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PROGRESS REPORT

Title: Structure and Variability of Water Vapor in the Upper Troposphere and Lower Stratosphere

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Upper-tropospheric humidity (UTH) has been synoptically mapped via an algorithm that rejects small-scale undersampled variance, which is intrinsic to asynoptic measurements of water vapor, cloud, and other convective properties (Salby and Sassi, 2001). Mapped distributions of UTH have been used, jointly with high-resolution Global Cloud Imagery (GCI), to study how the upper troposphere is humidified (Sassi et al., 2001). The time-mean distribution of UTH is spatially correlated to the time-mean distribution of cold cloud fraction η_c ($T < 230$ K). Regions of large UTH coincide with regions of large η_c, which mark deep convection. They also coincide with regions of reduced vertical stability, in which the vertical gradient of θ is weakened by convective mixing. Coldest cloud cover is attended convective overshoots above the local tropopause, which is simultaneously coldest and highest (Gettelman et al., 2001). Together, these features reflect the upper-troposphere being ventilated by convection, which mixes in moist air from lower levels.

Histograms of UTH and η_c have been applied to construct the joint probability density function, which quantifies the relationship between these properties. The expected value of UTH in convective regions is strongly correlated to the expected value of η_c. In ensembles of asynoptic samples, the correlation between E[UTH] and $E[\eta_c]$ exceeds 0.80. As these expectations reflect the most likely values, the strong correlation between E[UTH] and $E[\eta_c]$ indicates that the large-scale organization of UTH is strongly shaped by convective pumping of moisture from lower levels.

The same relationship holds for unsteady fields – even though, instantaneously, those fields are comprised almost entirely of small-scale convective structure. The spatial autocorrelation of UTH, constructed at high resolution from overpass data along ascending and descending tracks of the orbit, is limited to only a couple of degrees in the horizontal. This mirrors the spatial autocorrelation of η_c, which likewise operates coherently on short scales. The short correlation scale of UTH, which reflects the scale of individual convective systems, is comparable to the spacing of retrievals from MLS. These scales are undersampled in the asynoptic measurements. Despite their prevalence, the mapping algorithm described above successfully recovers synoptic behavior operating coherently on large scales. It reveals eastward migration of anomalous UTH from the Indian ocean to the central Pacific, in association with the modulation of convection by the Madden-Julian oscillation (Sassi and Salby, 2001).

These findings have now been extended upward, across the tropical tropopause and into the lower stratosphere. MLS retrievals of water vapor below 147 mb (Read et al., 1995) and above 48 mb (Waters, 1998) have been bridged with the water vapor retrieval of Pumphrey (1999), which has been synoptically mapped in like fashion. Collectively, these mapped data provide a continuous description of water vapor from the tropical upper troposphere through the stratosphere. Jointly with contemporaneous GCI and motion from ECMWF analyses, it reveals a close association between deep convection, thermal structure, and humidity structure.

The structure of anomalous mixing ratio clearly marks a convective source of moisture in the near equatorial region, maximizing at 200 mb. Relative humidity, on the other hand, maximizes somewhat higher, due to the influence of temperature, which continues to decrease up to 100 mb. Histograms of cloud fraction, represented in terms of potential temperature, indicate this altitude range as the layer of strong convective outflow, where convective detrainment and cloud anvil are prominent. The histogram of cloud brightness temperature exhibits a plateau at these levels, distinct from its sharp decrease with altitude at lower levels. In fact, a radiative calculation that accounts for the sharp decrease with height of liquid water content (Salby et al., 2001) recovers the characteristic bimodal distribution of cloud fraction, which then actually increases at upper levels. It's large near 200 mb, the same region where water vapor mixing ratio maximizes.

Cloud detrainment at these levels serves as a source of water vapor, which diverges from convective systems. The same structure appears for horizontal divergence. Both exhibit fluctuations that are strongly correlated to fluctuations of 200-mb humidity. Coincident with the layer of convective outflow is increased vertical separation of isentropes. Most noticeable in regions of cold cloud fraction, it reflects a weakening of vertical stability by convective mixing. It too fluctuates coherently with deep convection, which elevates isentropes above 200 mb while depressing them below 200 mb. Weakened stability, however, is visible up to 100mb, even though most of the anvil and outflow are restricted to lower levels. Cloud structure above 150 mb corresponds to overshooting towers, which dominate anvil (distinguished by much larger cloud fraction) at lower levels.

A relationship to convection is also found above 100 mb. There too, fluctuations of water vapor are strongly correlated to 200-mb divergence. Divergence above 100 mb, however, reverses sign. This suggests subsidence immediately overhead convection, as has been inferred from other features. It prevails on the winter side of convection, where poleward motion of the Hadley circulation is strong and water vapor mixing ratio surfaces are depressed. Conversely, on the summer side of convection, mixing ratio surfaces are elevated, implying ascending motion that comprises the Brewer-Dobson circulation.

References

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