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Land-total and Ocean-total Precipitation and Evaporation from a Community Atmosphere Model version 5 Perturbed Parameter Ensemble

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Disclaimer

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Land-total and Ocean-total Precipitation and Evaporation from a CAM5 Perturbed Parameter Ensemble

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This document presents the large scale water budget statistics of a perturbed input-parameter ensemble of atmospheric model runs. The model is Version 5.1.02 of the Community Atmosphere Model (CAM). These runs are the “C-Ensemble” described by Qian et al., “Parametric Sensitivity Analysis of Precipitation at Global and Local Scales in the Community Atmosphere Model CAM5” (Journal of Advances in Modeling the Earth System, 2015). As noted by Qian et al., the simulations are “AMIP type” with temperature and sea ice boundary conditions chosen to match surface observations for the five year period 2000-2004. There are 1100 ensemble members in addition to one run with default input-parameter values.

Ensemble Statistics

We study the water budget of the atmosphere by integrating separately over total land area and total ocean area. Following Trenberth et al., the units of all water-flux variables are thousands of cubic kilometers per year. Assuming a steady state in the atmosphere, precipitation (P) and evaporation (E) over land (subscript l) and ocean (subscript o) are related to the atmosphere’s ocean-to-land transport of water (T_{ol}) by the two equations

$$E_o - P_o = P_l - E_l = T_{ol}$$

With two equations relating five variables, only three variables can be independent. We choose P_l, P_o and T_{ol} as our independent set because evaporation is the least accurately observed of the five variables.

Hydrologic steady state within the atmosphere is a good approximation for multi-year climate statistics. It holds to better than 0.5% in the default-input-parameter run of the model. At the end of this Report, we verify the approximation for our perturbed-parameter ensemble.

Total Land Precipitation

The maximum-likelihood fit to the ensemble output is shown as a dashed red curve below, together with a histogram of the original output. The model’s output with default input-parameter settings is shown by the vertical red line. The model’s simulations may be compared with the observed mean ± 1 standard *deviation values* $116.5 \pm 5.1 \times 10^3$ km^3 yr^{-1} *from Rodell et al., "The Observed State of the Water Cycle in the Early Twenty-First Century," J. Climate 2015 (Fig. 2 with enforced water and energy budget closure) -- or alternatively with* 114×10^3 km^3 yr^{-1} *from Trenberth and Fasullo, "Regional Energy and Water Cycles: Transports from Ocean to Land," J. Climate 2013 (Table 1). All of these observations are from years 2000-2010. Trenberth and Fasullo's numbers come from the Global Precipitation Climatology Project (GPCP) which also provides ground-truth calibration for Rodell's numbers. Hence the two estimates are essentially identical.*

Although the model with default input parameter values simulates total land precipitation accurately, most of the ensemble is well below the observed land precipitation rate. This result is consistent with Qian et al.'s remark about "significant biases, especially over tropics and low latitudes, such as . . . underestimated rainfall associated with the monsoons over South America, Central Africa, and Southeastern Asia."

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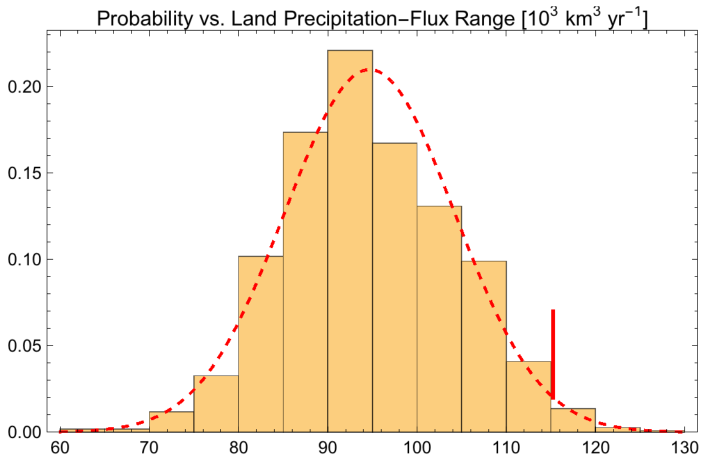

Total Ocean Precipitation

The maximum-likelihood fit to the ensemble output is shown as a dashed blue curve below, together with a histogram of the original output. The model's output with default input-parameter settings is shown by the vertical blue line. The model's simulations may be compared with the observed mean ± 1 standard deviation values $403.5 \pm 22.2 \times 10^3$ km^3 yr^{-1} *from Rodell et al., op. cit. -- or alternatively with* 386×10^3 km^3 yr^{-1} *from Trenberth et al., "Atmospheric Moisture Transports from Ocean to Land and Global Energy Flows, 2011 (Fig. 9). Trenberth's numbers again come from GPCP (for years 2002-2008) but in contrast to land precipitation, they are noticeably different from Rodell's. Probably this discrepancy is connected with the lack to rain-gauge measurements for ocean precipitation, which makes it more uncertain than land precipitation. Nevertheless, Rodell's estimate including error bars is marginally consistent with Trenberth's estimate (which does not include error bars). We will use Rodell's estimate as our observational baseline in future work.*

In any case, both the model with default input parameter values and nearly all of the perturbed-parameter ensemble gives ocean precipitation above all of the observed estimates. This result is consistent with Qian et al.'s remark about "significant biases, especially over tropics and low latitudes, such as the double ITCZ, [and] the overestimated magnitude of the northern branch of ITCZ . . ." A small fraction of the ensemble, however, gives total ocean precipitation in agreement with Rodell's estimate.

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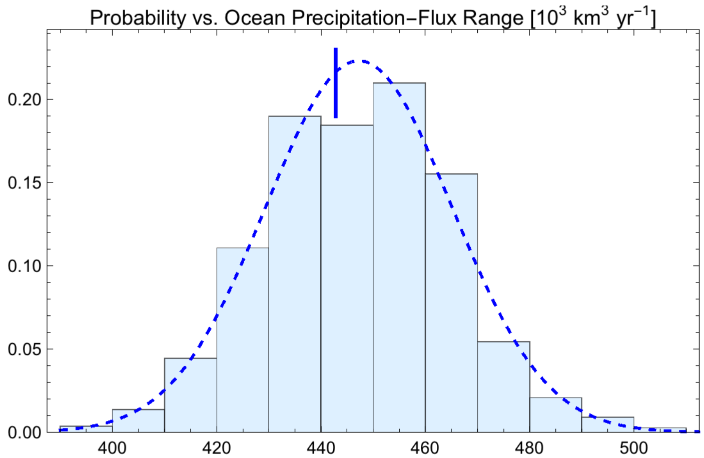

Ocean-to-Land Water Transport

The maximum-likelihood fits to the ensemble output are shown as nearly coincident dashed red and blue curves below, together with corresponding orange and blue histograms of the original output. The model's output with default input-parameter settings is shown by the vertical red and blue lines. Orange / red colors denote land $P-E$; blue colors denote ocean $E-P$. (Where histograms overlap, the orange and blue colors in the bin combine to make gray.) The near-coincidence of results using $P-E$ for land or $E-P$ for ocean is due to the model atmosphere being close to steady state, so that either method gives essentially the same atmospheric land-to-ocean water transport.

The model's simulations may be compared with the observed mean ± 1 standard deviation values 45.8 ± 4.4×10^3 km^3 yr^{-1} *from Rodell et al. 2015 -- or alternatively with* 40×10^3 km^3 yr^{-1} *from Trenberth et al. 2011 or* 33.7×10^3 km^3 yr^{-1} *from Trenberth and Fasullo 2013. We choose Trenberth and Fasullo's estimate as our observational baseline in future work, since it is based on the latest reanalysis including in situ wind and water vapor measurements (ERA-Interim). In contrast, space-based estimates of T_{ol} can be problematic, as noted by one of Rodell's coauthors (Kyle Hilburn, 2009: "The Passive Microwave Water Cycle Product," http://images.remss.com/papers/water_cycle/Hilburn_water_cycle_REMSS_TR_072409.pdf).*

Trenberth and Fasullo do not give error bars, but Figure 9 from Trenberth et al. 2011 shows five reanalyses covering years 2002-2008. For these five, ±1 standard deviation = $\pm6\times10^3$ km^3 yr^{-1}. *This number is quite conservative (large) for the Trenberth and Fasullo 2013 estimate, as some of the older reanalyses have known problems that were subsequently fixed.*

Trenberth and Fasullo's estimate implies that the model with default input parameter values simulates atmospheric water transport accurately. Most of the ensemble, however, gives transport values below observations (the average error is ~10% using Trenberth and Fasullo's estimate, and much worse using the other estimates). Nevertheless an appreciable fraction of the ensemble gives values that match Trenberth and Fasullo's estimate within our rather generous error bars.

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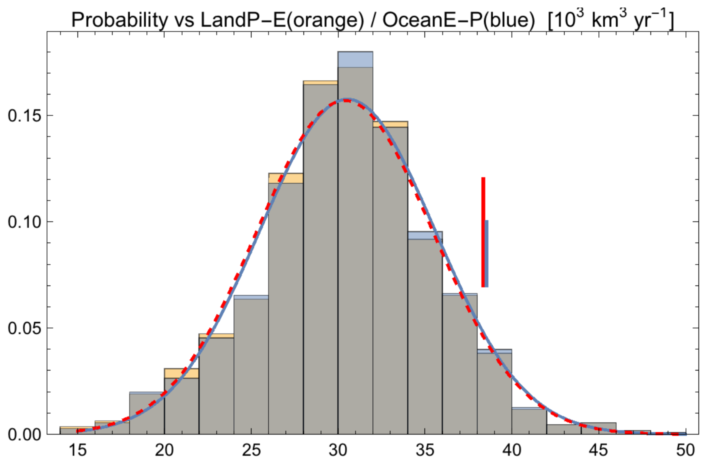

Checking for Steady State

A stronger verification of atmospheric steady state comes from differencing land $P - E$ and ocean $E - P$ for each individual ensemble member, then plotting histograms of the residuals. For each simulation, land $P - E$ equals ocean $E - P$ to within a few tenths of $10^3\ \mathrm{km}^3\ \mathrm{yr}^{-1}$, or ~1% of the ocean-to-land transport:

Out[52]=