The human element in science, illustrated by GATE

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NSF/NCAR/MMM

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The Student's "Scientific Method" (**individual**)

Ask a Question

Do background research

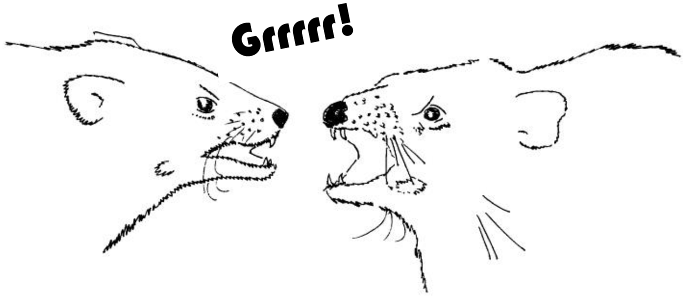
Construct a hypothesis

Test your hypothesis by doing experiment (or finding data)

Analyze your data and draw a conclusion

Communicate your results

http://www.sciencebuddies.org



The "Scientific Method" We Experienced in GATE

Collaboration

.. Planning a field phase

.. Conducting the field phase

.. Working with colleagues

.. Comparing results

.. Resolving differences

.. Communication to broader community

.. Resolving differences

…

…

The Groups in GATE: diversity in people AND data

Political

Americans
French
Germans
Brits
Soviets
+ 67
other
countries

SHIPS

Radar
Tethered Balloons
Surface fluxes
Surface weather
Radiosondes

AIRCRAFT

"Flight-Level" data
Gust probe data
Aircraft films
IR sensors
(up- and down-
looking)
Microphysics
(dust, precip)

SATELLITE

Images

MODELS

During GATE:
Forecast models

After GATE
LES
…

BOUNDARY-LAYER (PBL) RESEARCH

Changed during talk:
Two groups – mid-lats, tropical – GATE brought together

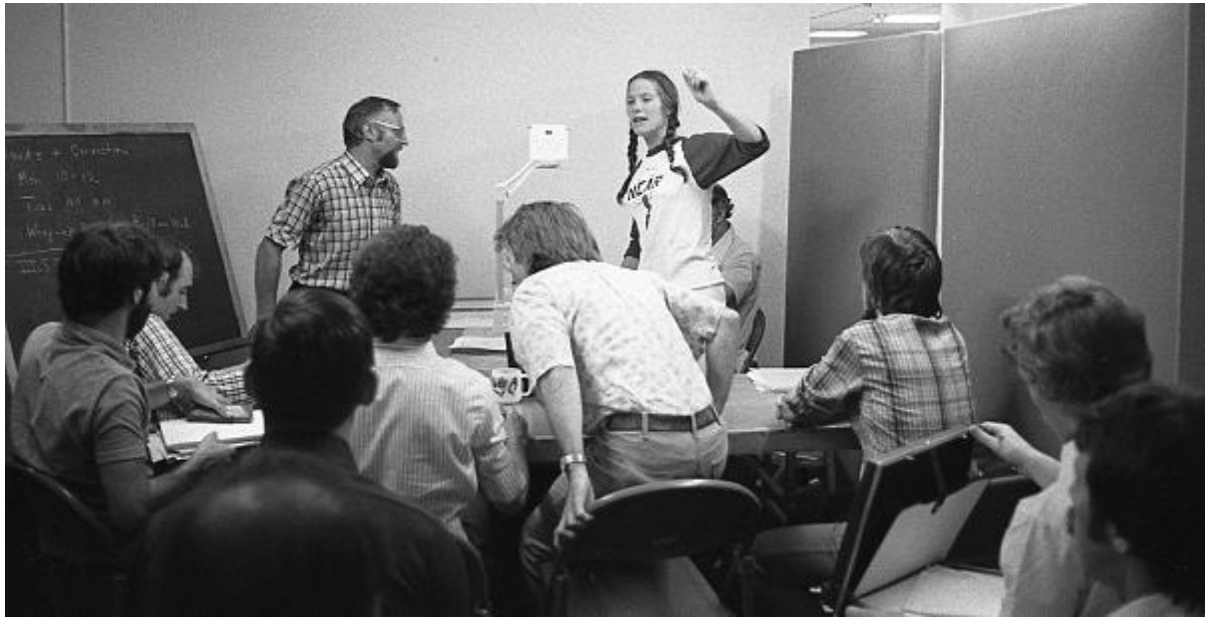
Pre-GATE

- Most PBL Work
  - In midlatitudes (except for ATEX, BOMEX, some Australian work)
  - Single-platform or instrument type
- Problems with measurements of temperature, mixing ratio

GATE

- Over the tropical ocean
- Multiple instruments, platforms, groups
- Improved instruments

GATE Workshop – 1977
Are we in the same universe????



But

MARCH 1980 BARNES, EMMITT, BRUMMER, LEMONE AND NICHOLLS

The Structure of a Fair Weather Boundary Layer Based on the Results of Several Measurement Strategies

GARY BARNES AND GEORGE D. EMMITT
University of Virginia, Department of Environmental Sciences, Charlottesville, VA 22903

BURGHARD BRUMMER
Max-Planck-Institut fur Meteorologie, Hamburg, Federal Republic of Germany

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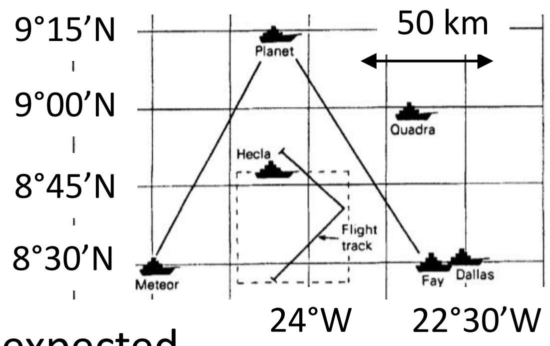
STEPHEN NICHOLLS
Meteorological Research Flight, Royal Aircraft Establishment, Farnborough, U.K.

(Manuscript received 15 February 1979, in final form 8 November 1979)

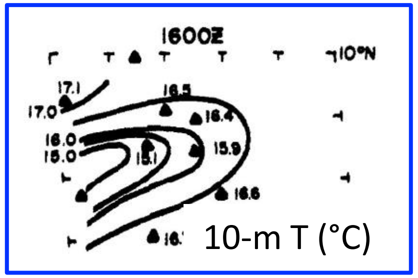
Authors Combined

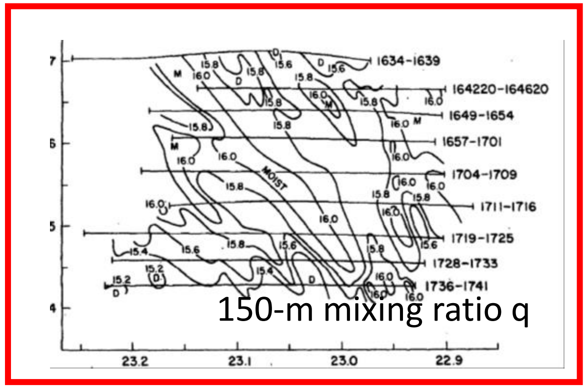
Aircraft, tethered balloons, balloon soundings, surface data

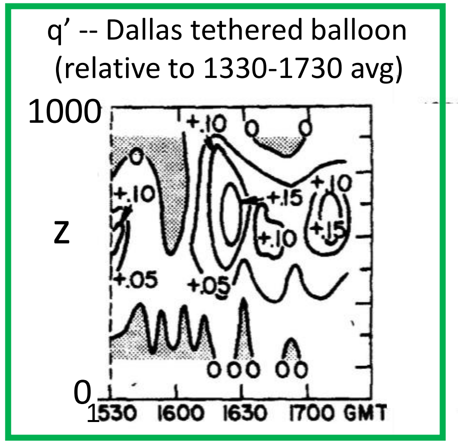


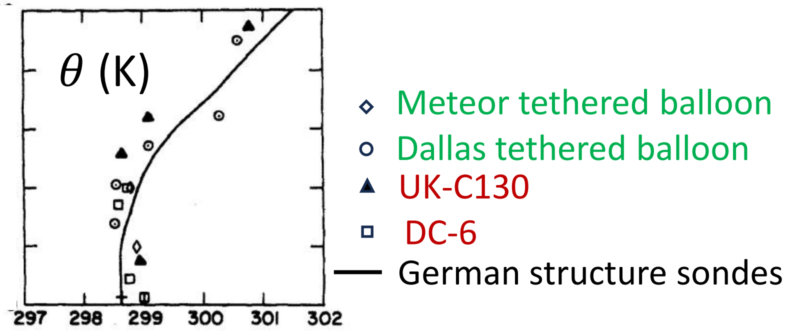
And learned

More horizontal variability than expected (outflow from previous day's storms)









Same universe and similar fluxes … but

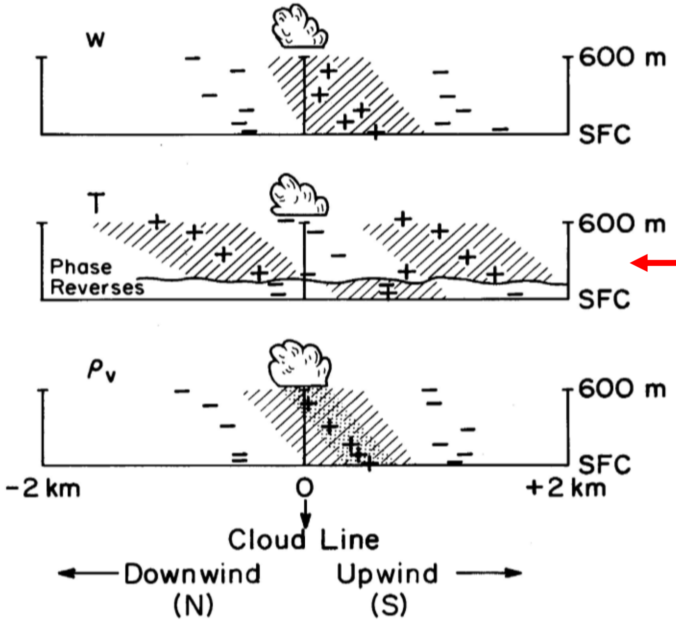
→ Need significant horizontal/time average to get meaningful CBL depth

→ Need significant horizontal average to get aircraft fluxes

→ C-scale triangle budgets suffer from nonlinear variability between ships

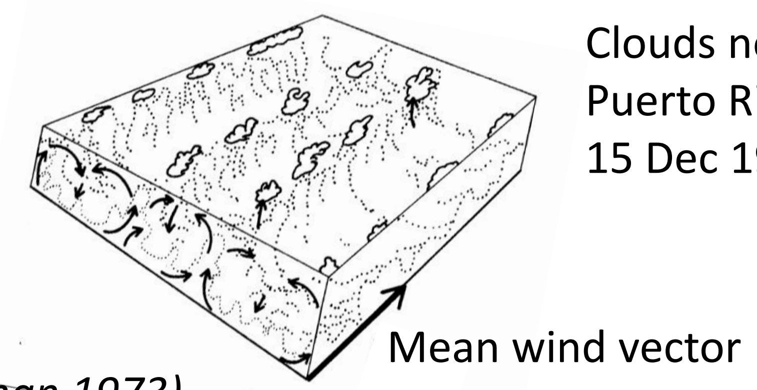
Improved water-vapor Instruments → Yes, Trade Cu DO have roots!

<u>EARLY 1970s Conventional wisdom</u>: No trade-wind cumulus roots
Suspected by Malkus and Riehl, but initial data suggested otherwise (Malkus 1962)
By BOMEX (Bean et al. 1972, Grossman 1972,1982) and later, had:
microwave radiometer (McGavin and Vetter 1965)
Lyman-α hygrometer (Buck 1976)
→ Clouds have roots



What Malkus (1962) found with no water vapor signal

Clouds north of Puerto Rico, 15 Dec 1972



→ Water vapor important to buoyancy *(known in BOMEX – e.g. Grossman 1973)*

15 Dec 72 data, LeMone and Pennell (1976)

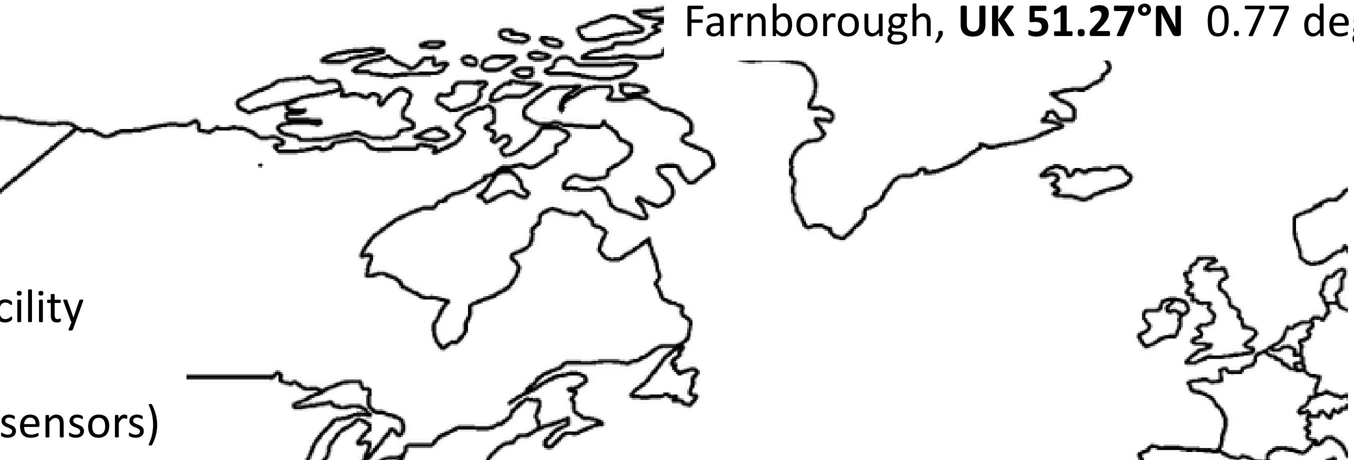
Steve Nicholls: Salt on fast temperature sensors → too-positive cloud-base heat flux

Steve Nicholls

(salt contamination
→ Condensation on Sensor at higher RH
→too-warm temperatures
→ too positive $\overline{w'T'}$ near cloud base
(Schmidt et al. 1978)

AND: salt-contamination problem a function of latitude!

Worst problem: UK-C130
Meteorological Research Flight
Farnborough, **UK 51.27°N** 0.77 deg E

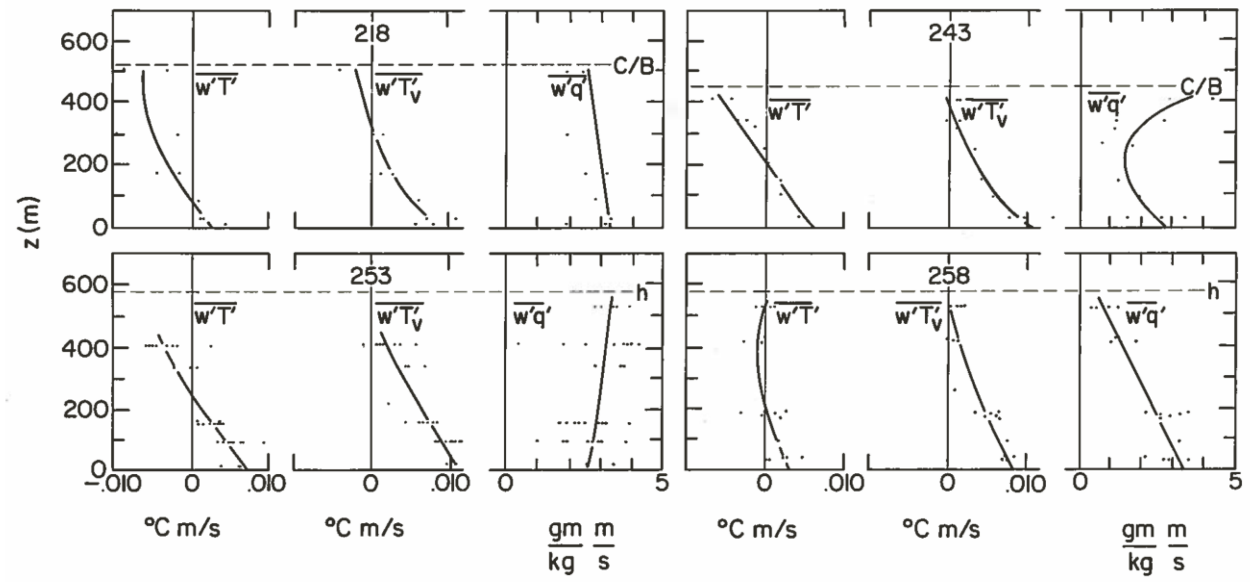


Intermediate: US L-188
NCAR Research Aviation Facility
39.91°N, 106.11°W
(flew through rain to clean sensors)

No problem: US NOAA DC-6
NOAA Aviation Operations Center
27.98°N, 82.02°W
(regularly cleaned temperature sensor with distilled water)

Fluxes with fast humidity **and** corrected fast temperature dataset

days 218, 253 in between



Most-developed Cumulus

clear

<u>At cloud base with more active cumuli</u>

heat flux $\overline{w'T'}$ more negative

water-vapor flux $\overline{w'q'}$ more positive

<u>At surface</u>

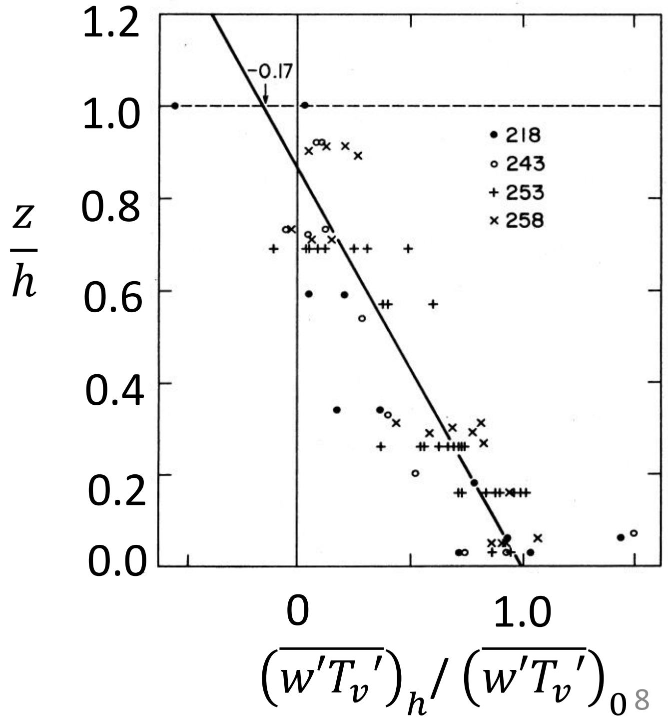
About half of $\overline{w'T_v'}$ from $\overline{w'q'}$

<u>Through subcloud layer</u>

Virtual-temperature flux fits "universal" profile

(for weak winds, steady state)

for h top of subcloud layer or cloudless CBL top



Nicholls and LeMone (1980, NL80)

LASTING IMPACT (mostly)

HETEROGENEITY FAIR-WEATHER MARINE CONVECTIVE BOUNDARY LAYER

recovering (atmospheric) cold pools

leftover fresh water from rain (seen in GATE, documented more in COARE, predicted by Katsaros)

Mesoscale CBL structure

after GATE: Role of air/clouds *above* the CBL (e.g. Clark et al. 1986, Balaji et al. 1993)

IMPORTANT ROLE OF WATER VAPOR

Removal of salt contamination necessary

Recognition that clouds over tropical ocean DO have roots (impact "mass-flux" parameterizations)

MOST mid-latitude boundary-layer meteorologists start using virtual temperature instead of temperature for buoyancy fluxes, scaling parameters involving buoyancy fluxes

SOME land-based PBL scientists still resist

$-0.2 = \left(\overline{w'T_v{}'}\right)_h / \left(\overline{w'T_v{}'}\right)_0$ ≡ "entrainment constant" (weak wind CBL only) in some PBL schemes

(but doesn't apply rapidly-growing CBLs over land; and seems to of secondary importance late in the day)

MESOSCALE CONVECTIVE SYSTEMS
(blend data/ideas within groups)

Pre-GATE, deep convection

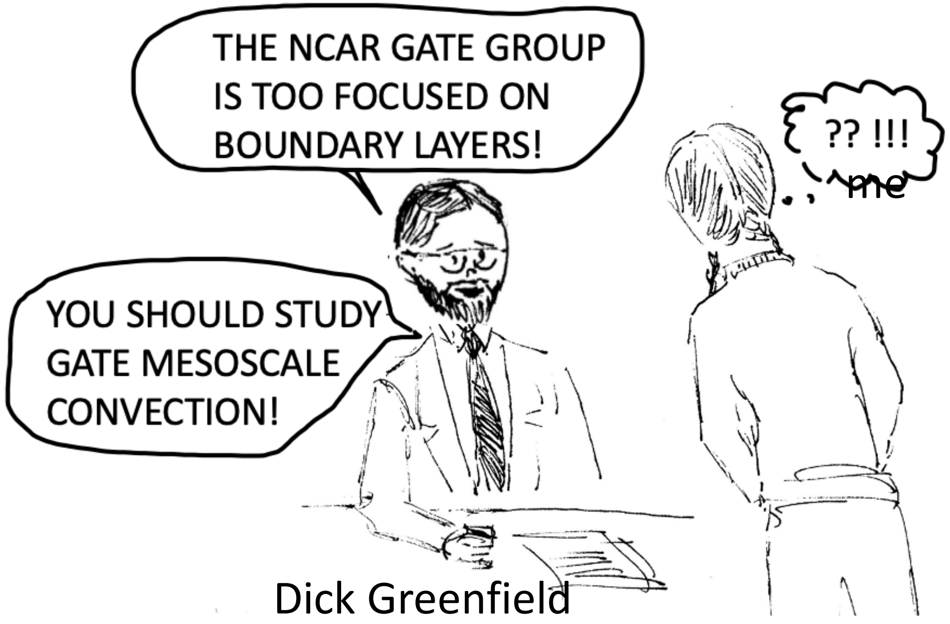
- Mostly midlatitude continental
- Squall lines (perpendicular to low level shear) or supercells
- Multiple instruments

GATE

- New (tropical, marine) regime

WHY I'M INVOLVED

GATE WORKSHOP, 1977



Expecting praise for our accomplishments, I instead am strongly encouraged by Dick Greenfield of NSF to work on deep convection.

Discouraging? Yes, but also the equivalent of being told to consume a chocolate sundae!

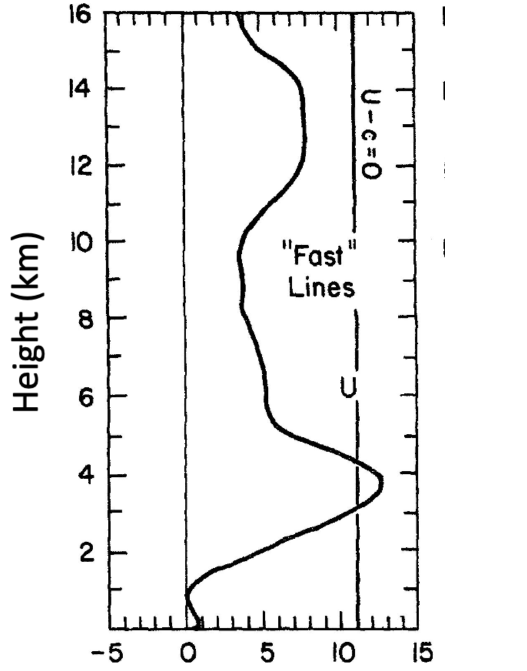
Meaurements **integrated within individual groups**:

e.g., Houze and students; Zipser group (Garpee Barleszi) and Zipser students

Radar →
Precip (pink),
Relevance of stratiform rain
Melting layer

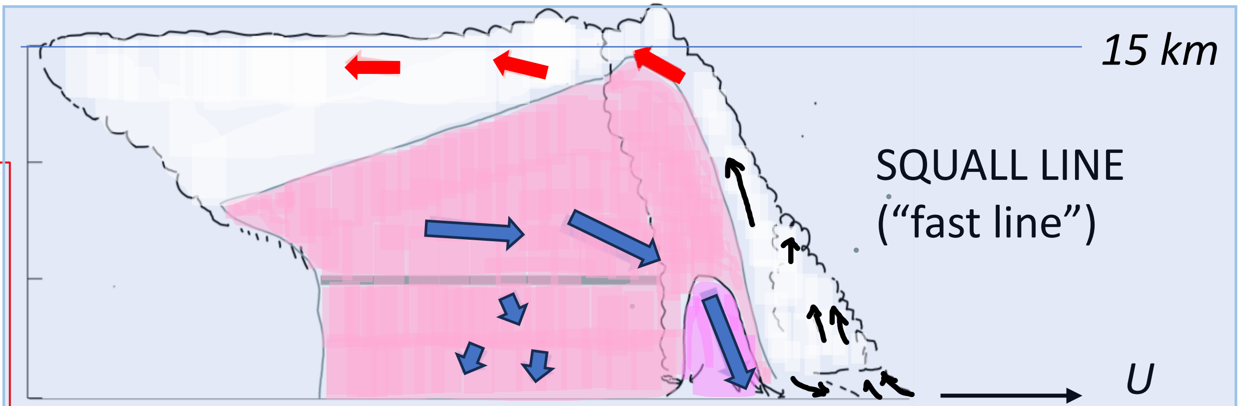
Satellite
+aircraft (a/c)
in-situ data + film
Clouds

Radar → Tilt of echo
a/c in-situ data
+ IR temp cloud tops =
+ film →
Tilt of cloud leading edge



U (Soundings, aircraft)
LeMone et al. (1984a)

Convective updrafts, downdrafts
weak and small
a/c in-situ data
Radar reflectivity profiles

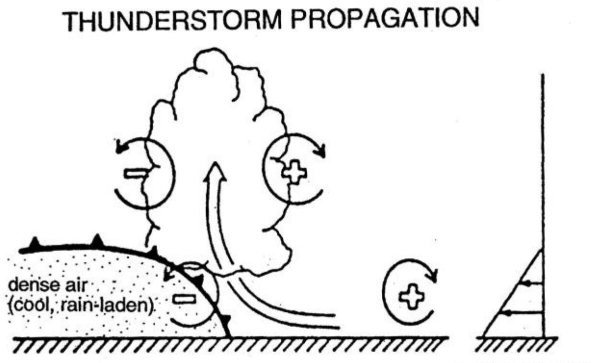


(idealized cross section from Houze 1977 + Zipser 1977)

radar, aircraft → winds

Aircraft gust-probe winds →
Vertical flux of line-normal momentum (u'w')

For "fast" lines, inflow U
shear-cold-pool
interaction explains tilt
Rotunno/Klemp/Weisman
(1988, aka RKW)

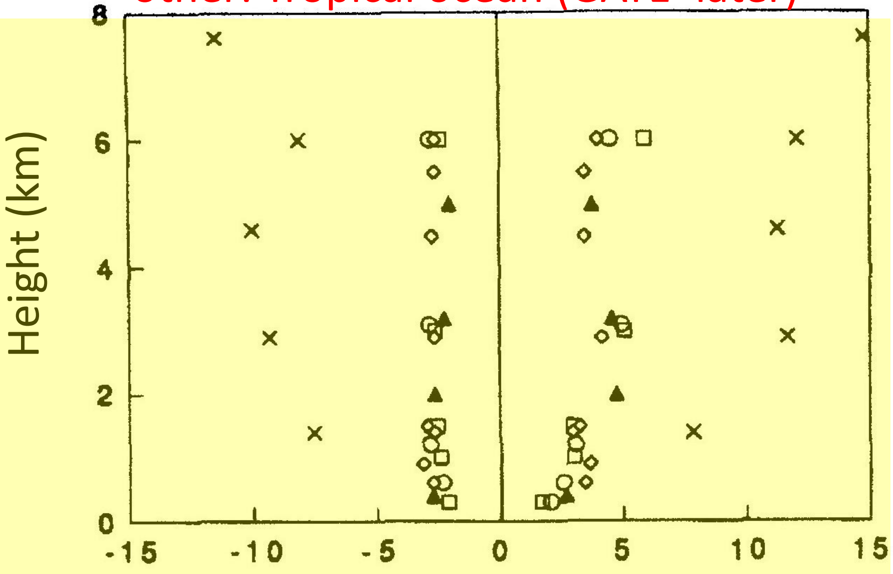


RKW (1988)

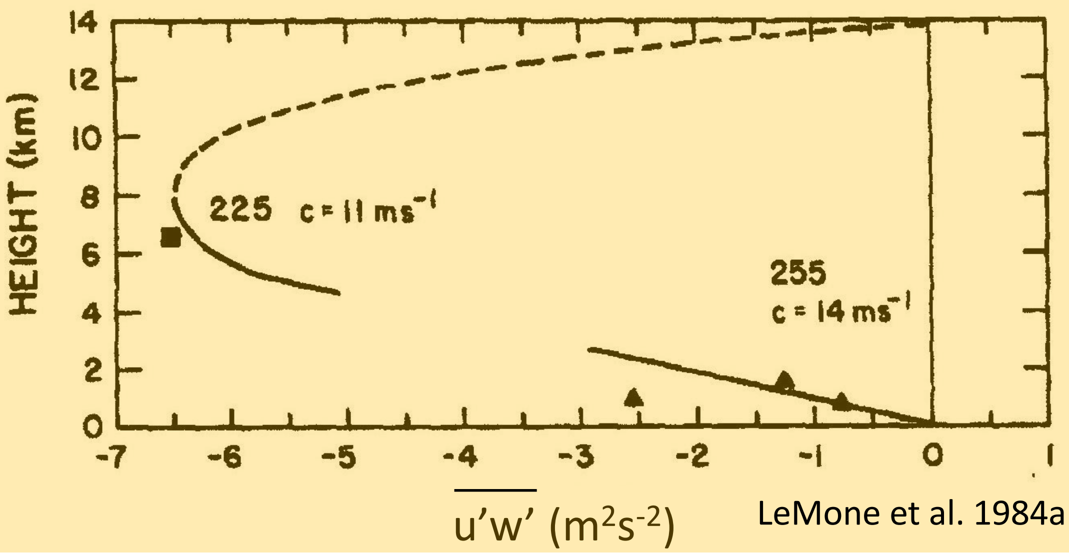
SURPRISES

- Much less "random" convection than expected (in field) (noted in talk: also importance of mesoscale)
- Significant precipitation beneath stratiform cloud (Houze 1982, etc.)
- Weak up- and downdrafts in MCS (didn't have to send aircraft back to U.S. for inspection)
- Line normal momentum transport (INCREASED shear normal to line) (anticipated by VIMHEX)
- Abundance of slow lines

x = continental US (thundertorm Project)
other: Tropical ocean (GATE+later)



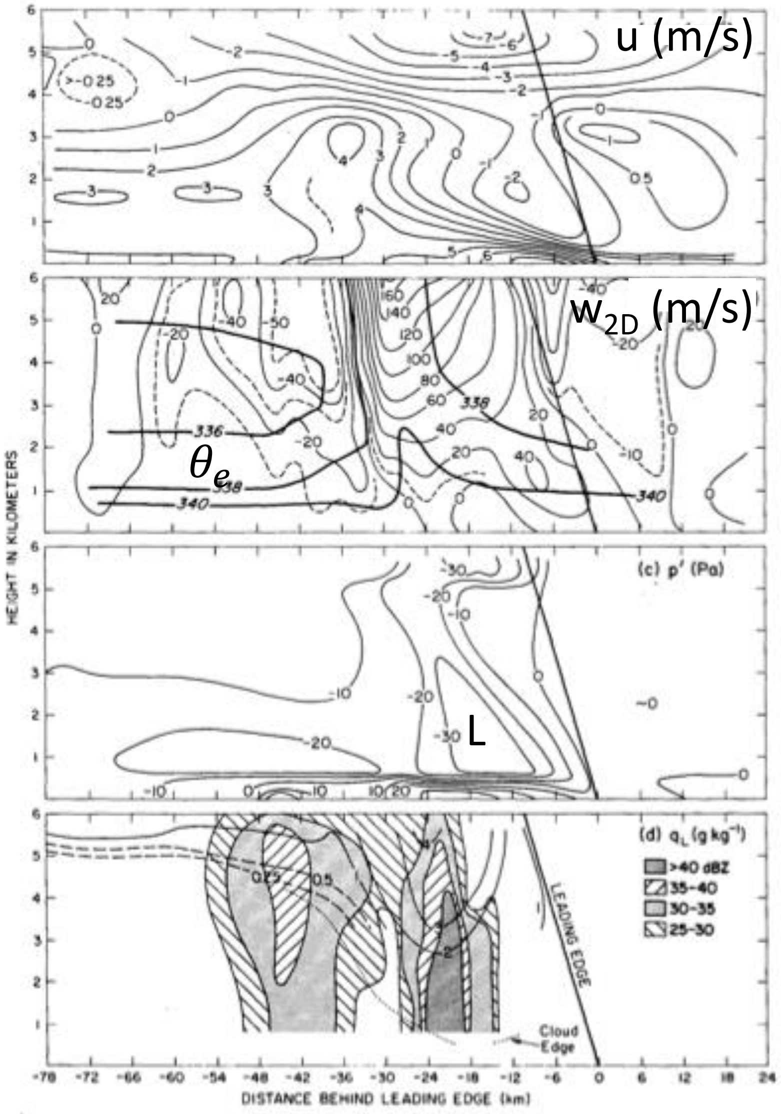
Lucas et al '94



LeMone et al. 1984a

SLOW LINES (majority of GATE MCSs)

–*(Pestaina-Haines and Austin 1976; Houze and Cheng 1979)*



14 Sept (*LeMone 1983*)

Weaker circulation

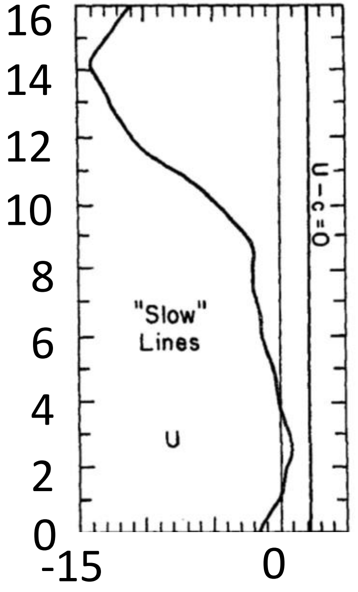
Much less θ_e Difference (weak cold pool)

L:
low pressure (largely from buoyancy)

Line-normal (U)-momentum flux independent of shear for squall lines and slow lines

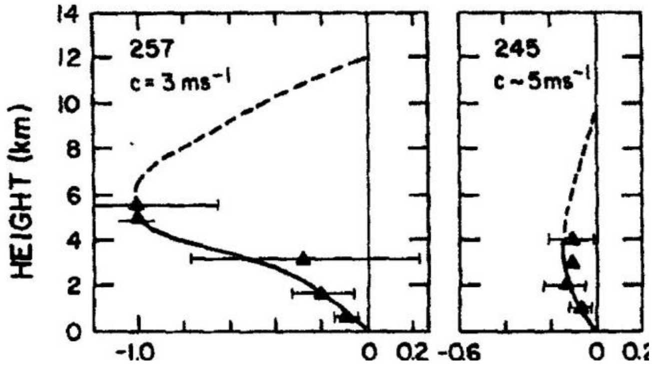
(LeMone et al. 1984a)

Doesn't Match RKW

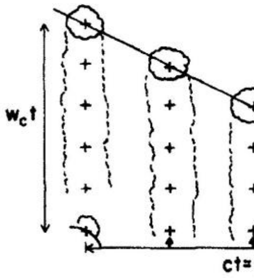


Leading-edge relative U (m s^{-1}

Similar u-momentum flux

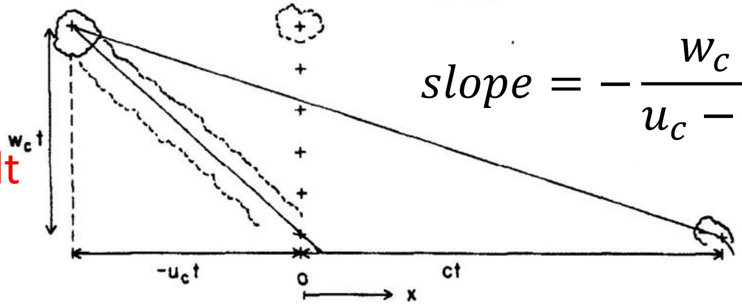


$\overline{u'w'}$ (m^{2}s^{-2})



$$slope = -\frac{w_c}{c}$$

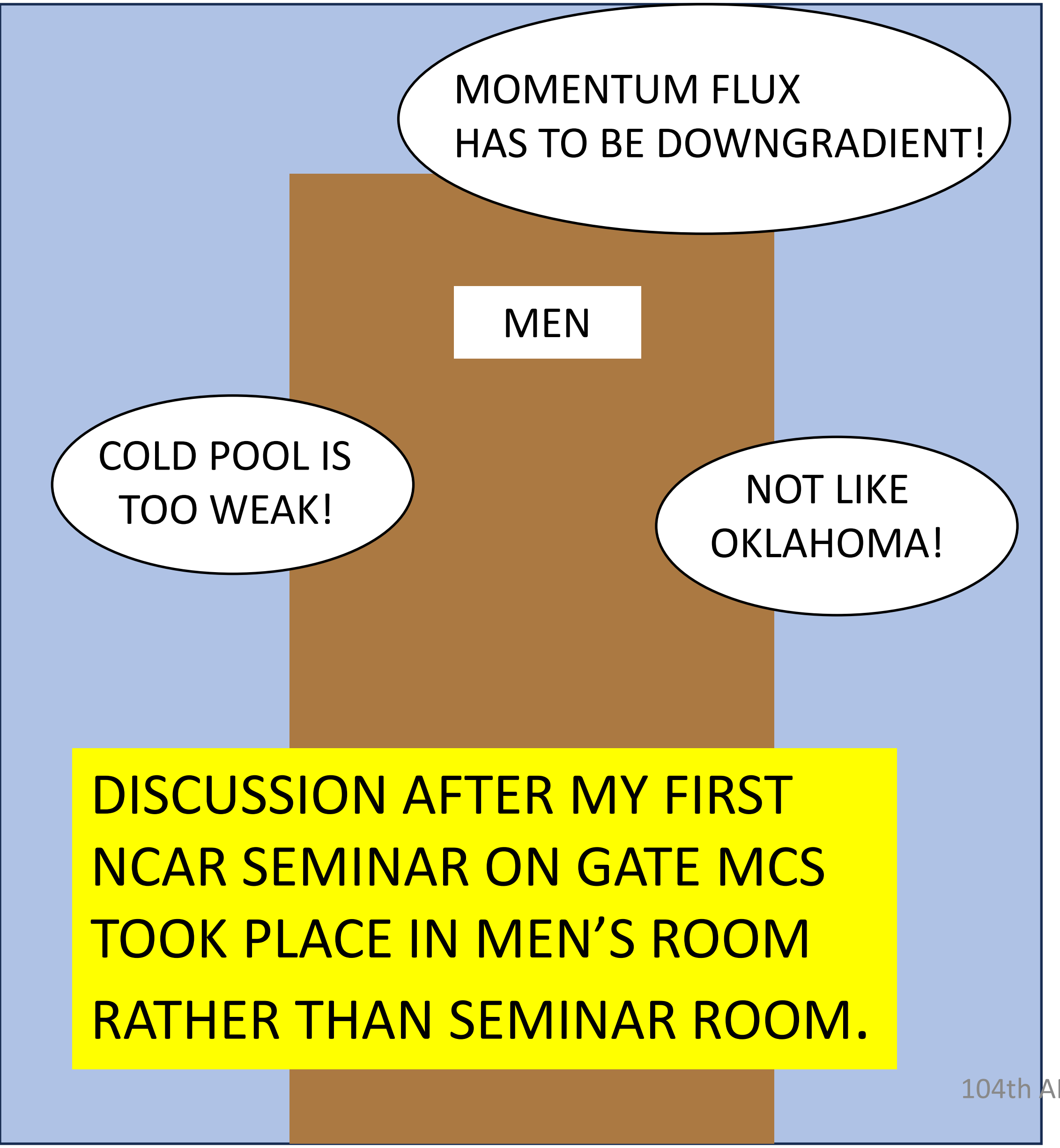
cloud growth at front of convective band important for leading-edge tilt *(LeMone et al. 1984b)*



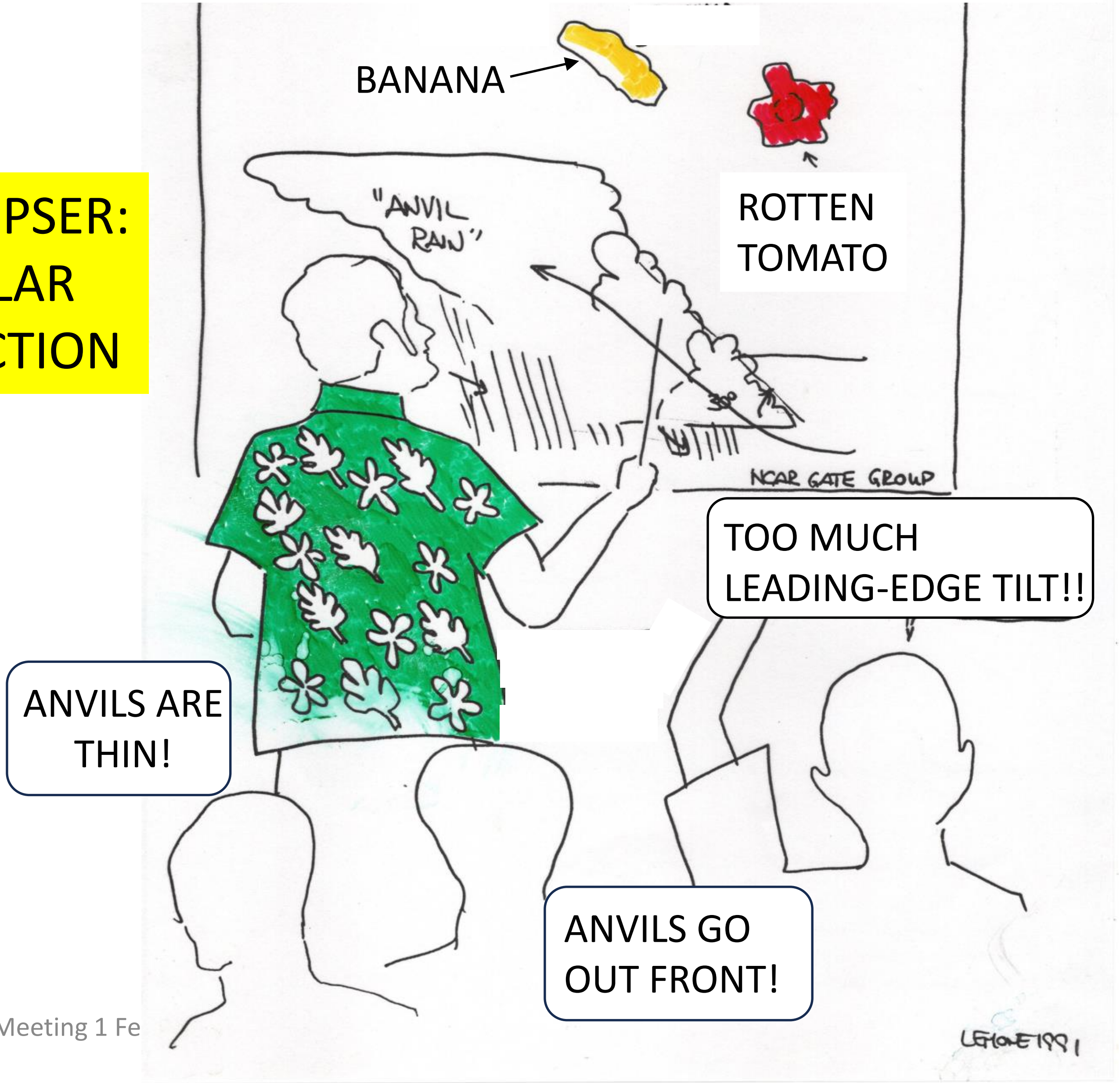
$$slope = -\frac{w_c}{u_c - c}$$

Initial resistance from the midlatitude Community

1970s—1980s TROPICS-BASED CONVECTIVE BAND DESCRIPTIONS DERIDED BY SCIENTISTS RAISED ON OKLAHOMA-TYPE SQUALL LINES



ED ZIPSER: SIMILAR REACTION



IMPACT

<u>Dataset for testing/verifying numerical simulations</u>

<u>Demonstration of importance of stratiform rain (added in talk)</u>

Cited by Simpson and Tao (1999, AMS GATE 25th anniv.

<u>Momentum transport by quasi-2-D bands</u>

a natural follow-on to VIMHEX (Betts, Grover, Moncrieff 1976)

an example of Starr's (1968) "negative viscosity phenomena"

one line orientation accounted for in Wojtek Grabowski's (2001)

2-D "Superparameterizaton"; development continues.

<u>Weak updrafts</u>

verified for MCSs in other tropical marine locations

and radar reflectivity profiles (Szoke et al. 1986)

→explanation for dearth of lightning over tropical

oceans (Zipser 1994, Zipser and Lutz 1994)

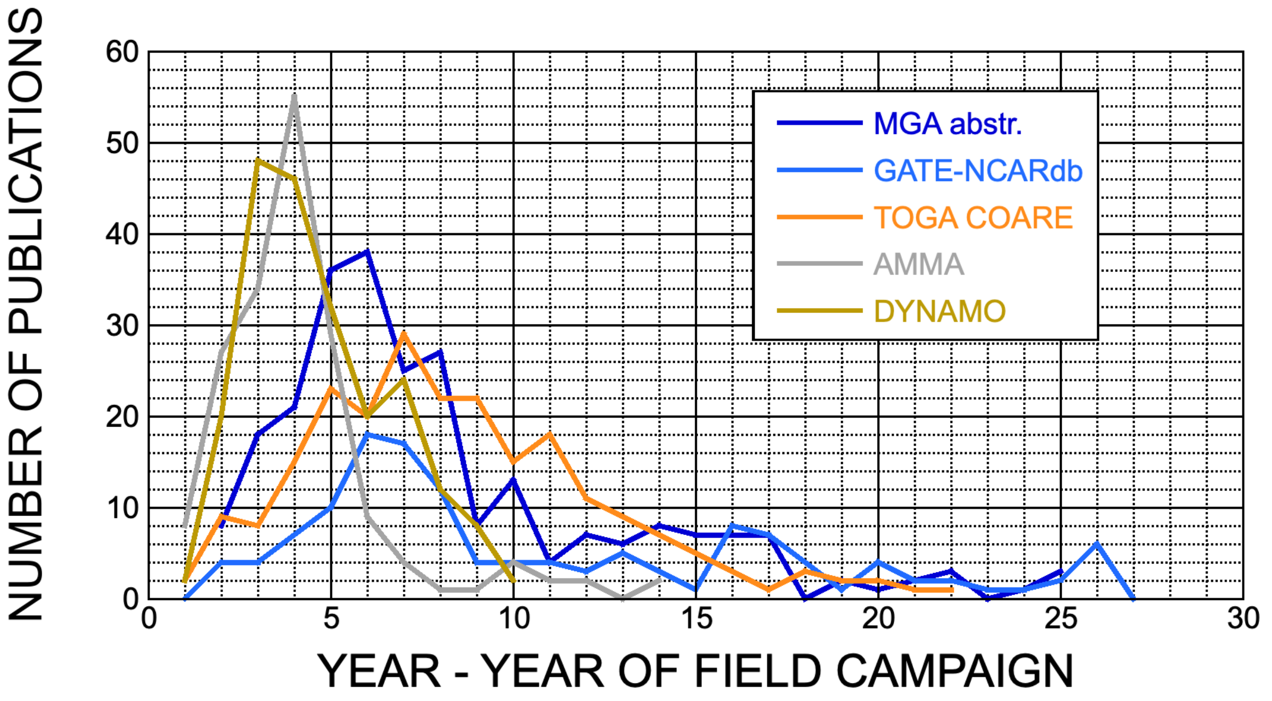
Slow lines (parallel to low-level shear)Still not fully understood

Will we need high-resolution GCMs to get momentum flux right?

Measurement of in-cloud temperature still a challenge

Conclusions

- Collaborative science in diverse group enhances discovery
  - Sharing of ideas, approaches, measurements from different platforms
  - Discovering problems
  - Overcomes individual biases
  - More experience to draw from
- Acceptance not guaranteed by other communities
- Many factors determine publication timing
  - Validation, bias removal, correction of data
  - Science culture
  - Field-program timing



Adapted from Zhang and Moore (2023)

Contribute to “Out Years”?
Access microfilm and links to digital data:
https://www.eol.ucar.edu/field_projects/gate

GATE

NSF | NCAR Operated by UCAR

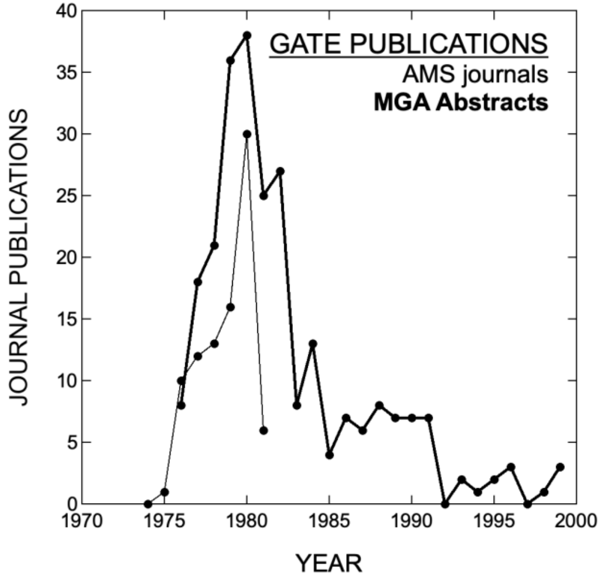
IMPACT -- PUBLICATION

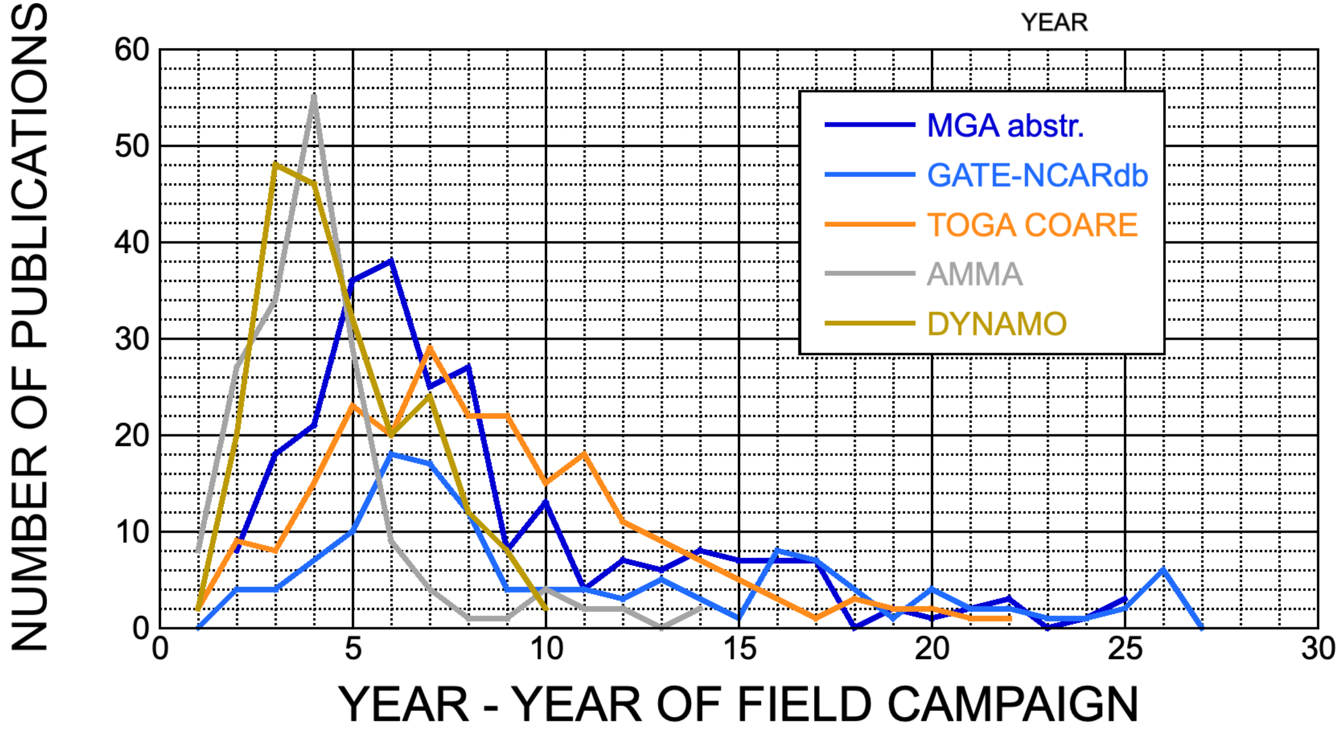
- Peak faster with time?
- Long tail desirable

CAVEATS

- Hard to count (3 counts for GATE)
- A function of country (USSR early)
- A function of subfield
  - Single-instrument first
  - Integrative papers later
- A function of institution
  - University – 1974 – student publish after graduate, now publish before.
  - NCAR – scientists did own analyses (lag for NCAR GATE partially due to data-validation efforts)
  - NSF, etc. funding cycles
- Spacing of field campaigns

GATE
AMS Journals – LeMone 1983
MGA abstr – LeMone 2003
NCAR database (Zhang+Moore 2023)
GATE NCAR database (1974)
TOGA COARE (1992-1993)
AMMA (2002-2010)
DYNAMO (2011-2012)





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