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Convection in GATE---recognition and importance of the **cloud cluster**

Houze 1977

GATE B-scale array
100-1000 km

Radar network used to develop statistics on echo sizes, convective organization and precipitation processes (convective and stratiform)

3-hourly sounding from the Ships in this array
Cloud clusters (MCSs) are major pathways for the transport of mass and heat in the troposphere. They are also major contributors to rainfall and energetics over the mid- and low-latitudes.

A view looking aft from the R/V Researcher in GATE 1974 (photo by Bob Houze)
The distribution of echo sizes from the GATE radars

Population dominated by isolated, small cells

Large cloud clusters are relatively rare but these large systems produce dominant fraction of ITCZ rainfall

The largest of the cloud clusters contain multiple Mesoscale Precipitation Features so cloud clusters span the mesoscale to synoptic scale

GATE showed that cloud clusters modulated by Easterly Waves with 3-5 day periodicity

Cloud clusters: include squall and non-squall types

Fig. 7. Frequency of occurrence of D, C, and B/C scale radar echoes during GATE. From Houze and Cheng [1977].
GATE provided first comprehensive measurement of convective cell widths and updraft/downdraft intensities—based on aircraft penetrations

Two key papers, LeMone and Zipser; Zisper and LeMone (both in 1980)

Drafts: > .5 m/s for 1 second

Cores: > 1 m/s for at least 500 m width.

Updrafts are weak!

Core diameters are small.

Downdrafts are somewhat weaker than updrafts.

Large rainout from warm phase processes.

Rapid falloff in radar reflectivity with height.
Summarize draft stats from these 2 papers

Above cloud base, updrafts tend to be smaller but more intense than downdrafts. Updrafts and downdrafts near cloud base are comparable in size and intensity. Downdraft cores are smaller than updraft cores at all altitudes. They also are weaker, except near cloud base, where updraft and downdraft cores have comparable intensity. In the middle troposphere, only 10% of the updraft cores have mean vertical velocities greater than 5 m s⁻¹, and only 10% have diameters in excess of 2 km.

Why are the convective updrafts so weak? Discussion topic....
Why are updrafts weak over the oceans?

CAPE; integrated thermal buoyancy
Warm cloud depth
Freezing level height - Cloud base height

Tropical oceanic convection; moderate to high CAPE (narrow thermal buoyancy), low CBH (deep WCD) and low CCN concentrations. Narrow drafts subject to considerable entrainment.

Parcel temperature is far from the environmental temperature profile

Tropical continental convection; moderate to high CAPE (wide thermal buoyancy), high CBH (shallow WCD) and high CCN concentrations. Broad updrafts less subject to entrainment.
• Classic paper by Houze (1977) from GATE. **First shipbased radar (non-Doppler) observations of tropical convection.** Merged ship radar, sounding data, satellite and surface data to reveal dynamical and thermodynamical structure.

• Zipser (1969) previously identified several key features of these systems from the Line Is. experiment. Zipser (1977) from GATE was a parallel study to Houze (1977).

• **Convective region characterized by new convective cells developing ahead of mature cells.** A mesoscale downdraft prevailed in the mid and lower troposphere below the trailing anvil cloud.

• The trailing anvil cloud was stratiform and contributed 40% of the total precipitation. **The possibility of a mesoscale updraft was mentioned, as well as its role in producing anvil precipitation.** The anvil was fed by incorporation of dissipating convective elements from the squall line............but did it have an internal mechanism for producing precipitation?
60/40 split between convective and stratiform rain from GATE 5 September cloud cluster

Radar derived via GATE Z-R relationship $Z = 230 R^{1.5}$

$Z$ in mm$^6$ m$^{-3}$ and $R$ in mm h$^{-1}$; no convective/stratiform partitioning done

For convective-stratiform partitioning,

Gan Is./Manus Is.
Thompson et al. (2015, JAS)

$Z = 126 R^{1.46}$ Convective
$Z = 230 R^{1.55}$ Stratiform

$10 \log R = 10 \log Z - 10 \log A$

85/15 Convective/stratiform
The well known Zipser 1977 conceptual model for a GATE MCS

A tell tale sign of mesoscale subsidence is the marked divergence beneath stratiform anvil cloud
Aircraft and radiosonde derived in and near the stratiform precipitation region on 5 September 1974

The famous “onion-skin” sounding

Subsidence warming and drying driven by a mesoscale unsaturated downdraft---sort of a derivative of convective scale saturated updrafts

Zipser (1977)
A Diagnostic Modeling Study of the Trailing Stratiform Region of a Midlatitude Squall Line

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(Manuscript received 30 July 1986, in final form 13 April 1987)

ABSTRACT

A kinematic model with continuity equations for sensible heat, water vapor, cloud water, cloud ice, rain, snow, and graupel is used to determine the steady-state thermodynamic and microphysical processes associated with the observed mesoscale air motion fields in the trailing stratiform region of the 22 May 1976 Oklahoma squall line. Two versions of the observed air motions are used: a low-resolution but areally extensive flow pattern derived from the composite sounding data of Ogura and Liou, and a high-resolution but less areally extensive flow field obtained from the dual-Doppler radar analysis of Smull and Houze.

Model calculations based on the high-resolution Doppler-derived mesoscale air motions show that the location and horizontal scale of the region of most intense stratiform precipitation are determined by the pattern of horizontal transport and fallout of snow and low-density graupel particles advected into the stratiform region from the leading line of convective cells. The stratiform-region water budget implied by these calculations further indicates that the amount of stratiform rain reaching the surface is considerably enhanced by the passage of these particles through the region of mesoscale upward motion in the stratiform cloud behind the convective line. Vapor deposition onto existing ice particles and the collection of snow generated by the mesoscale ascent are the dominant growth processes in the stratiform region. Simulations using the low-resolution sounding-derived air motions as input to the model show that the mesoscale updraft accounts for the extensive nonraining stratiform cloud to the rear of the surface precipitation area.

\[ R_m = C_{mu} - E_{md} - T + C_A, \]

\( R_m \) is rain from trailing mesoscale region

\( C_{mu} \), condensation in mesoscale region

\( E_{md} \), evaporation in mesoscale downdraft

\( T \), advection of condensate off the grid

\( C_A \), condensate influx from convective region

---

Hydrometeors input from convective region prescribed using aircraft data from Heymsfield and Hjemfelt (1984)

---

TABLE I. Values of the water budget components. Results of model simulations are denoted by HHSN, NCSN, HHSNNU and HHSNUN, as explained in the text. The values in the GH categories are from Gamache and Houze (1983) and are based on observations of an oceanic tropical squall line. The data from Chong (1983) are based on observations of a continental tropical squall line. All terms have units of kg m\(^{-1}\) s\(^{-1}\), where the unit length is the unit distance perpendicular to the model x-z domain.

<table>
<thead>
<tr>
<th>Case</th>
<th>( R_m )</th>
<th>( C_{mu} )</th>
<th>( -E_{md} )</th>
<th>( -T )</th>
<th>( +C_A )</th>
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<tbody>
<tr>
<td>HHSN</td>
<td>43</td>
<td>87</td>
<td>-48</td>
<td>-40</td>
<td>44</td>
</tr>
<tr>
<td>NCSN</td>
<td>2</td>
<td>81</td>
<td>-23</td>
<td>-56</td>
<td>0</td>
</tr>
<tr>
<td>HHSNNU</td>
<td>11</td>
<td>5</td>
<td>-37</td>
<td>-1</td>
<td>44</td>
</tr>
<tr>
<td>HHSNUN</td>
<td>0</td>
<td>47</td>
<td>-55</td>
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GATE science established that there are convective (up and down) drafts and mesoscale (up and down) drafts in tropical cloud clusters. Both scales are critical for transporting heat and momentum. So cumulus parameterizations now had to account for the mesoscale processes which prior to GATE the science community had only crude knowledge of.