Using HDO and H_2O Measurements from the Tropospheric Emission Spectrometer to Constrain a Quasi-Lagrangian Mass Transport Model

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Stable water isotopes are useful in diagnosing the global hydrologic cycle since isotopic fractionations, which occur during evaporation and condensation, give rise to measurable variations in the isotopic composition of water vapor. In this study, a quasi-Lagrangian mass transport model assumes that the balances of moisture and isotopes along trajectories arriving at Tropospheric Emission Spectrometer (TES) observation sites are explained by losses from precipitation and gains via turbulent transport from the near-surface.

Vertically integrated H_2O (hereafter q) and HDO/H_2O (hereafter R) values are found at the TES observation locations using the mass weighted values from the respective TES profiles for the 500-825 hPa layer. In order to establish a Lagrangrian framework with which to study the regional isotopic budgets, back trajectories originating from each TES observation location from September, 2004 to March, 2008 (614064 instantaneous observations) were calculated, assuming an arrival height in the middle of the 500-825 hPa layer.

Along the set of back trajectories, the TES observations that occur within one hour and one half of a degree along the one to three day portions of the back trajectories are found (hereafter crossings). Derived values of q and R at the crossings are found from the respective TES profiles using the vertically integrated, mass weighted values for the 325 hPa thick layer centered at the pressure level of the parcel (as deduced from the trajectory model). As such, the net result is 95963 one to three day back trajectories with endpoints in three dimensional space containing mass weighted TES q and R values found over a 325 hPa thick layer.

Using these segments, we have devised a model with two budget equations that approximates the gains and losses of water and deuterium into and out of the parcels. The equation for change in water amount over time along the trajectories is represented simply as

$$\frac{\partial q}{\partial t} = S - L = k(q_s - q) - aq \qquad (1)$$

where the terms, S and L [(mm of H_2O)]/day], represent the rate of supply of water by turbulent transport and the loss of water via precipitation, respectively. The rate parameters k and a (days^{-1}) are used as free variables to solve for the timescales of refreshment and losses of moisture into and from the parcels, respectively. The term, q_s (mm of H_2O), represents the saturation specific humidity at the moisture source region, and is a function of near-surface temperature. A similar budget for deuterium (hereafter s, which is equivalent to Rq) is represented by

$$\frac{\partial s}{\partial t} = S_s - L_s = k\mu(s_s - s) - a\alpha s \qquad (2)$$

where the terms, S_s and L_s [(mm of HDO)]/day], represent the rate of supply of HDO from turbulent transport and the loss of water via precipitation, respectively. Additionally, s_s is a free parameter representing the amount of HDO at the source region, μ represents kinetic isotopic fractionation during diffusive mixing (0.995 for this study), and α is a free parameter representing the effective isotopic fractionation during condensation.

Equations (1) and (2) may be integrated analytically to generate modeled values of q and R given the upwind q and R values, the length of the trajectories, and the free parameters in the model (k, a, s_s, and α). Minimization of the mass weighted, percent differences of modeled versus observed downstream values of q and R over a set of seasonal trajectories proceeds by use of a cost function,

$$J = \frac{\sum_{obs} \Theta^2 \cdot \left\{ \left[\frac{(q_{\mathrm{mod}} - q_{obs})}{q_{obs}} \right]^2 + \left[\frac{R_{\mathrm{mod}} - R_{obs}}{R_{obs}} \right]^2 \right\}}{\sum_{obs} \Theta^2}$$

where the term, Θ, represents mass weighting and is equal to q at the downstream TES observation. We use numerous trajectories ($n \geq 100$) to estimate the free parameters for the group as a whole that minimize the cost function, J, given that each trajectory in the group varies in length and has unique q and R values provided by TES. For five by five degree grid boxes over the domain 0-360E and 60S-60N, the set of trajectories used for each grid point is found by incorporating all trajectories that have their downstream TES observation within a circle of radius 1000 km (approximately ten degrees) from the location of the respective grid point. This method thus oversamples the trajectory information to produce a five by five degree grid of the best-fit parameters for each grid point.

Preliminary results show good agreement between moisture divergence values derived from our model (simply $S - L$) and those derived diagnostically from the NCEP/NCAR analysis (not shown). However, one advantage of the isotopic model is that we can separate out the source and loss components individually. **Figure 1** shows the timescale for moisture refreshment due to turbulent transport of near-surface moisture. The tropical convection zones show quick refreshment of moisture in the 500-825hPa layer, whereas the subtropical high-pressure areas show much longer timescales for moisture refreshment.

Figure 2 shows the effective equilibrium fractionation seen in the model runs. Fractionation over the monsoonal regions (SE Asian in JJA and N Australia and the Amazon in DJF) is greatest, as expected by 'amount effect' theory.

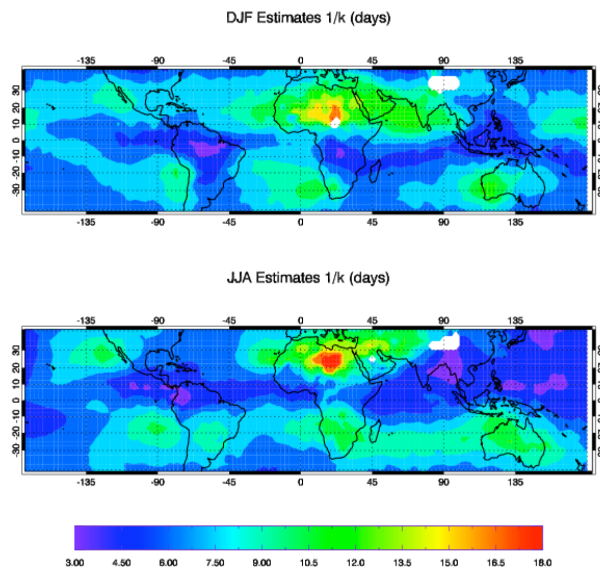

Figure 1: Timescale for H_2O refreshment in parcels

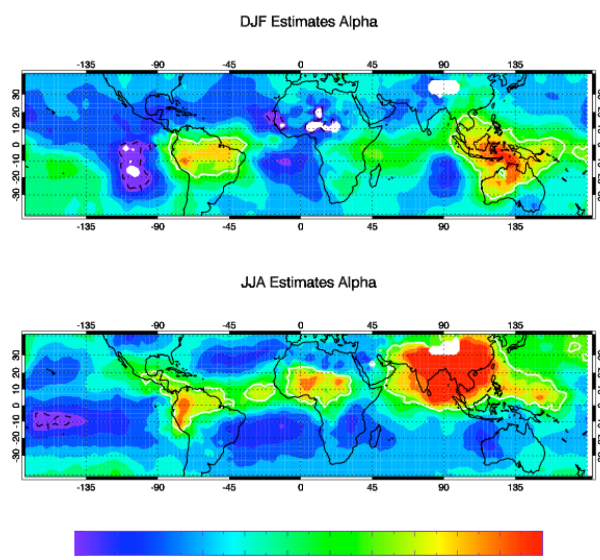

Figure 2: Effective equilibrium fractionation in parcels