Precipitation Recycling in the North American Monsoon Region

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Motivation

The NAMS region is composed of a variety of ecoregions, from deserts (lightest green) to tropical dry forests (darkest green).

What role does moisture from local evapotranspiration play in the NAMS?

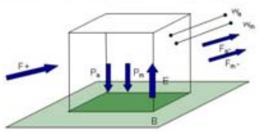
If evapotranspiration is a significant contributor to NAMS precipitation, changes in land surface hydrology will affect precipitation regimes.

We have developed the Dynamic Recycling Model to study recycling at the intra-seasonal timescale, and link precipitation recycling to moisture and energy fluxes at these timescales.

- How much of the total NAMS precipitation comes from evapotranspiration?
- As a link between the long-memory soil moisture storage and the atmosphere, what is the role of precipitation recycling in NAMS sustenance?
- Which are the primary source and sink regions for recycled precipitation? What is the spatial distribution of precipitation recycling?

Precipitation Recycling Model

The Dynamic Recycling Model is a simple and efficient way to calculate precipitation recycling at a daily timescale.



Local Recycling Ratio

$$\rho = \frac{P_m(x,y)}{P(x,y)}$$

Using the vertically integrated conservation of mass equation for the precipitable water of recycled origin:

$$\frac{\partial w_m}{\partial t} + \frac{\partial (w_m u)}{\partial x} + \frac{\partial (w_m v)}{\partial y} = E - Pm$$

$$\frac{\partial \rho w}{\partial t} + \frac{\partial (\rho w u)}{\partial x} + \frac{\partial (\rho w v)}{\partial y} = E - \rho P$$

To solve, change coordinate system.

$$\eta = x - ut \qquad E(x,y,t) \rightarrow E(\eta,\zeta,t)$$
$$\zeta = y - vt \qquad \rho(x,y,t) \rightarrow R(\eta,\zeta,t)$$
$$\tau = t \qquad w(x,y,t) \rightarrow \omega(\eta,\zeta,t)$$

Basically follow the path of the air column

$$w\frac{\partial (1-R)}{\partial \tau} = -E(1-R) \qquad R = 1 - \exp\left[-\int_0^{\tau} \frac{E}{w} d\tau'\right]$$

- The dynamic recycling model is derived formally from the equation of conservation of atmospheric moisture.
- Since the storage term is not neglected, the model is applicable at smaller temporal scales.
- The model is also computationally efficient, and enables extended spatio-temporal analyses.

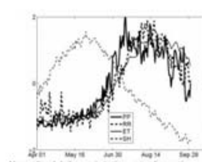
Dominguez, F., P. Kumar, X. Liang and M. Ting, 2006: Impact of atmospheric moisture storage on precipitation recycling. ***J. Climate****, 19, 1513-1530*

Data

- CEC Level II Ecoregions implicitly take into account the complex land-atmosphere interactions.
- Land-Atmospheric variables obtained from the North American Regional Reanalysis (NARR) project (Mesinger et al. 2006). NARR focuses on improved hydrologic modeling.
- NDVI data is obtained from the NOAA/NASA AVHRR 8km data.

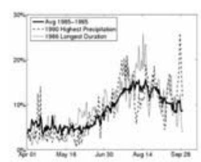
Recycling Climatology

The 11-year (1985-1995) analysis of NAMS reveals a positive feedback mechanism between monsoon precipitation and subsequent increase in precipitation of recycled origin.



Normalized daily precipitation, recycling ratio, evapotranspiration and sensible heat. The values are averaged over the region and 11 years of analysis.

The NAMS is characterized by an increase in precipitation, evapotranspiration and precipitation of recycled origin and a decrease in sensible heat.

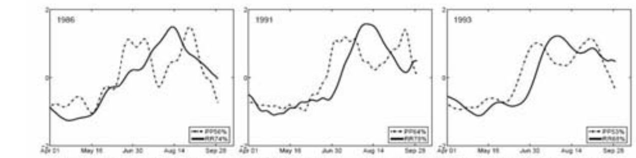


Recycling ratio for the 11-year period, and for the years with monsoons of highest precipitation and longest duration

At the peak of the season, an average of 15% of precipitation comes from evapo-transpiration, although some days it can be as high as 25%.

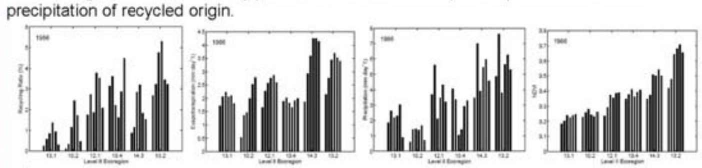
Recycling during Monsoons of Long Duration

The three longest monsoons in the 1985-1995 period (1986, 1991 and 1993) are characterized by two precipitation peaks, with an intermediate mid-summer dry period in August. Precipitation recycling peaks during the intermediate dry period.



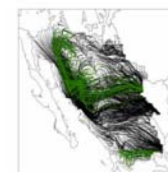
Dominant modes of precipitation (PP) and recycling ratio (RR) obtained using 18-variable M-SSA for the years with the longest monsoons. M-SSA is used to remove oscillations and trends and only extract the variability common to the entire dataset.

For example, during the 1986 Monsoon the first precipitation peak brought an increase in vegetation greenness and evapotranspiration which remained high throughout the season, even during the mid-summer dry period. The sustained evapotranspiration enhanced precipitation of recycled origin.

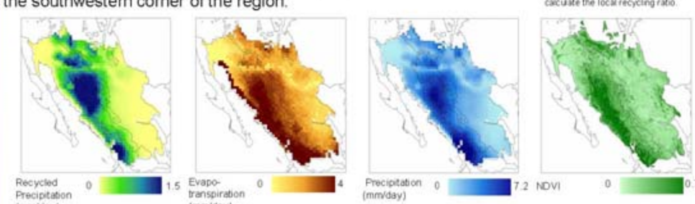


Level II Ecoregion-average recycling ratio, evapotranspiration, precipitation and NDVI for the year 1986. The six bars within each ecoregion correspond to the 15-day periods beginning Jun 16-Jun 30 in the left to Sep 1-Sep 15 in the right.

The spatial distribution during August 1-15, 1986 shows that the precipitation, evapotranspiration and vegetation greenness is higher in the southwest of the region. Recycling is highest when the moisture, which mostly enters through the east, traverses the southwest and is then transported north and east, to later precipitate in the northern Sierra Madre Occidental, its piedmont, and reaching to the northern NAMS region. Another recycling peak can be seen in the southwestern corner of the region.



Paths for August 10th 1986 used to calculate the local recycling ratio.



Conclusions

- Along with the abrupt increase in precipitation, the NAMS is characterized by higher evapotranspiration rates, and higher precipitation of recycled origin. After monsoon onset, recycling significantly contributes to monsoon rainfall. This indicates a positive feedback between precipitation and recycling.
- On average, during the peak of the monsoon 15% of precipitation comes from local evapotranspiration , but during certain periods, this value can be as high as 25%.
- The longest monsoons in the 1985-1995 period are characterized by a double peak in precipitation with recycling peaking in the intermediate dry period. This indicates a negative feedback between precipitation and recycling during monsoons of long duration.
- While the tropical dry forests of the western Pacific coastal plains, and the temperate forests of the Sierra Madre Occidental have the highest evapotranspiration, a significant amount of precipitation of recycled origin falls north east of these regions.

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