DETAILS OF THE FORCING DATA

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A complete list of the input fields for the LSSs is given in Tables S1–S3. The derivation of the meteorological forcing data listed in Table S3 is described here. A complete description of the forcing data is given in Zhao and Dirmeyer (2003). Here we present a summary to acquaint the reader with the process of hybridization of observational and model (reanalysis) data that we have used, and to point out issues that may ultimately bear on the Second Global Soil Wetness Project (GSWP-2) analysis.

All GSWP-2 models were run on the land grid points of the International Satellite Land Surface Climatology Project (ISLSCP) Initiative II 1° grid. The 3-hourly near-surface meteorological data from National Centers for Environmental Prediction (NCEP)/Department of Energy (DOE) reanalysis (Kanamitsu et al. 2002) was regridded for ISLSCP Initiative II. To coregister the T62 (Gaussian grid) resolution (192 × 94 grid boxes globally) NCEP/DOE reanalysis on the ISLSCP 1° grid, the reanalysis dataset was regridded as consistently as possible with the land–sea mask definitions of each grid. The NCEP/DOE land–sea mask and the ISLSCP land–sea mask are used to ensure that land points are transformed into land points and sea points are used for sea points. For every grid box on the target ISLSCP grid, there are either one, two, or four overlapping grid boxes of the input NCEP/DOE grid; only those points are selected that are of the same type as the target grid point (sea for sea and land for land). All intersecting grid boxes of the same type are used to perform a bilinear interpolation of the data. If none of the intersecting grid boxes have the same type, they are all used for bilinear interpolation. This may occur at locations where, for instance, the ISLSCP mask has a lake, whereas the NCEP/DOE mask has only land points in the surroundings. In this case, the consistency between land–sea masks is lost. Figure S1 shows the consistency between the two masks. Grid boxes are shaded red where ISLSCP Initiative II has land but the overlapping NCEP/DOE grid has only water, and green shading indicates where ISLSCP Initiative II has water but NCEP/DOE has land.

Precipitation. Global observational datasets of quantities such as precipitation are probably superior to reanalysis estimates of precipitation, but they are far from perfect. Incomplete gauge coverage, difficulty in collecting observational data, national variations in instruments and calibration, and problems with the instruments themselves can lead to very uneven coverage and quality of observational data. Oki et al. (1999) showed that in GSWP-1, runoff was systematically underestimated over high latitudes where snow is a significant contributor to annual precipitation. Motoya et al. (2002) have examined this

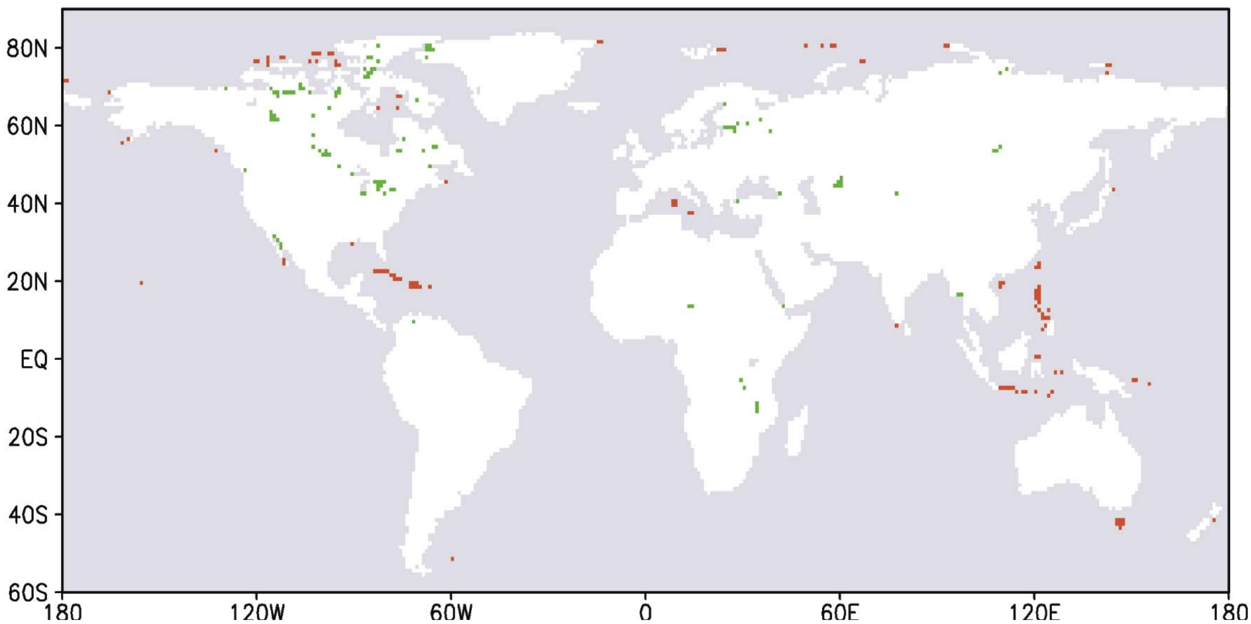

Fig. S1. ISLSCP grid boxes where ISLSCP is land but NCEP/DOE is water (red) and where ISLSCP is water but NCEP/DOE is land (green).

Table S1. Global fields of soil parameters used in GSWP-2. The source C84 refers to tables from Cosby et al. (1984).

Name	Description	Units	Source	Time scale
SoilClass	Soil texture class	—	ISLSCP-II	Fixed
SoilDepth	Depth of active soil column	m	ISLSCP-I	Fixed
Clay	Clay fraction	—	ISLSCP-II	Fixed
Sand	Sand fraction	—	ISLSCP-II	Fixed
Silt	Silt fraction	—	ISLSCP-II	Fixed
Organic	Organic fraction	—	ISLSCP-II	Fixed
Elevation	Mean grid elevation	m	ISLSCP-II	Fixed
Slope	Mean slope	$m\ m^{-1}$	ISLSCP-II	Fixed
CTI	Compound topographic index	—	ISLSCP-II	Fixed
W_fieldcap	Field capacity	$m^3\ m^{-3}$	ISLSCP-II	Fixed
W_wilt	Wilting point	$m^3\ m^{-3}$	ISLSCP-II	Fixed
W_sat	Saturated water content	$m^3\ m^{-3}$	ISLSCP-II C84	Fixed
W_bpower	B exponent	—	C84	Fixed
W_sat_hydc	Saturated hydraulic conductivity	$m\ s^{-1}$	ISLSCP-II C84	Fixed
W_sat_matp	Saturated matric potential	m	C84	Fixed
Albedo_vi	Visible albedo of soil (snow free)	—	ISLSCP-I	Fixed
Albedo_ir	Near-infrared albedo of soil (snow free)	—	ISLSCP-I	Fixed

issue in detail and provided an algorithm for gauge correction for wind-caused undercatch (which varies geographically depending on national instrument characteristics) that was applied in GSWP-2. The precipitation product for the baseline simulations in GSWP-2 is a hybrid of reanalysis, observations, and

Table S2. Vegetation parameter data used in GSWP-2.				
Name	**Description**	**Units**	**Time scale**	**Period**
VegClass	Vegetation class	—	Fixed	—
LAI	Leaf area index	$m^2\ m^{-2}$	Monthly	1982–95
vegFrac	Fraction of vegetation cover	—	Fixed	—
grnFrac	Greenness fraction (green LAI/Total LAI)	—	Monthly	1982–95
classFrac	Fraction of each VegClass (not in ALMA variable list)	—	Fixed	—
NDVI	Normalized difference vegetation index	—	Monthly	1982–95
FPAR	Fraction of photosynthetically active radiation	—	Monthly	1982–95
Z0Surf	Roughness length	m	Monthly	1982–95
DisplH	Zero plane displacement height	m	Monthly	1982–95
Albedo	Snow-free albedo	—	Monthly	1982–95
RootDepth	Root depth (mean 50% and 95% ecosystem rooting depth)	m	Fixed	—
Rs_min	Minimum stomatal resistance	$s\ m^{-1}$	Fixed	—

Table S3. Meteorological forcing data used for the baseline simulation of GSWP-2.				
Name	**Description**	**Units**	**Source**	**Time Scale**
Tair	Near-surface air temperature at 2 m	K	NCEP/DOE, CRU	3 hourly
Qair	Near-surface specific humidity at 2 m	$kg\ kg^{-1}$	NCEP/DOE, CRU	3 hourly
Wind	Near surface wind speed at 10 m	$m\ s^{-1}$	NCEP/DOE	3 hourly
SWdown	Surface incident shortwave radiation	$W\ m^{-2}$	SRB (with NCEP/DOE for spinup period)	3 hourly
LWdown	Surface incident longwave radiation	$W\ m^{-2}$	As above	3 hourly
Psurf	Surface pressure	Pa	NCEP/DOE, EDC	3 hourly
Rainf	Rainfall rate	$kg\ m^{-2}\ s^{-1}$	NCEP/DOE, GPCC, GPCP (and CRU for spinup period)	3 hourly
Rainf_C	Convective rainfall rate	$kg\ m^{-2}\ s^{-1}$	As above	3 hourly
Snowf	Snowfall rate	$kg\ m^{-2}\ s^{-1}$	As above	3 hourly

empirical corrections. In the hybridization process for precipitation, the reanalysis systematic errors are removed via a multiplicative scaling factor that is based on the ratio of observed monthly rainfall to reanalysis estimates:

$$[P]_{Y,M,D,T} = \frac{[P_{\mathrm{OBS}}]_M}{[P_{\mathrm{NCEP}}]_M}[P_{\mathrm{NCEP}}]_{Y,M,D,T}. \quad \text{(S1)}$$

To get the adjusted forcing data for precipitation, for instance, the value at a grid box of one of the reanalysis precipitation terms (total or convective) in a given year (Y), month (M), day (D), and 3-h time interval (T) is scaled by the ratio of the monthly mean observed precipitation to the corresponding mean value from the reanalysis for that month. This approach avoids problems of negative values in positive-definite quantities with frequent zeroes, such as precipitation. It provides the best attainable improvement in the reanalysis estimates given the lack of a long-term submonthly global observationally based dataset.

No attempt is made to adjust the monthly storm frequency (Liston et al. 1993), as was done for the 6-hourly precipitation estimates in the ISLSCP Initiative I dataset (Mitchell and Lin 1994). Neither is any attempt made to adjust the diurnal cycle, which is known to be in error in reanalyses over many regions. The main constraint is that the monthly mean precipitation should agree with the observation data, with some small differences introduced as a result of spatial interpolation. This preservation of observed monthly means is also in effect for all other hybridized variables.

Several observational precipitation datasets are available from ISLSCP Initiative II. The Climate Research Unit (CRU) (New et al. 1999, 2000) dataset from the University of East Anglia is a high-resolution (0.5°) gauge-only product, but relies on only operational data sources, does not correct for gauge undercatch, and relaxes the data to a mean annual cycle climatology when in situ data are not available. The Global Precipitation Climatology Centre (GPCC) (Rudolf et al. 1994) maintains a gridded gauge analysis that contains more stations than the CRU analysis; these data are also provided to ISLSCP Initiative II on a 0.5° grid. They do provide a separate monthly climatological correction factor to adjust for wind-caused gauge undercatch. The Global Precipitation Climatology Project (GPCP) (Huffman et al. 1997) also provides monthly analyses, which blend corrected gauge and satellite estimates. This dataset may be the best for interannually varying precipitation data, but it has the lowest native spatial resolution (2.5°). GSWP-2 uses NCEP/DOE hybrid with GPCC gauge data for the baseline period (1986–95), and CRU for the spinup period (July 1982–December 1985; when GPCC data are not available), applying the gauge correction of Motoya et al. (2002). Where the gauge density is low, the GPCP product is blended in. In this way, gauge correction can be applied at a higher spatial resolution, while maintaining the benefit of satellite data where there are no gauges.

The process used for GSWP-2 is as follows. Aggregated monthly GPCC, or CRU data, are calculated, transformed from 0.5° to 1° (the GPCP data provided by ISLSCP Initiative II are available at 1°). The Motoya et al. (2002) wind correction is applied to the unadjusted GPCC or CRU data, based on the reanalysis 10-m wind speed. First, an "uncorrected gauge" for the reanalysis precipitation is estimated based on the catch ratio (C_R) correction factor calculated by the Motoya algorithm using the daily mean reanalysis wind:

$$P_{\text{NCEP\_gauge}} = \frac{P_{\text{NCEP}}}{C_R}. \qquad \text{(S2)}$$

This is necessary because the precipitation as estimated by the analysis model is unaffected by wind, so the corresponding undercatch error must be introduced into the model estimate before adjustment. This step ensures that the final wind-corrected precipitation estimates maintain the same relative storm-to-storm totals as the NCEP/DOE reanalysis.

Second, we hybridize this "NCEP/DOE gauge" with GPCC or CRU gauge data as indicated in Eq. (S1), so that the monthly total agrees with the uncorrected gauge data. Then we reapply Motoya's wind correction to the hybrid data:

$$P_{\text{Wind\_corrected}} = C_R \; P_{\text{Hybrid\_uncorrected}}. \qquad \text{(S3)}$$

In regions of low gauge density, this result is combined with the hybridized 3-hourly version of the GPCP data:

$$P_{\text{GSWP2}} = aP_{\text{Wind\_corrected}} + (1-a)P_{\text{Hybrid\_GPCP}}, \qquad \text{(S4)}$$

where

$$\begin{aligned} a &= 1, \text{ GPCC or CRU gauge density} \geq 2, \\ a &= 0.5, \text{ GPCC or CRU gauge density} = 1, \\ a &= 0, \text{ GPCC or CRU gauge density} = 0. \end{aligned} \qquad \text{(S5)}$$

The final step is the separation of the precipitation components into rainfall and snowfall, convective and large scale. The NCEP/DOE reanalysis reports total precipitation rate, as well as a snowfall rate that is diagnosed at each model time step from the 850-hPa air temperature (or lowest model air layer temperature if the surface pressure at a given grid point is lower than 850 hPa). If this temperature is equal to or less than 0.0°C, then snowfall is designated, otherwise rainfall is chosen (K. Mitchell, 2002, personal communication). Since the snowfall criterion is based on the atmospheric model state aloft, and not surface conditions, no re-estimation of snowfall is conducted based on the hybrid near-surface air temperature. Rainfall is assumed to be total precipitation minus snowfall; no account is made for hail, sleet, ice pellets, or graupel. The NCEP/DOE reanalysis also reports a convective precipitation rate. For GSWP-2, to conform to ALMA standards, a convective rainfall rate is given where

$$\text{Rain}_{\text{Conv}} = \frac{P_{\text{Conv}}}{P_{\text{Total}}}(P_{\text{Total}} - \text{Snow}). \qquad \text{(S6)}$$

Large-scale rain would be $Rain - Rain_{Conv}$, and if necessary, convective snowfall can be estimated assuming the same ratio as for total precipitation in the equation above.

Some decisions had to be made where inconsistencies were apparent. For instance, in the bilinear interpolation of the precipitation data from the reanalysis grid to the ISLSCP grid, there were instances near coastlines where the interpolated snowfall rate exceeded the total precipitation rate. In these cases, the rainfall rate was set to zero. During hybridization, there were instances where one but not both of the observed monthly precipitation or the reanalysis precipitation was equal to zero. In these situations, it was assumed that precipitation for the month was zero. Also, due to wind correction, instances occurred where the snowfall is greater than 0.0085 kg m^{-2} s^{-1} (the ALMA limit). In these cases, the rate was reset to 0.0085 kg m^{-2} s^{-1}.

After the first set of model integrations it was found that the wind speeds from the NCEP/DOE reanalysis used for gauge correction are generally too strong, and they were not interpolated from the 10- to the 2-m level. As a result, there is a tendency for overcorrection of precipitation in the model, particularly in the case of snow. This has introduced a general positive bias in model fields such as runoff. Future versions of the forcing data and baseline simulations are planned to address this shortcoming.

Temperature. There is also more than one potential choice for near-surface temperature observations, although only the CRU dataset from the University of East Anglia is included in ISLSCP Initiative II. The monthly CRU temperature data are calculated as anomalies from a 12-month climatology that is derived relative to a fixed elevation model at 0.5°. In order to make a consistent adjustment of near-surface air temperature to the ISLSCP grid, the CRU temperatures are corrected for the altitude difference between the CRU grid and the ISLSCP Initiative II mean altitude derived from the Geographical Topography data at 30' (GTOPO32) dataset (Verdin and Verdin 1999). First, the CRU elevation data are recreated by aggregating the GTOPO5 elevation data from 5' to 0.5°. The monthly CRU temperature data are then corrected to the ISLSCP-II elevation:

$$T_1 = T_{\text{CRU}} - \frac{6.5}{1000}(Z_{\text{ISLSCP2}} - Z_{\text{CRU}}). \qquad \text{(S7)}$$

The monthly CRU data are then aggregated from 0.5° to 1°, and hybridized with the 3-hourly NCEP/DOE reanalyses 2-m air temperature data by correcting the differences of monthly diurnal range and mean:

$$T_{\text{GSWP2}} = \delta(T_{\text{NCEP}} - \overline{T_{\text{NCEP}}}) + T_1, \qquad \text{(S8)}$$

where

$$\delta = \frac{D_{\text{CRU}}}{D_{\text{NCEP}}}, \qquad \text{(S9)}$$

constrained so that

$$0.5 \le \delta \le 2.0, \qquad \text{(S10)}$$

where D is the monthly mean diurnal range of the temperature, which is reported for the CRU data, and has been calculated from the original hourly data from the NCEP/DOE reanalyses. Limits are placed on the diurnal scaling factor δ to prevent unreasonable extreme temperatures. Nevertheless, modelers have discovered unrealistic temperatures can occur over Greenland in the GSWP-2 forcing data. Results in that region should be used with caution.

Surface pressure. An altitude correction is applied to the surface pressure data, to adjust from the reanalysis model grid elevations to the ISLSCP Initiative II mean altitude:

$$P_{\text{s\_corr}} = P_{\text{s\_NCEP}} \exp\left[-\frac{g}{R\overline{T}}(Z_{\text{ISLSCP2}} - Z_{\text{NCEP}})\right], \qquad \text{(S11)}$$

where Z_{NCEP} and Z_{ISLSCP2} are the grid box mean altitudes for the reanalysis and ISLSCP Initiative II respectively, g is the acceleration due to gravity, and R is the gas constant. Here T is the mean temperature between the two altitudes, calculated using the same lapse rate used to adjust temperature:

$$\overline{T} = T_{\text{GSWP2}} - \frac{1}{2}\left[\frac{6.5}{1000}(Z_{\text{ISLSCP2}} - Z_{\text{NCEP}})\right]. \qquad \text{(S12)}$$

Specific humidity. The adjustments to temperature and surface pressure also affect the estimated specific humidity. Thus, it is also necessary to adjust the humidity to avoid incidents of supersaturation. This is done by assuming the same relative humidity (RH) before and after the corrections, and then adjusting the specific humidity accordingly to agree with the adjusted temperature, that is,

$$\begin{aligned} RH &= \frac{Q_{\text{\_before}}(0.622 - Q_{\text{s\_before}})}{Q_{\text{s\_before}}(0.622 - Q_{\text{\_before}})} \\ &= \frac{Q_{\text{\_after}}(0.622 - Q_{\text{s\_after}})}{Q_{\text{s\_after}}(0.622 - Q_{\text{\_after}})}; \end{aligned} \qquad \text{(S13)}$$

thus,

$$Q_{\text{GSWP2}} = \frac{0.622\ Q_{\text{s\_after}}\text{RH}}{0.622 - Q_{\text{s\_after}} + Q_{\text{s\_after}}\text{RH}}, \qquad \text{(S14)}$$

where Q is the specific humidity and Q_s is the saturation specific humidity. Also, in order to avoid $RH >$ 100% due to round-off error, if $Q > Qs$, then $Q = \min(Q, Q_s)$.

Radiation. Radiation forcing comes from the 3-hourly Surface Radiation Balance (SRB; Stackhouse et al. 2000) product produced at National Aeronautics and Space Administration (NASA) Langley

Research Center, and is used directly without the need for hybridization. However, SRB radiation data only cover the period from January 1986 to October 1995, and they are instantaneous fields. Therefore, we use different methods to process downward shortwave and longwave data in different time periods. To adjust downward radiation, the diurnal cycle is particularly important. Studies by Dirmeyer and Tan (2001) have shown that the radiation errors in the NCEP–National Center for Atmospheric Research (NCAR) reanalysis are very systematic from year to year, but vary substantially across both the seasonal and diurnal cycles. We create a hybrid radiation forcing dataset from reanalysis estimates by removing the climatological monthly mean diurnal cycle systematic errors calculated from the SRB and reanalysis data over the period. Some decisions had to be made where SRB data are not available. For example, there are some "undetermined" points for high-latitude bands where the solar zenith angle approaches 90° in the shortwave fields. These have been arbitrarily set equal to a small value: 10 W m^{-2}. An artifact of the original SRB data handling procedure is that shortwave radiation data are discontinuous between each month; that is, there are data gaps at the start and end of each month in the data acquired for GSWP-2 (R. Pinker 2002, personal communication). Thus, we must hybridize with NCEP/DOE reanalyses to create data for the missing points and unavailable time periods (the 1982–85 spinup period and November–December 1995).

When SRB data are available, they must be changed from instantaneous to time-averaged fields to be consistent with NCEP/DOE data. For shortwave data, we first calculate the effective solar footprints for shortwave (SW) data at time t and t+3 as well as for NCEP/DOE data at each 20-min model time step over the 3-h averaging period. Then, we compute the correction factor to multiply with $[SW(t)+SW(t+3)]/2$ to create an effective average equivalent (SW_{CSRB}) to the NCEP/DOE 3-h average over $(t,t+3\text{-}dt)$, where dt is the NCEP/DOE model time step. Since the correction factor is a ratio, it is limited (from 0.5 to 2) to avoid the extreme values (e.g., $SW_{CSRB} > 1360$ W m^{-2}). For longwave (LW) data, we simply average SRB LW(t) and LW(t+3) to create the new LW_{CSRB} data.

When SRB data are missing or not available, a multiplicative scaling is used to adjust the reanalysis as was done for precipitation. We calculated 10 (January–October) or 9 (November–December) years averaged monthly–3-hourly data from the newly created SW_{CSRB} and NCEP/DOE (not monthly mean in order to simulate the correct diurnal range), then hybridize with NCEP/DOE data:

$$(SW_{Hybrid})_{Y,M,D,T} = \frac{(SW_{CSRB})_{M\text{-}3\text{-}T}}{(SW_{NCEP})_{M\text{-}3\text{-}T}}(SW_{NCEP})_{Y,M,D,T}. \qquad (S15)$$

During hybridization, there are instances where one but not both of the observed monthly–3-hourly shortwave radiation fields from the observations or the reanalysis radiation was equal to zero. In these situations, it is assumed that radiation was zero. The combined SW_{Hybrid} and SW_{CSRB} data are the final product for GSWP-2 baseline run. The same calculation is applied for longwave data. The scaling limits and the hybridization for periods of missing SRB data have been found to leave a detectable signature in the time series of radiation forcing, but these irregularities have not been reported to have caused noticeable problems in the LSS simulations.

Other fields. The reanalysis wind products are used as is, with the 10-m wind speed provided in the forcing dataset.

Model initialization. GSWP recommended that all LSSs start their integrations from an initial condition of soil temperature based on the mean June air temperature, soil moisture at 75% of saturation, and no snow cover over ice-free points. Spinup is performed using forcing data beginning 0300 UTC 1 July 1982. LSS integrations loop through the first 12 months of forcing data until the modeler is satisfied that soil moisture has spun up and is sufficiently equilibrated. A lesson from GSWP-1 was that this spinup process overamplifies the impact of climate anomalies from that looping year on the land surface state variables. Therefore, the models then proceed with their integrations forward from July 1983–December 1985 so as to converge to a realistic "land climate" at the start of the evaluation period. The 10-year baseline integration of record covers the 10-year period from 0000 UTC 1 January 1986 to 0000 UTC 1 January 1996. If an LSS needs forcing data more frequently than every 3 h, disaggregation algorithms are provided by GSWP that conserve the time mean properties of the original data.

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