Using Regional Climate Models and Lagrangian Back Trajectories to Estimate the Source Areas of Water Vapor

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Where did the water vapor that rained here, come from? This is the basic question behind studies into water vapor source regions and precipitation recycling. Estimates of precipitation recycling using highly simplified bulk formulations have existed for some time. Over the last decade, attempts to estimate water vapor source regions more generally using back trajectories have appeared. Some fairly strong and often broken assumptions are required by these back trajectory methods. In this study I use the output from a regional climate model simulation to calculate back trajectories and estimate water vapor source regions. This is done multiple times, each time further relaxing the assumptions involved. The impact this has on the water vapor source regions, precipitation recycling and the limitations of the method are explored.

1. Introduction

Knowledge of the source regions of water vapor is required in order to quantify precipitation recycling and the potential impacts of land use changes and changes in Sea Surface temperatures etc. There is a large and growing body of regional climate model simulations with resolutions that can capture the regional and local scale effects on precipitation. Here I attempt to use this regional climate model and Langrangian back trajectories to quantify water vapor source areas.

2. Regional Climate Model

MM5
- nonhydrostatic
- compressible
- primitive equation
- terrain following σ vertical coordinate
- parameterizations include
  - Grell cumulus scheme
  - MRF PBL
  - Reisner microphysics
  - RRTM radiation scheme
  - Noah land surface scheme

LBC – NCEP/NCAR Reanalysis

Simulation
•27km horizontal resolution
•23 levels in vertical
•1999 – 2004
•3 hourly output
•1st 2 months discarded as spin-up

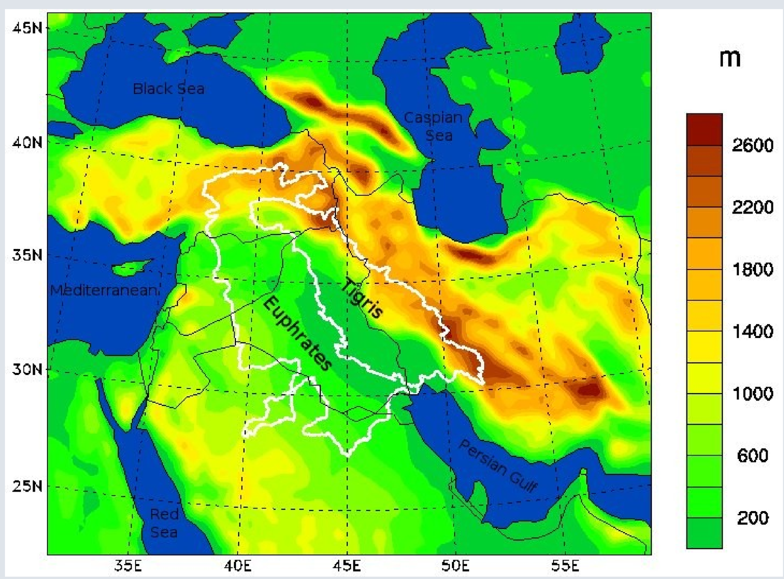

Figure 1: Regional Climate model terrain.

3. Back Trajectory Model

The basic back trajectory model is based on the quasi-isentropic model of Dirmeyer & Brubaker (1999). In their application of the model they combined model and observed data, here all data comes from the regional climate model. The method as implemented here is
- Calculated for every grid cell with >0.5mm of precipitation that day.
- 300 largest precipitation days for each watershed calculated. (% of total precip Euphrates-77.3%, Tigris-85.7%, Euphrates-Tigris-76.5%)
- Back trajectories are calculated using a fully implicit approach horizontally and are assumed to travel along isentropes vertically (unless this would drive them into the ground)
- Height of parcel release is determined randomly from a humidity weighted vertical profile
- Time of parcel release (within the day) is determined randomly from a precip weighted time profile
- Parcels are tracked using 10 minute time steps with wind, temperature etc interpolated linearly in space and time from the MM5 27km 3 hourly dataset
- At each step the fraction of the precipitable water accounted for by the evaporation is recorded until
  - The total evaporation equals the precipitable water
  - A domain boundary is reached.

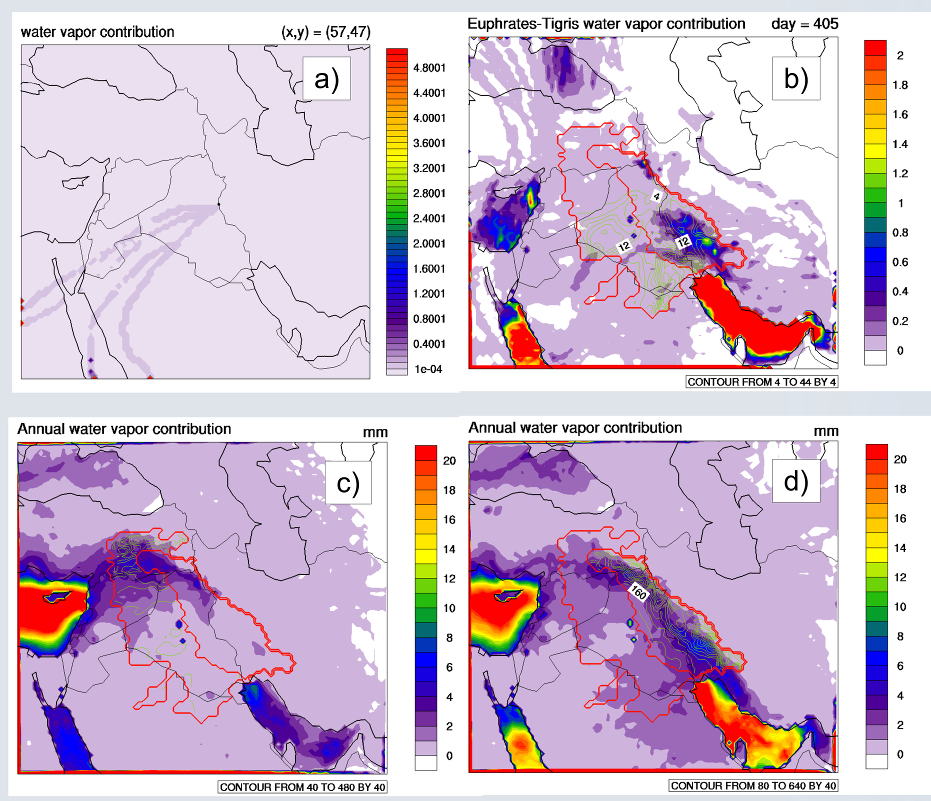

Figure 2: Examples of water vapor source regions for a) 6 parcels released released from a single point; b) all parcels released within the Euphrates-Tigris watershed on a single day; and the mean annual water vapor contribution for a) the Euphrates watershed and b) the Tigris watershed. Red contour shows the Euphrates-Tigris watershed. Green contours show the precipitation

Model Assumptions

•The vertical distribution of water vapor indicates where the precipitation forms.
•The entire atmospheric column is vertically well mixed.
•Parcels always move along isentropes.
•The only source for parcel moisture is surface evaporation
•The only sink for parcel moisture is precipitation

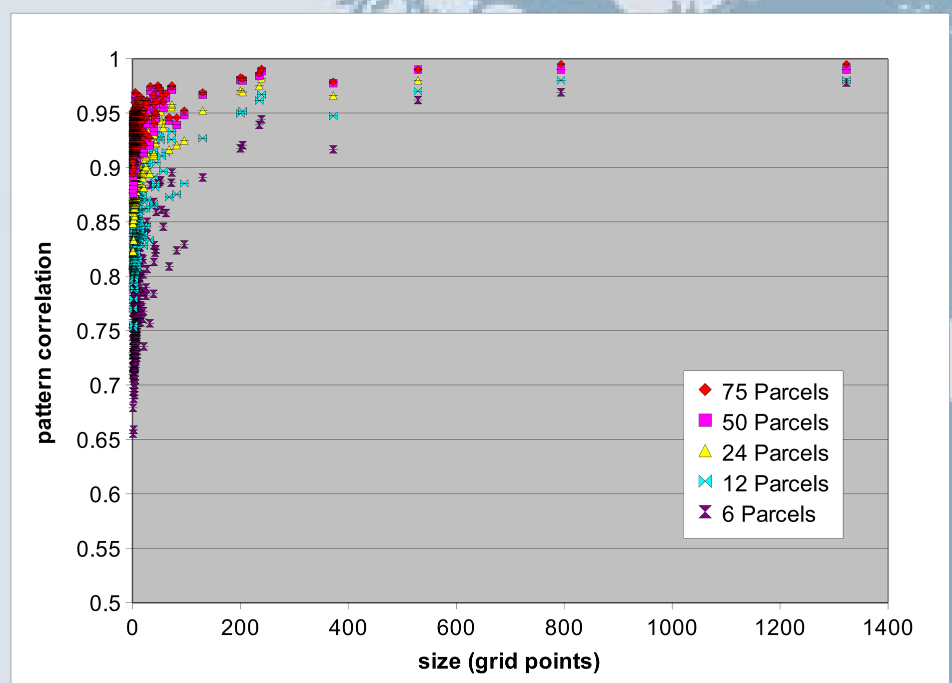

Figure 3: Pattern correlations for various size watersheds and various numbers of parcels compared to 100 parcels.

4. How many parcels?

Since the number of parcels released is directly related to the computation time required, it is desirable to release the smallest number of parcels that produces results that are “close enough” to the result obtained by releasing a very large number of parcels. Here I measure the pattern correlation between the water vapor contribution obtained when 100 parcels are released every day and when fewer parcels are released. Results are plotted in figure 3 for all 222 sub-watersheds of the Euphrates-Tigris. Results show that for an area of at least 17 pixels releasing 24 parcels produces a pattern correlation better than 0.9. The following experiments all use 24 parcels.

5. Experiments relaxing assumptions

Various experiments were conducted that relaxed some of the original assumptions. The change in the back trajectory model and the resulting pattern correlation when compared to the original model, and the precipitation recycling in the Euphrates-Tigris watershed are shown in Table 1.

5. Conclusions

Changing the release height of parcels or the method of vertical advection causes changes in the pattern of water vapor contribution but results in only minor changes to the amount of precipitation recycling. Assuming the atmosphere is well mixed only within the PBL means that changes in moisture in parcels above the PBL cannot be linked directly to evaporation occurring at the ground below it. Moisture changes in parcels above the PBL tend to happen faster than parcels within the PBL can accumulate moisture from evaporation.

Experiment	Description of change	Pattern Correlation	Precipitation recycling
0	No change	1	1.13%
1	Parcel release height based on vertical profile of water vapor plus condensed hydrometeors	0.66	1.23%
2	Parcels follow equivalent potential temperature surfaces	0.72	0.90%
3	2 & split the atmosphere at the PBL. Within the PBL surface evaporation contributes as a fraction of the within PBL precipitable water, above the PBL changes in mixing ratio are tracked (that is, entrainment and detrainment is permitted)	In PBL – 0.372 Total – 0.638	In – 0.79% Total – 29.36%
4	3 & convective precipitation mixes the whole column, hence surface evaporation effects whole column	In – 0.376 Total – 0.643	In – 0.73% Total – 28.83%
5	1 & 3	In – 0.373 Total – 0.640	In – 0.78% Total – 29.88%
6	1 & 4	In – 0.377 Total – 0.646	In – 0.72% Total – 29.79%
7	1 & 3 but instead of 2 parcels are advected using w	In – 0.456 Total – 0.713	In – 1.27% Total – 17.9%
8	1 & 4 but instead of 2 parcels are advected using w	In – 0.457 Total – 0.714	In – 1.05% Total – 17.3%

Table 1: Change from Dirmeyer and Brubaker (1999) for each experiment. The pattern correlation compared to D & B (1999) and the precipitation recycling in the Euphrates-Tigris watershed.

Dirmeyer, P.A., and K.L. Brubaker (1999), Contrasting evaporative moisture sources during the drought of 1988 and the flood of 1993, J. Geophys. Res.-Atmos., 104(D16), 19383-19397.