12A.11 CLIMATOLOGICAL STUDIES WITH DOPPLER RADAR

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1. PERVERSE DATA, NATURAL ANALYSIS

Radar is an eccentric tool, reporting bizarre quantities in awkward geometry. Nonetheless, it is incomparably efficient at sampling 3D structure in the atmosphere, and so cannot be ignored. To take best advantage of radar data, analysis must treat radar's "features" as strengths rather than weaknesses wherever possible. In this spirit, a new analysis method - cylindrical binning (CYLBIN) - has been devised.

One obvious strength of radar data is its sheer abundance. Millions of samples of the troposphere per minute are recorded, spanning the convective and "meso" scales with aspect ratios ~10^{-2}-10^{2}. We would like to utilize all available samples, reducing data volume in a way that minimizes regrettable averaging. Instead, the measured quantities (reflectivity, radial velocity, spectral width, etc.) are binned into histograms. The information we choose to discard in this data reduction is fine-scale structure in the horizontal and time dimensions, making CYLBIN complementary to traditional case-study and rain-map analyses.

A major "feature" of Doppler radar is the antenna-centered coordinate system in which radial velocity is measured. This is unfortunately a true weakness, since spherical coordinates obstruct scientific interpretation and so must be abandoned. The special importance of the vertical direction leads to an overriding interest in having observations arranged by altitude. For example, microphysics depends strongly on altitude, through its dependence on temperature. Furthermore, because the atmosphere is stably stratified, altitude profiles of horizontal wind divergence have a scientific interpretation in terms of heating profiles (Mapes and Houze 1995). In the tropics, where isentropes stay flat and level to a good approximation, heating of the atmosphere by deep convection is detectable as removal of mass from low altitude (entropy) layers and mass addition to higher layers.

Another peculiarity of radar geometry is that measurements have special dependences on range and tilt angle. Beams rise and widen with range, sampling atmospheric volumes (solid angles) ranging over 2-3 orders of magnitude. Attenuation is also range-dependent. At steep tilt angles, hydrometeor fall speeds are blended with horizontal and vertical air motions to yield almost uninterpretable radial velocity measurements. These considerations militate against use of Cartesian coordinates, where range and tilt information are obscured.

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For these reasons, CYLBIN was devised in cylindrical coordinates (actually, spherical cap coordinates, with altitude defined above the curved earth). Data are stratified by altitude, so vast data sets can easily be brought to bear on statistical studies of vertical structure. Data are stratified by range (and hence sample volume), so statistical studies can glimpse effects at the smallest scales sampled (10s-100s of meters), albeit entangled with attenuation effects. The ratio of altitude to range isolates the high tilt angle data for exclusion. Accurate horizontal wind divergence averaged over substantial regions can be obtained by the divergence theorem, along with horizontal wind estimates, using standard Velocity-Azimuth Display (VAD) techniques.

2. CLIMATOLOGY AND COMPARISONS

CYLBIN processes large amounts of data from many different radar deployments into a consistent, convenient form for exploratory data analysis. To date, the method has been tested on ~month-long shipborne Doppler radar deployments in the tropical Indian, west Pacific, and east Pacific oceans. Figure 1 shows ~2000 hours of an index of radar echo coverage from these data sets. This index is nonzero during all but the most suppressed conditions, and measurements of no radar echo have value as well. Comparative studies with these data will reveal both differences and universalities in convection over different regions of the tropical oceans.

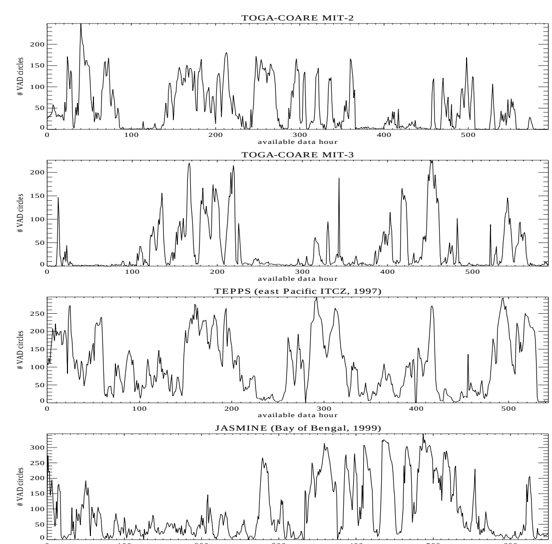

Figure 1. Time series (with arbitrary hours as the ordinate) of the availability of sufficient echo forVAD analyses of wind and divergence. a) TOGA COARE cruise 2. b) TOGA-COARE cruise 3. c) TEPPS cruise in the east Pacific. d) JASMINE cruise in the Bay of Bengal.

3. SPECIFIC SITUATIONS

A graphical summary of CYLBIN results for two particular hours is plotted in Figs. 2-3. Fig. 2 was during the passage of an intense squall line in westerly winds, as shown by the low-level echo coverage in a); the high frequency of echoes up to 50 dbZ in the lower troposphere in b); and the profiles of VAD wind and wind divergence in c) and d).

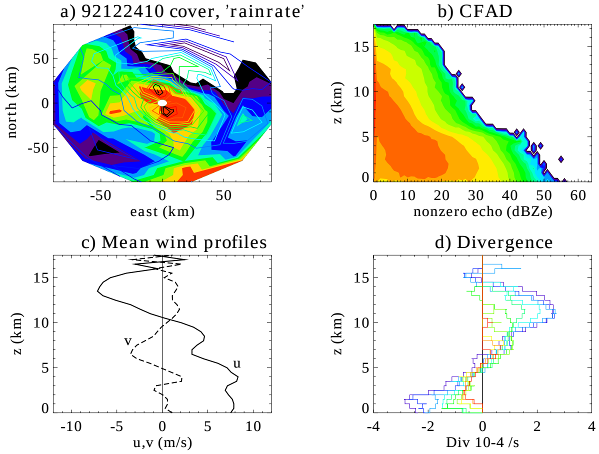

Figure 2: A CYLBIN hourly summary from shipborne radar in the western Pacific, 24 December 1992, 10-11 UTC. a) Plan view reflectivity information at low levels (2km). b) Contoured frequency by altitude diagram showing dbZ histograms at each height in the circle r<80km. c) VAD wind. d)VAD divergence for various radii

Useful information can also be obtained during less dramatic weather. For example, Fig. 3 shows an hour with spotty cumulus showers in the lower troposphere under a cloud layer near 10-12 km altitude. Convergence below and divergence above this cloud layer imply heating in the cloud layer. With thousands of hours of data, organized convective systems can be placed in climatological context with more typical conditions.

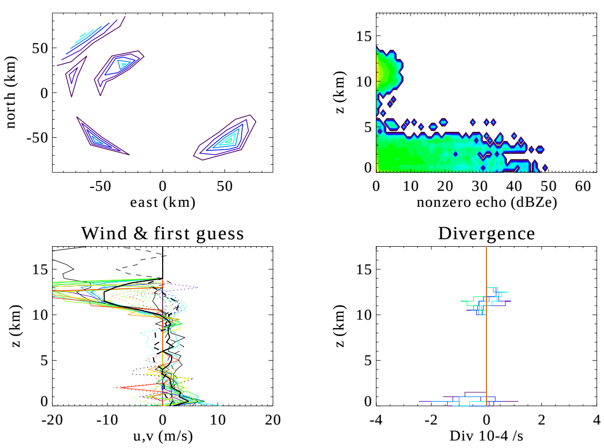

Figure 3: As in Fig 2, but 11 May 1999 4-5 UTC in the Bay of Bengal.

4. STATISTICS AND SCALES

CYLBIN's nested circular regions offer a large, convenient data set on convective processes at multiple scales, from 10s of meters (beamwidth dependences) to 100s of km (the largest circles), and minutes to months in time. Classic issues (e.g. the diurnal cycle) and deeper statistical issues (e.g. scaling) can be addressed to high (and increasing with data amount) degrees of statistical significance. Especially interesting are shipborne data sets on the open ocean, where the arbitrariness of ship location minimizes the possibility of sampling biases.

5. CORRELATIONS AND CONNECTIONS

Coincidence and correlation can be used to explore connections between various measured quantities. Artful analyses can tease out data problems and, occasionally, discover important scientific relationships. Fig. 4 is a crude example, a regression of area-averaged near-surface rainrate (from a simple Z-R relationship) against divergence at every altitude. A deep upward motion is clearly indicated in association with rain, with the level of non divergence near 6 km. Two distinct convergence layers (at different scales) are seen at 0-1 and 3km, but this puzzling scale dependence remains to be confirmed and interpreted. The divergence profile and rainrate should be related, since both are related to latent heating. Bringing together the completely independent reflectivity (Z) and Doppler data may offer a new constraint on Z calibration and Z-R relationships.

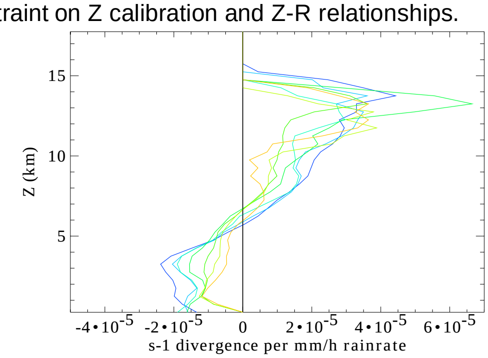

Figure 4: Regression coefficient relating wind divergence at various heights to 2km rainrate computed from a simple Z-R relationship. Lines are from different sized cylinders, unclear in black and white.

Even more interesting will be the search for relationships with other data, e.g. with soundings which are often launched at radar sites. The possibilities are numerous, and the project is just beginning. A postdoc is sought to pursue this work in collaboration with the author. Please inquire if interested.

6. REFERENCES

Mapes, B.E., and R.A. Houze, Jr., 1995: Diabatic divergence profiles in western Pacific mesoscale convective systems. *J. Atmos. Sci*., **52**, 1807-1828.

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