# Dominant Balances and Exchanges of the Atmospheric Water Cycle


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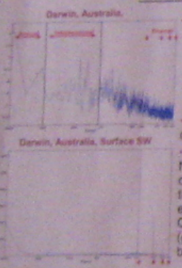
## 1. Introduction and Background

- Recent improvements in observations and data assimilation techniques enable high-resolution evaluations of the atmospheric water cycle, but the regional and temporal behaviors of the water cycle are still not fully characterized. Ruane and Roads (2007a) showed that the regional simulation of diurnal water cycle components showed distinct regional behaviors that governed the balances and exchanges of moisture througout the atmospheric column, often propagating errors or bypassing physical mechanisms with inadequate parameterizations. Ruane and Roads (2007b) identified unique behaviors in the variance of precipitation across a range of subseasonal time scales in both global models and high-resolution precipitation products, but the nature of these variations could not be assessed without examining the coincident variations in other water cycle components. This study, soon to be submitted to the *Journal of Climate* and carried out using model output developed under the framework of the Coordinated Enhanced Observing Period (CEOP; Koike, 2004), attempts to track the variation in moisture as it moves between water cycle components at different scales.

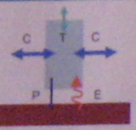
## 2. Methodology



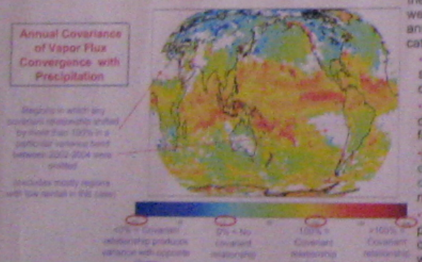

- Atmospheric water may be balanced according to:

$$\frac{\partial\{q\}}{\partial t} = -\nabla \bullet \{vq\} + E - P$$

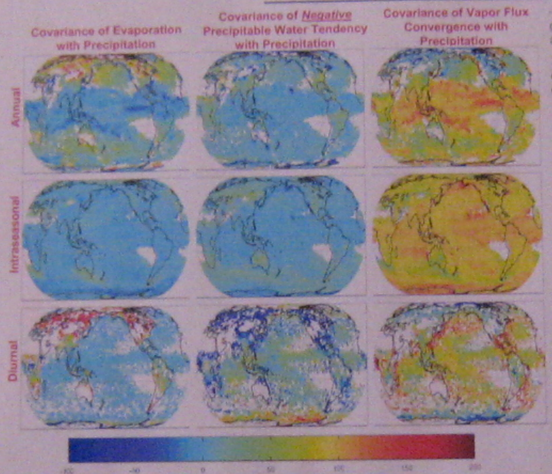
Precipitable Water Tendency = Vapor Flux Convergence + Evaporation - Precipitation




- This balance holds for both the mean and transient portions of each component of the water cycle, the latter being the focus of this study.
- Global 0-3hr and 3-6hr forecasts from successive 6-hour initializations of the NCEP/DOE Reanalysis-2 (Kanamitsu et al., 2002) were linked together to form a comprehensive time series covering 2002-2004. Precipitation (governed mainly by the Simplified Arakawa-Schubert convection scheme, Pan and Wu, 1995), evaporation (governed by the thermodynamics of the Oregon State Univeristity's OSU2 land-surface model, Pan and Mahrt, 1987), and precipitable water tendency (governed by assimilated observations) come directly from the model framework, but vapor flux convergence was calculated as a residual of the other three to close the balance. These three annual time series were then bandpass-filtered into orthogonal annual, intraseasonal, and diurnal variance categories:
  - Annual Band: 80 days – 1 year. Captures seasonal shifts, monsoons, and the migration of the ITCZ.
  - Intraseasonal Band: 7-80 days. Contains dynamical interchanges that are independent from direct solar forcings.
  - Diurnal Category: Narrow bands centered on 24-, 12-, 8-, and 6-hour periods as dictated by solar forcing. Captures the mean diurnal cycle of precipitation.
- Covariance maps between each component pair (such as the one to the left) were calculated and are evaluated here. Regions with large interannual variations in covariance were omitted.




## 3. Covariant Behavior of Water Cycle Components

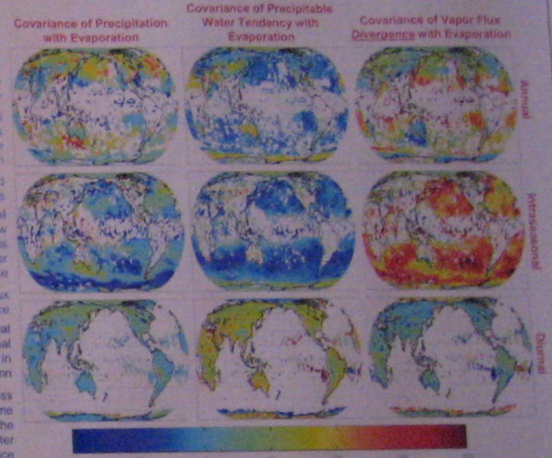



- Notable meridional gradient in dominant annual exchanges
  - ➢ Tropical precipitation covaries with vapor convergence
  - ➢ High-latitude precipitation covaries with evaporation
- Shift from continental to marine air mass evident in northern ocean basins
- Intraseasonal precipitation dominated by vapor convergence
  - ➢ particularly over oceans
- Strong land/sea diurnal differences
- Precipitation over land tends to occur in afternoon when evaporation is normally at its peak
  - ➢ not necessarily the same days
- Precipitation over oceans covaries with vapor convergence

### PRECIPITATION

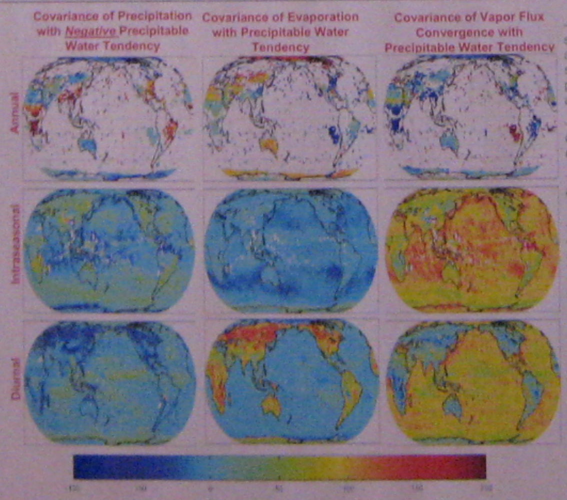
- Large differences in precipitation's covariance between annual, intraseasonal, and diurnal variance categories.
- Unique behaviors in the water cycle are also evident in different regions and surface types. Comparisons with high-resolution precipitation products show similar results.

- Annual tropical evaporation signal is insignificant
- Evaporation from land normally covaries with precipitation
  - ➢ Column holds additional moisture over land regions with large-scale convective inhibition
  - ➢ Over ocean evaporated moisture often diverges
- Weak intraseasonal evaporative signal has low significance and is dominated by other components' variance
  - ➢ particularly vapor flux divergence
- Regular diurnal evaporative moisture signal is mostly held in atmospheric column
  - ➢ Precipitation occurs less regularly but with the same phase, reducing the precipitable water tendency's covariance
- Lack of diurnally-varying SSTs lead to low-significance over oceans




### EVAPORATION

- Evaporation's variance is significant almost exclusively over land in diurnal category, but almost exclusively over the ocean in the intraseasonal category.
- Large meridional gradients in significance are also evident in the annual band.

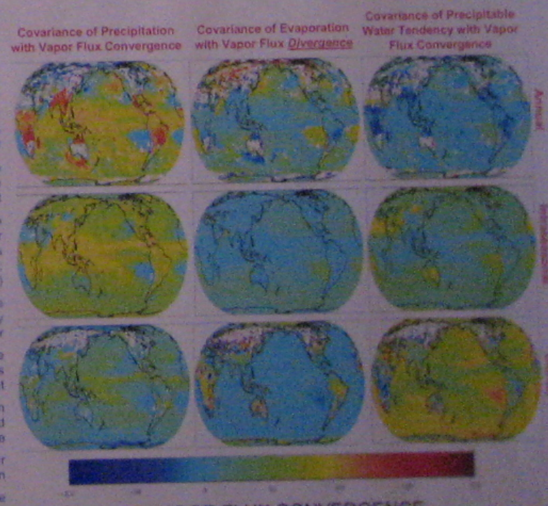



- Low annual significance due to approximate steady-state of annual precipitable water amounts
- Precipitation dominates low-latitude covariance
- Evaporation dominates arid regions
- Vapor flux convergence dominates intraseasonal variance
- Evaporation shows very little covariance
- Large diurnal land/sea contrast
  - ➢ Precipitable water tendency over land is thermodynamically controlled (evaporation)
  - ➢ Precipitable water tendency over ocean is dynamically controlled (vapor flux convergence)

### PRECIPITABLE WATER TENDENCY

- Precipitable water tendency only shows annual signal in regions with large annual temperature (and thus specific humidity) variation.
- The land/sea contrast is clear in the diurnal band, with precipitable water governed by thermodynamical activity over the land and dynamical activity over the oceans.

- Vapor flux convergence covaries with monsoonal precipitation
- Zonal gradient in mid-latitude ocean basins indicative of shifts in air mass
- Negative precipitable water tendency covariance signifies strong precipitation signal
- Vapor convergence is the dominant variance of the intraseasonal band
  - ➢ Most often leads to precipitation, particularly over tropical oceans (in regions associated with MJO; Madden and Julian, 1994)
  - ➢ Areas with large-scale convective inhibition react by increasing precipitable water
- Dynamical convergence over ocean mostly lifts precipitable water content
- Moisture from evaporation diverges from tropical land masses on diurnal scale
- Diurnal convergence over ITCZ leads to precipitation
- Dynamics over high-latitude land masses are inconsistent




### VAPOR FLUX CONVERGENCE

- Vapor flux convergence is controlled primarily by low-level dynamical activity.
- Dominates intraseasonal variance and activity over the oceans in all other components, but moisture is favorably transferred into precipitation in most regions.

## 4. Conclusions

- Covariance between each component of the atmospheric water cycle was calculated from 2002-2004 at every grid point in the NCEP/DOE Reanalysis-2 for diurnal, annual, and intraseasonal time scales. Results demonstrate that the water cycle has unique characteristics owing to temporal scale, spatial scale, surface type, latitude, and interactions with the large-scale circulation, among other influences.
- Many features are simulated well, including the Inter-Tropical Convergence Zone (ITCZ), monsoonal regions, arid and stratocumulus regions, diurnal thermodynamics, and annual variations in precipitable water. The patterns of low-significance are also informative, and further study of regional behaviors show promise.
- Precipitable water over land is shown to be thermodynamically constrained, while over the oceans it is dynamically-constrained. The transition from continental to marine influence of the mid-latitude westerlies is also apparent.
- Intraseasonal variance is dominated by vapor flux convergence generated by propagating systems, as the lack of direct external forcings at these scales leaves dynamical constraints in nearly complete dominance of the water cycle.

## References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