3.5 MODEL-BASED ESTIMATES OF MOISTURE CYCLING OVER THE US AND GLOBE

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1. INTRODUCTION

We examine the ability of atmospheric general circulation models to reproduce seasonal and interannual variations in the distribution of moisture and moisture fluxes using results from the second phase of the Atmospheric Model Intercomparison Project (AMIP-2), which covers the 17-year period 1979-1995. The AMIP project (Gates 1992; Gates et al. 1999) is an effort to determine how current atmospheric general circulation models are able to simulate aspects of climate variability. Our focus here is precipitation, evaporation, and the water cycling rate globally, over North America, and over the conterminous United States.

Currently, output from 20 modeling centers is available for the AMIP-2 experiment (Fig. 1). The models have different resolutions, gridding methods, and schemes to parameterize physical processes; those concerning the important land-surface process are also indicated in Fig. 1.

We use the NCEP-NCAR reanalysis for the same 17-year period against which to compare the model results. The reanalysis incorporates the variety of observed data throughout this period in a relatively consistent way, although in data sparse regions, model biases play an important role. Despite some shortcomings in the reanalysis' characterization of the hydrological cycle (e.g., Roads et al. 1999), broader scales are captured sufficiently well for the comparisons here.

2. PRECIPITABLE WATER AND MOISTURE DIVERGENCE

Figure 2 shows maps of mean precipitable water (W) over North America from the model ensemble for winter and summer, as well as for the difference between the mean and the NCEP-NCAR reanalysis for the same time period. The general north to south gradient and the presence of high moisture in the southeastern US and Mexico are well captured by the models. The models show a small moist bias, however, throughout most of central and northern North America, and they are drier in the southwest and south central areas, especially in summer.

A measure of seasonality in precipitable water for the conterminous United States, shown in Fig. 3, indicates that individual model values range from around 12 to 25 mm, a substantial spread. The seasonal difference for reanalysis is around 16.5 mm.

We used the water balance relationship between the local rate of moisture divergence and the difference between evaporation (E) and precipitation (P) to examine moisture divergence signals over the conterminous United States. Seasonally, the region is an area of convergence over all but the summer season in both models and reanalysis (Fig. 4). The models tend to attain summerlike conditions earlier in the year than does the reanalysis. Interannual anomalies in moisture divergence (Fig. 5) appear to be related to the El Niño signal. The warm episodes in 1982-1983, 1986-1987, and the early 1990s all have lower than normal divergence both in the model mean and reanalysis, with La Niña periods featuring mostly positive anomalies for moisture divergence. The overall correlation between model mean and reanalysis is a significant, though not very large, value of 0.47.

3. MOISTURE RESIDENCE TIMES

It is instructive to examine simulations of precipitation and evaporation rates directly because they, together with precipitable water, relate to the overall vigor of the moisture circulation. Areas with the largest spreads in these quantities among the models tend to be moister regions. For example, in the area surrounding much of North America (not shown) a large range among models for both precipitation and evaporation occurs across lower

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latitudes, like the Caribbean, Pacific Ocean, and parts of Mexico, as well as the moist area on the Alaskan Pacific coast.

The amount of time that a water molecule will stay in the vapor state before returning to the surface by precipitation (or arriving from it by evaporation) is known as the residence time; its reciprocal is the global cycling rate. We estimate the residence time from the various models as the ratio of W/P or W/E (e.g. Trenberth 1998). In principle, these two values should be the same for a given model over a long period because global-mean precipitation and evaporation should match exactly. In some models, though, it is apparent that such a balance does not strictly occur. The calculations reveal that the range of water residence times may be considerable, from under 7 to somewhat more than 10 days (Fig. 6).

We are interested additionally in the interannual variability of the moisture residence time to discover how the models reflect variability associated with El Niño. The interannual anomalies of moisture residence time for each season during the 17-year AMIP-2 period are shown in Fig. 7. There are rather clear signals, with 1982-1983 and the1987 El Niño events (the latter extending into 1988) containing two examples of longer residence time than normal. Though both precipitable water and precipitation are larger during these years, the larger precipitable water appears to dominate here, so the ratio W/P increases; increased precipitation is still not large enough to make up for the larger reservoir of atmospheric water. Therefore the moisture cycling is slowed up, increasing the residence time.

4. FURTHER COMMENTS

The AMIP models show a significant spread in moisture related quantities, but collectively they appear to be reasonably close to the moisture quantities in reanalysis. Relating the attributes of models to the success of simulation is needed to determine which model characteristics most impact moisture statistics. Land-surface and cumulus parameterizations appear to be among the more significant differences from model to model, yet generally there does not appear at this time to be a large enough sample of each parameterization type to form firm conclusions about how they relate to the overall moisture parameters, like precipitable water, moisture divergence and residence time. More insight could be gained if additional AMIP-2 model simulations as well as those of succeeding experiments were available for intercomparison studies.

ACKNOWLEDGMENTS

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Model	Modeling center	Resolution	Land surface scheme	Model	Modeling center	Resolution	Land surface scheme
CCC	Canadian Centre for Climate Research	T47 L32	"bucket"	**MPI**	Max Planck-Institut für Meteorologie	T42 L19	"bucket"
CCSR	Center for Climate System Research	T42 L18	"bucket"	**MRI**	Meteorological Research Institute, Japan	T42 L30	SiB
CNRM	Centre Nationale de Recherches Meteorologiques, France	T63 L45	ISBA	**NCAR**	National Center for Atmospheric Research	T42 L18	LSM
COLA	Center for Ocean-Land-Atmosphere Studies	R40 L18	SiB	**NCEP**	National Center for Environmental Prediction	T42 L18	"bucket"
DNM	Department of Numerical Mathematics of the Russian Academy of Sciences	4x5 L21	Volodin and Lykossov (1998)	**PNNL**	Pacific Northwest National Laboratory	T42 L18	BATS
ECMWF	European Centre for Medium-Range Weather Forecasts	T63 L50	Blondin and Böttgerm (1987)	**SUNYA**	State University of New York at Albany	T42 L18	LSM
GISS	Goddard Institute for Space Studies	4x5 L12	Abramopoulos et al. (1988)	**UGAMP**	Universities Global Atmospheric Modelling Programme, U.K.	3.75x2.5 L58	MOSES
GLA	Goddard Laboratory for Atmospheres	4x5 L20	SiB	**UIUC**	University of Illinois at Urbana-Champaign	4x5 L24	other
JMA	Japan Meteorological Agency	T63 L30	SiB	**UKMO**	U.K. Meteorological Office	3.75x2.5 L19	MOSES
MGO	Main Geophysical Observatory	T30 L14	other	**YONU**	Yonsei University, Korea	4x5 L15	"bucket"

* The Simple Biosphere (SiB) scheme - Sellers et al. (1986)
* The Meteorological Office Surface Exchange Scheme (MOSES) - Cox et al. (1999)
* The Land Surface Model (LSM) - Bonan (1996)
* Biosphere-Atmosphere Transfer Scheme (BATS) - Dickinson et al. (1993)
* The Interactions between Soil-Biosphere-Atmosphere (ISBA) scheme - Noilhan and Planton (1989)
* "bucket" - Manabe et al. (1965)

Fig. 1. Models contributing to the second phase of the Atmospheric Model Intercomparison Project and some of their characteristics.

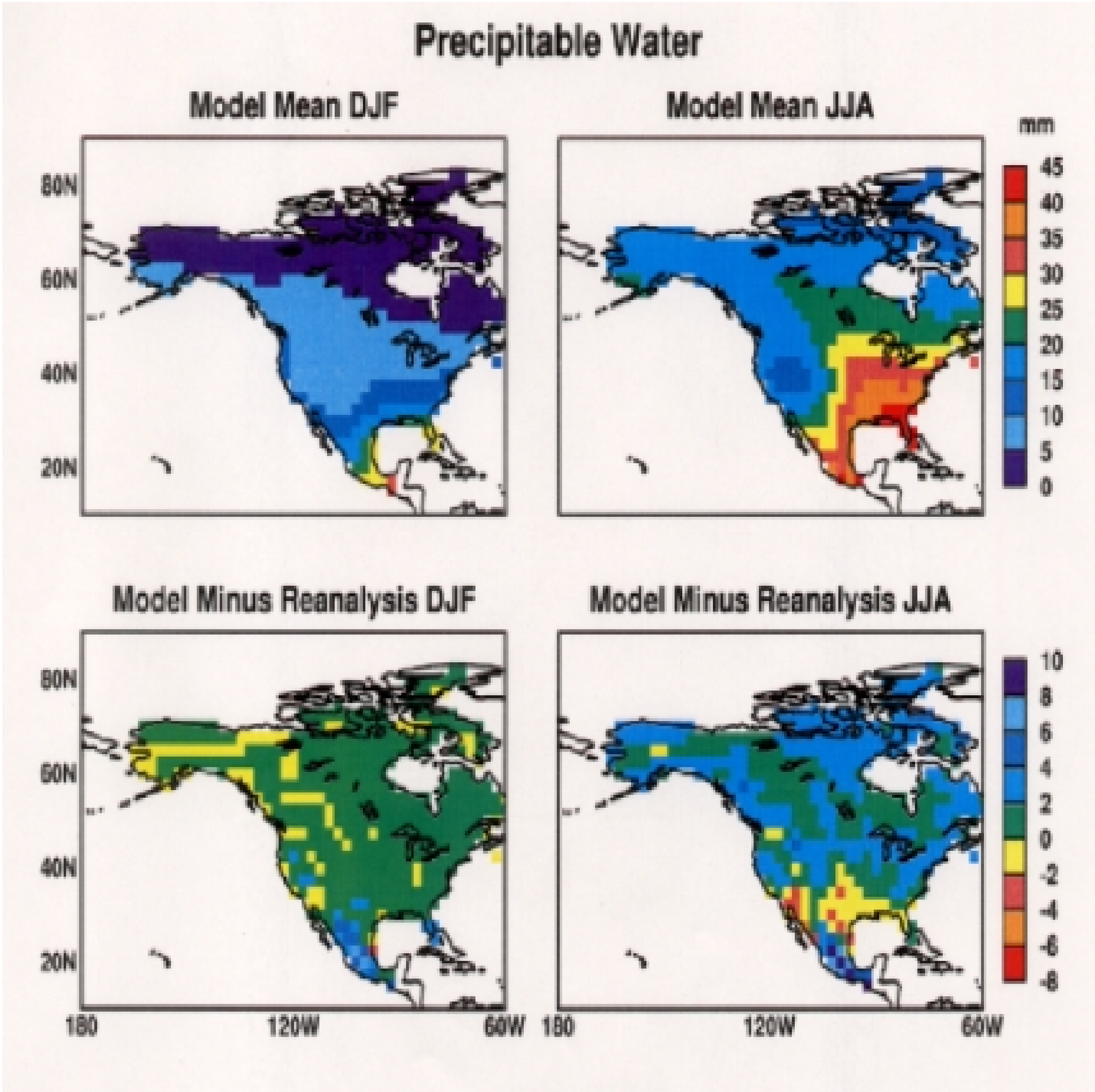

Fig. 2. Mean precipitable water over North American land areas from models contributing to AMIP-2 for each of the four composite seasons during 1979-1995. Units are mm.

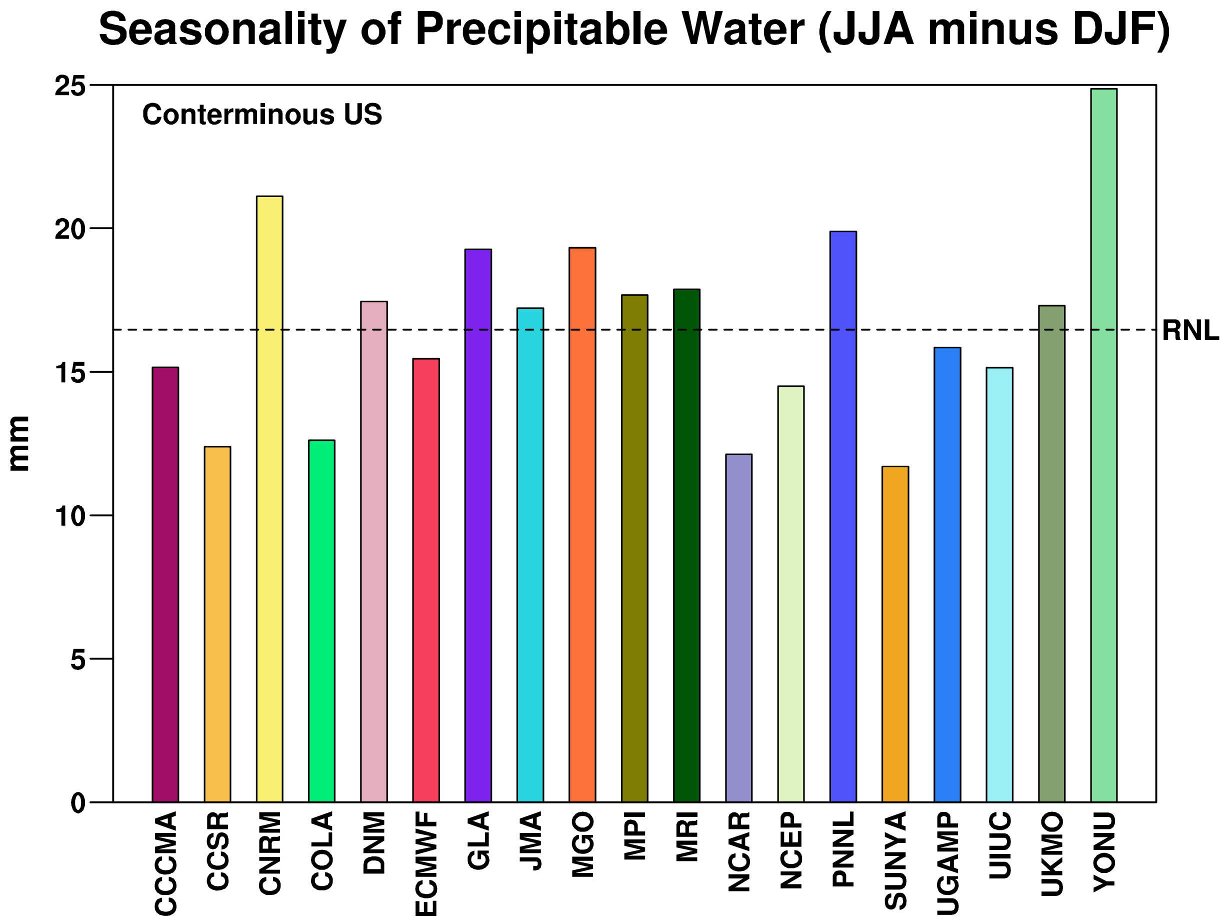

Fig. 3. The difference between summer and winter in precipitable water over the conterminous United States for each of 19 models contributing to AMIP-2. The horizontal line shows the value for the NCEP-NCAR reanalyses, which is 16.5 mm. The mean of the models, at 16.7 mm, is very close to the reanalysis value; the spread among the models has one standard deviation of 3.4 mm.

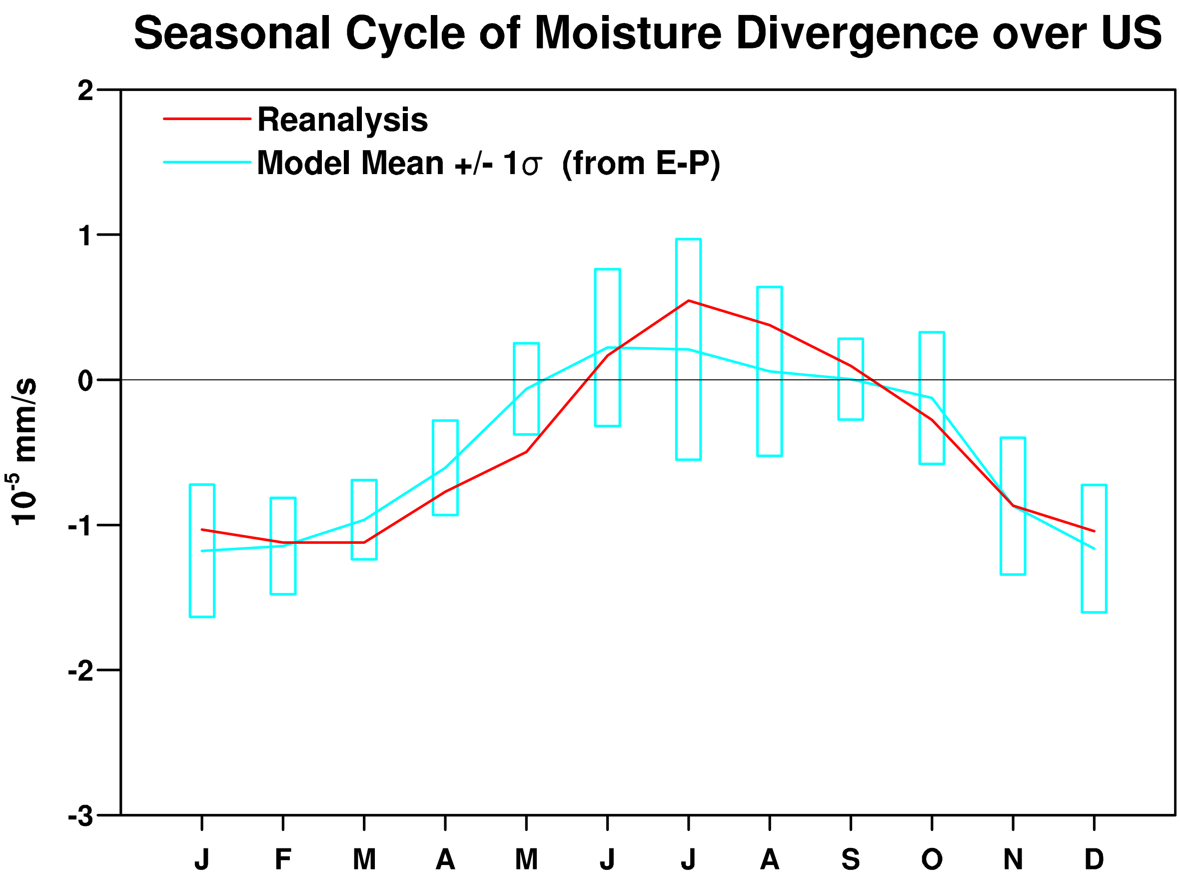

Fig. 4. The seasonal cycle of moisture divergence over the conterminous United States from NCEP-NCAR reanalysis (red line), from the mean of the model values (blue line), and from one standard deviation of model values about that mean (top and bottom of boxes). Model values are based upon the difference between evaporation and precipitation. Units are 10^{-5} mm/s.

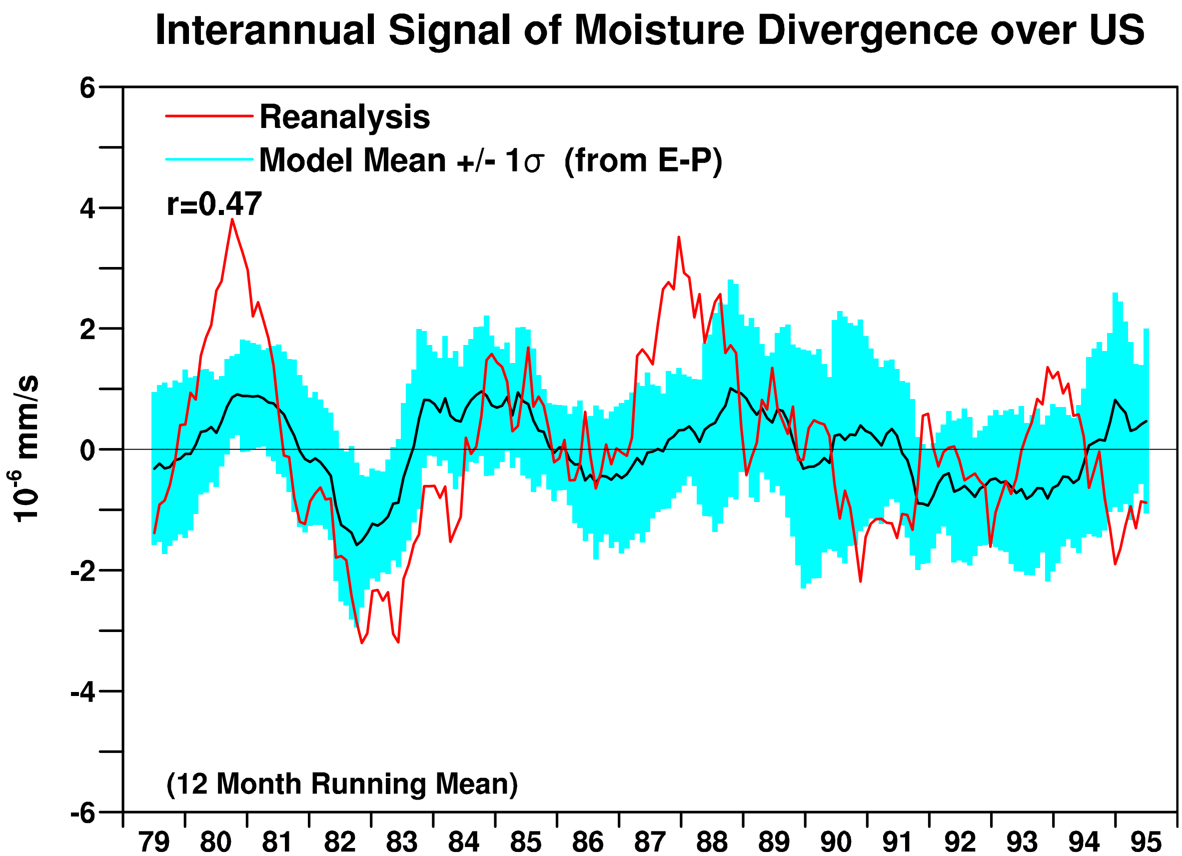

Fig. 5. The interannual signal of moisture divergence over the conterminous United States from the NCEP-NCAR Reanalysis (red line), from the mean of the model values (black line) and from of one standard deviation of model values about that mean (edge of shaded region). Model values are based upon the difference between precipitation and evaporation. Units are 10^{-6} mm/s.

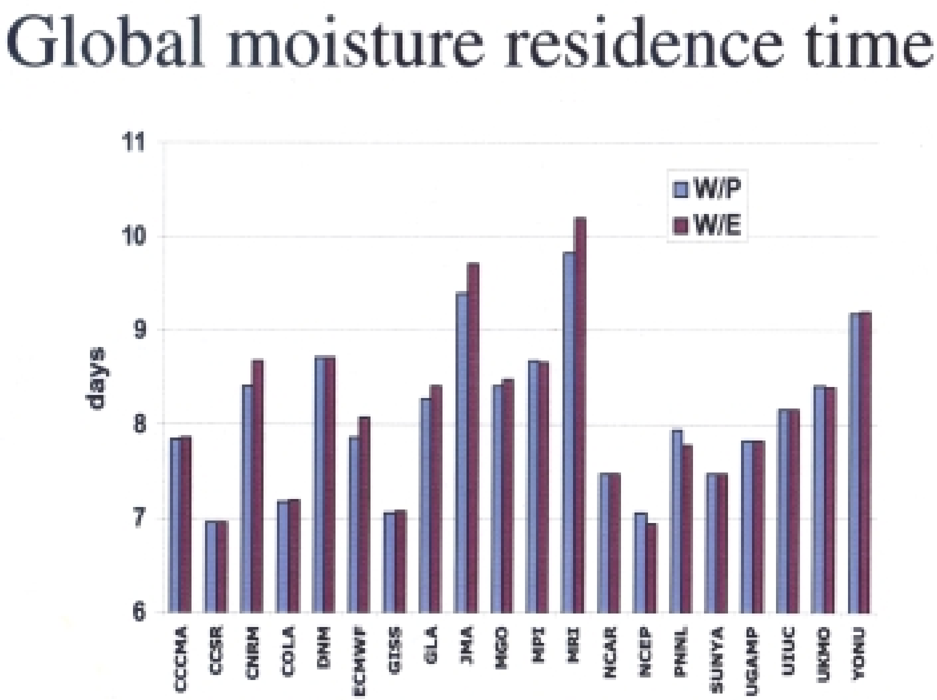

Fig. 6. Measures of the mean global atmospheric moisture residence time defined by either the ratio of precipitable water to precipitation or the ratio of precipitable water to evaporation. Units are days.

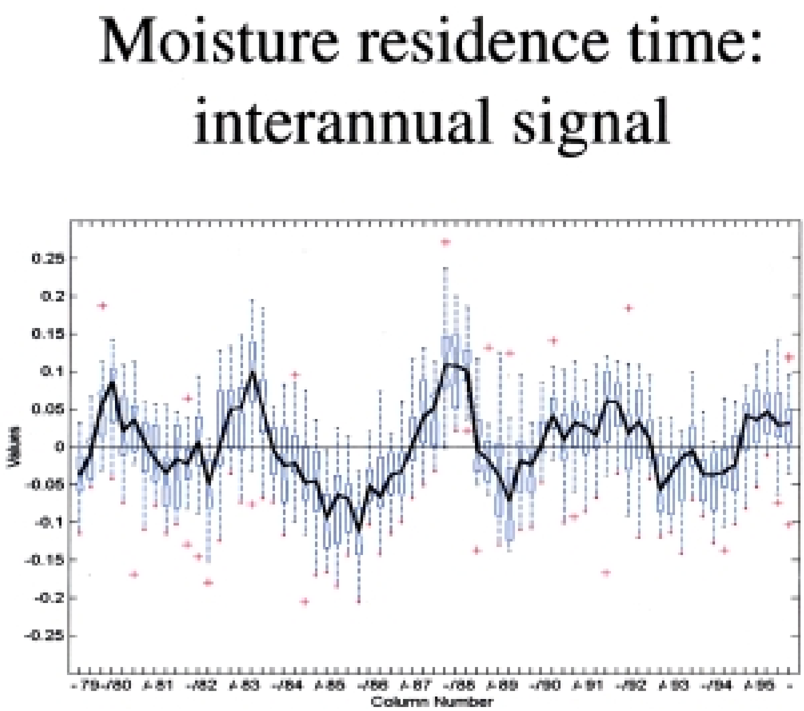

Fig. 7. Interannual anomaly for all seasons during 1979-1995 of moisture residence time based on the ratio of precipitable water to precipitation. Units are days.