme results, those from a set of coupled simulations would be less than those from off-line simulations. The contrary outcome which we find here is particularly interesting because the off-line simulations already show quite a large scatter. Explanations include the fact that different land-surface scheme groups appear in the coupled and off-line simulations and that our analysis relates only to two locations. Since the conclusions are deemed interesting, further studies seem to be warranted that encompass larger geographical regions and, perhaps, additional experiments using the same land-surface schemes in both coupled and off-line simulations. This is the basis of PILPS Phases 4(a) and 4(b).

Acknowledgements

We wish to thank Dr. P. Gleckler from PCMDI for making the AMIP revisit data available for this analysis. We thank Mr. A. Slater and Dr. C.A. Schlosser for providing Valdai experiment results. We also thank Dr. T. Phillips for providing the documentation for the BMRC and LMD models relevant to their revisit AMIP experiments and Dr. B. McAvaney, Dr. J. Fraser, and Dr. J. Polcher for providing detailed information about their AMIP revisit experiments. All the PILPS participants in Phase 2(a) (Cabauw), 2(d) (Valdai) and 3 (AMIP I) are also acknowledged and thanked for their contributions. This work was funded by the Australian Research Council (ARC) and the NOAA Office of Global Change through the University of Arizona.

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