Organized convection

Wojciech Grabowski

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Boulder, Colorado

THE THUNDERSTORM

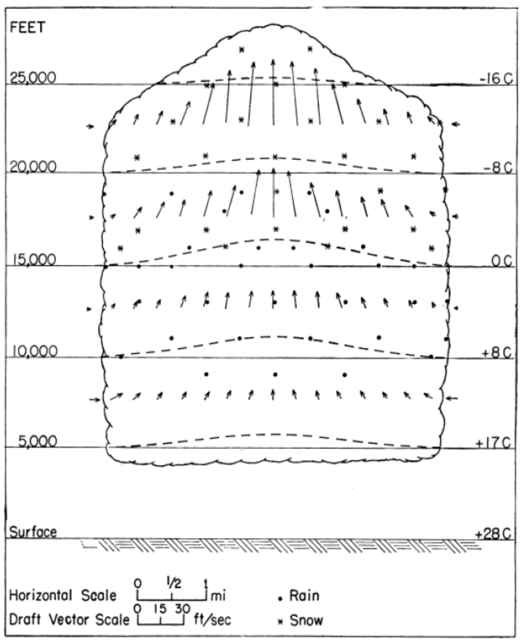
REPORT OF THE THUNDERSTORM PROJECT

(A joint project of four U. S. Government Agencies: Air Force, Navy, National Advisory Committee for Aeronautics, and Weather Bureau)

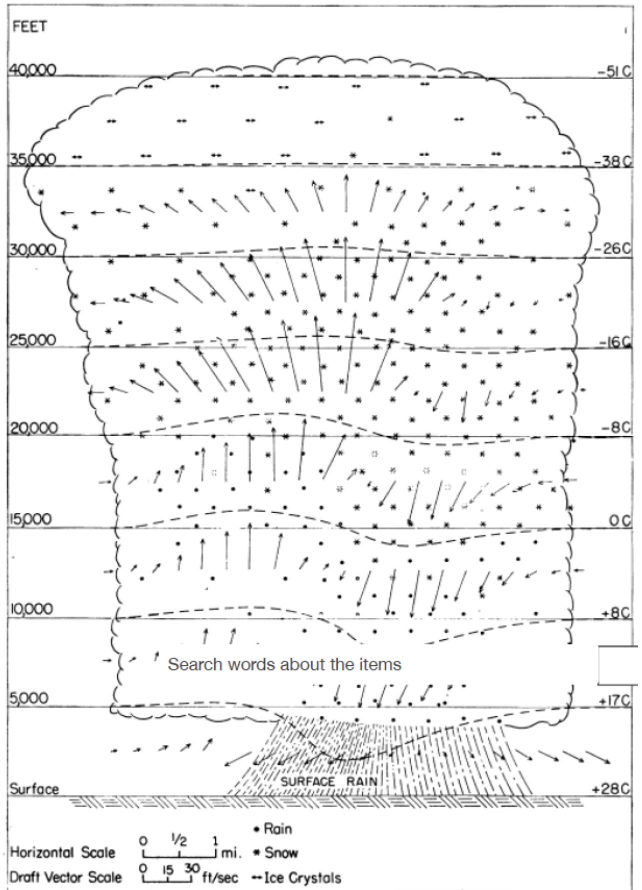
HORACE R. BYERS, *Director* ROSCOE R. BRAHAM, Jr., *Senior Analyst*

Life cycle of a single deep convection cell (30-60 minutes)

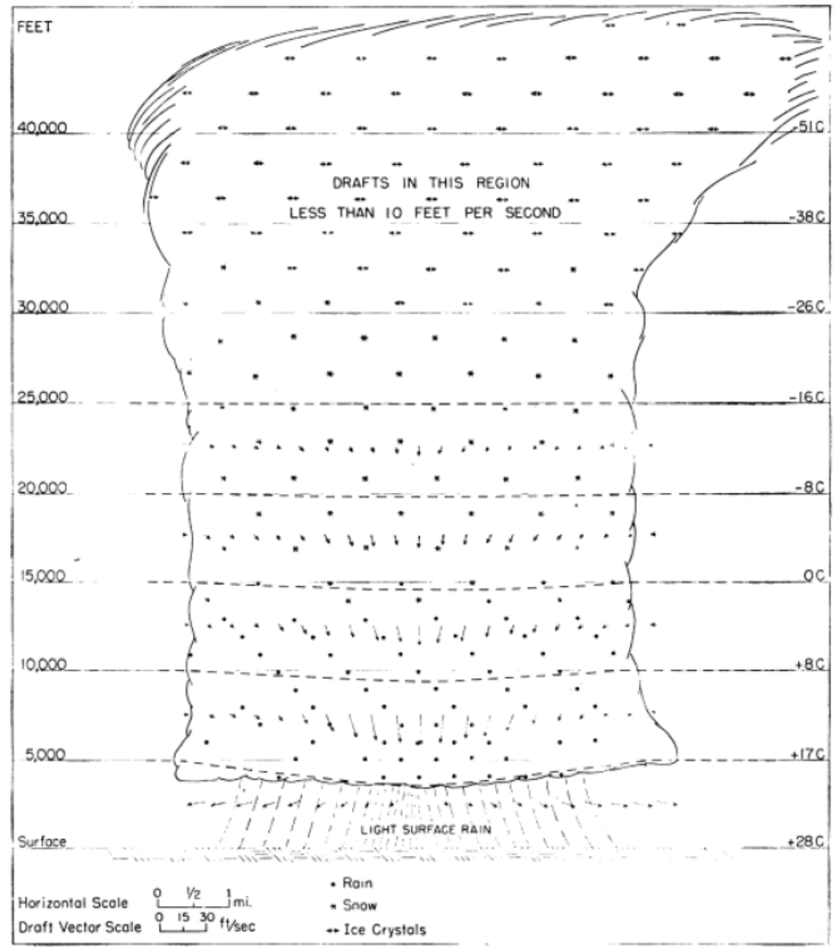
1949



Developing stage

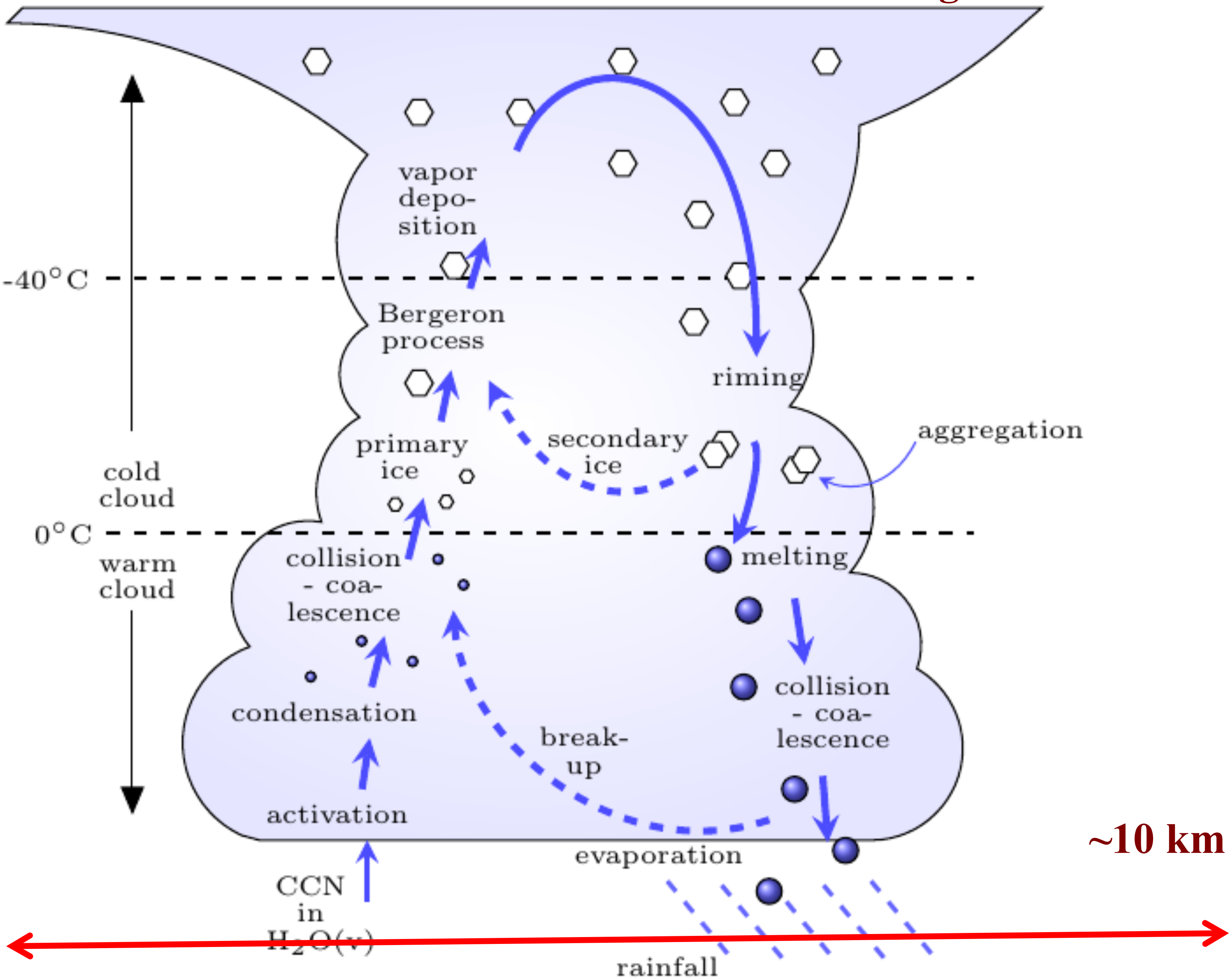


Mature stage



Dissipation stage

Single convective cell



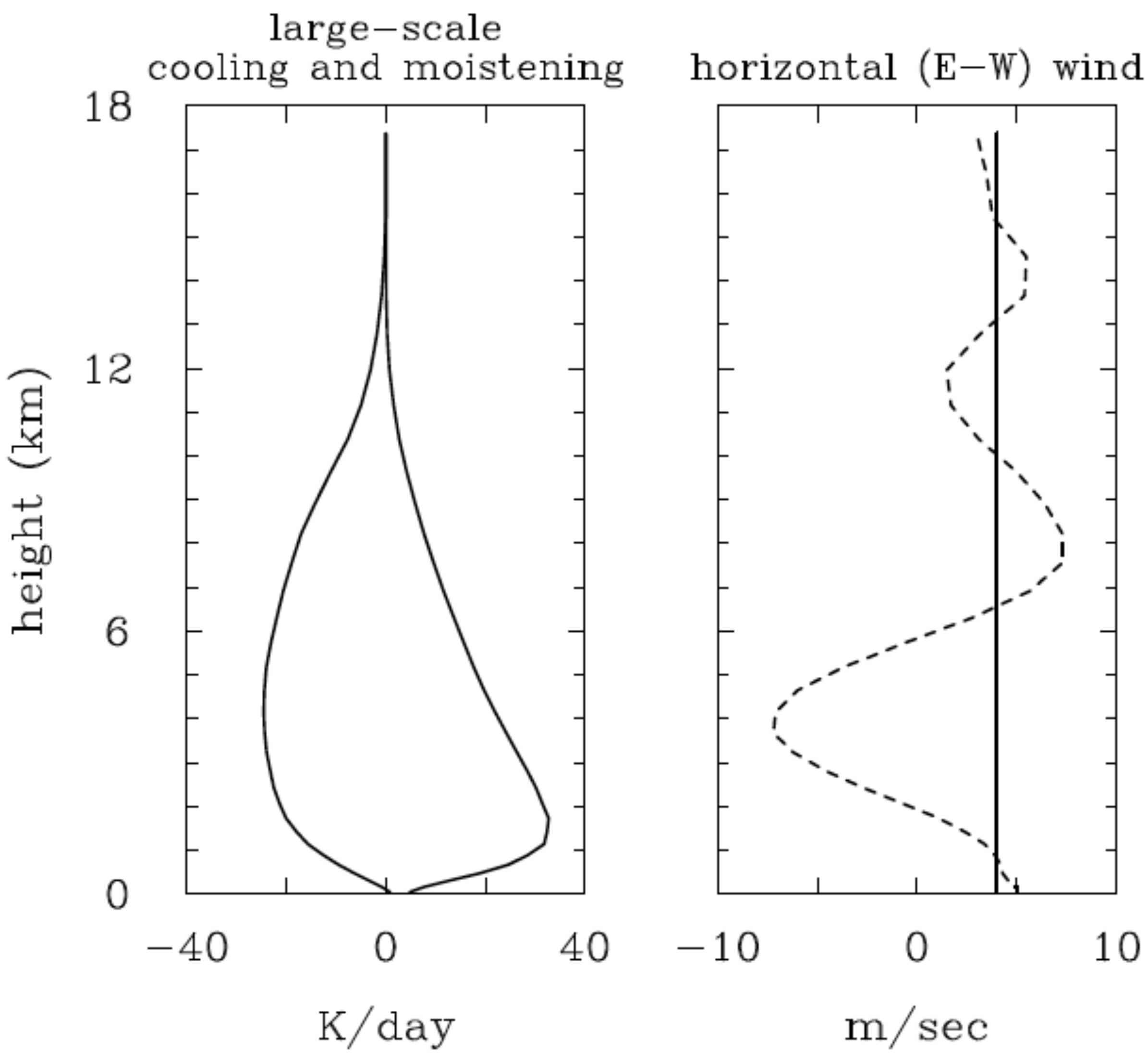
Microphysical processes in a deep convective cloud (U. Lohmann, ETH).

What does it mean "organized convection"?

What does it mean "organized convection"?

Since I am a modeler, I will explain this using a numerical model…

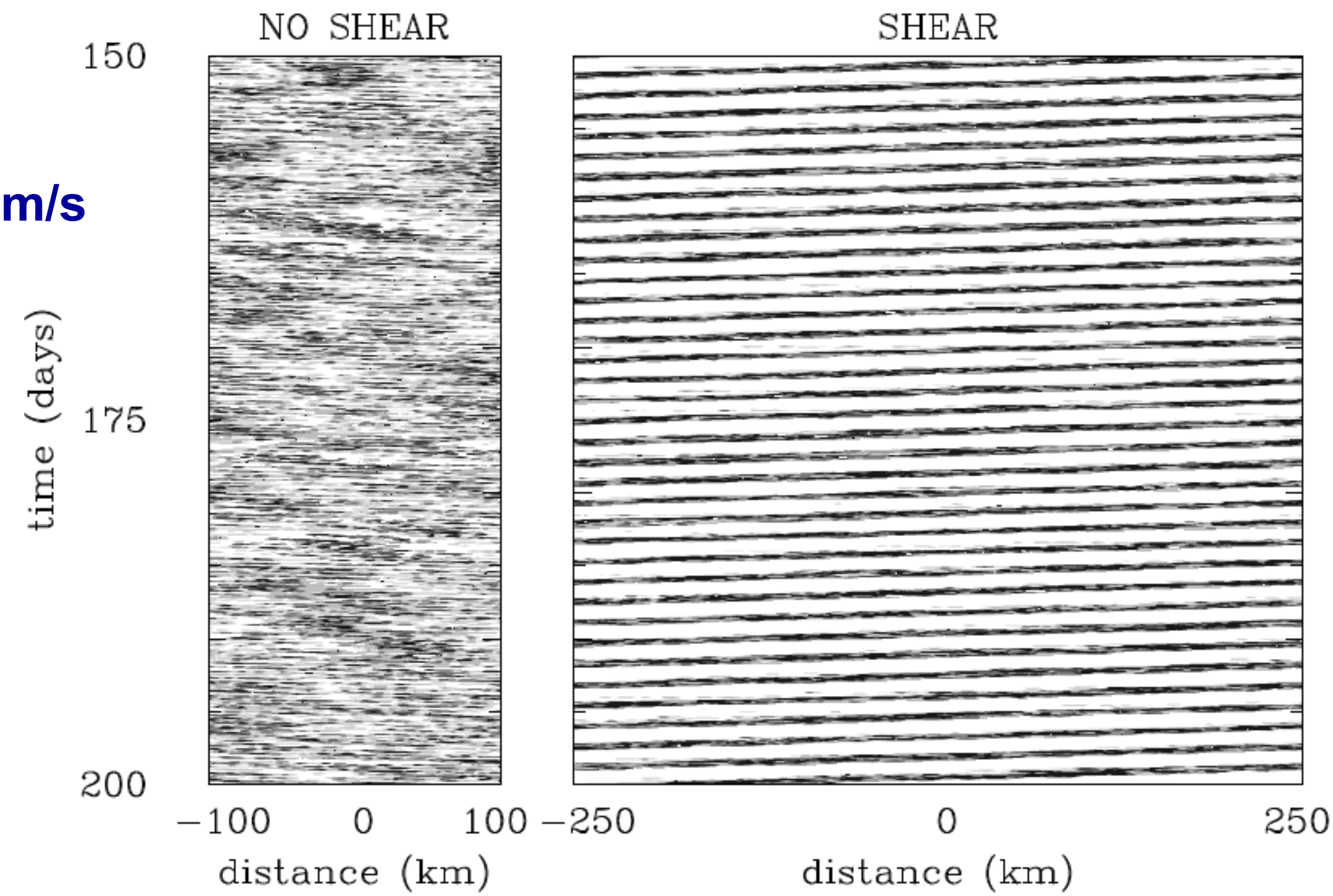
2D simulations of convection in the mean GATE environment (following Jung and Arakawa *MWR* 2005): sheared versus no-shear environment.



dx = 2km
dz ~ 300 m

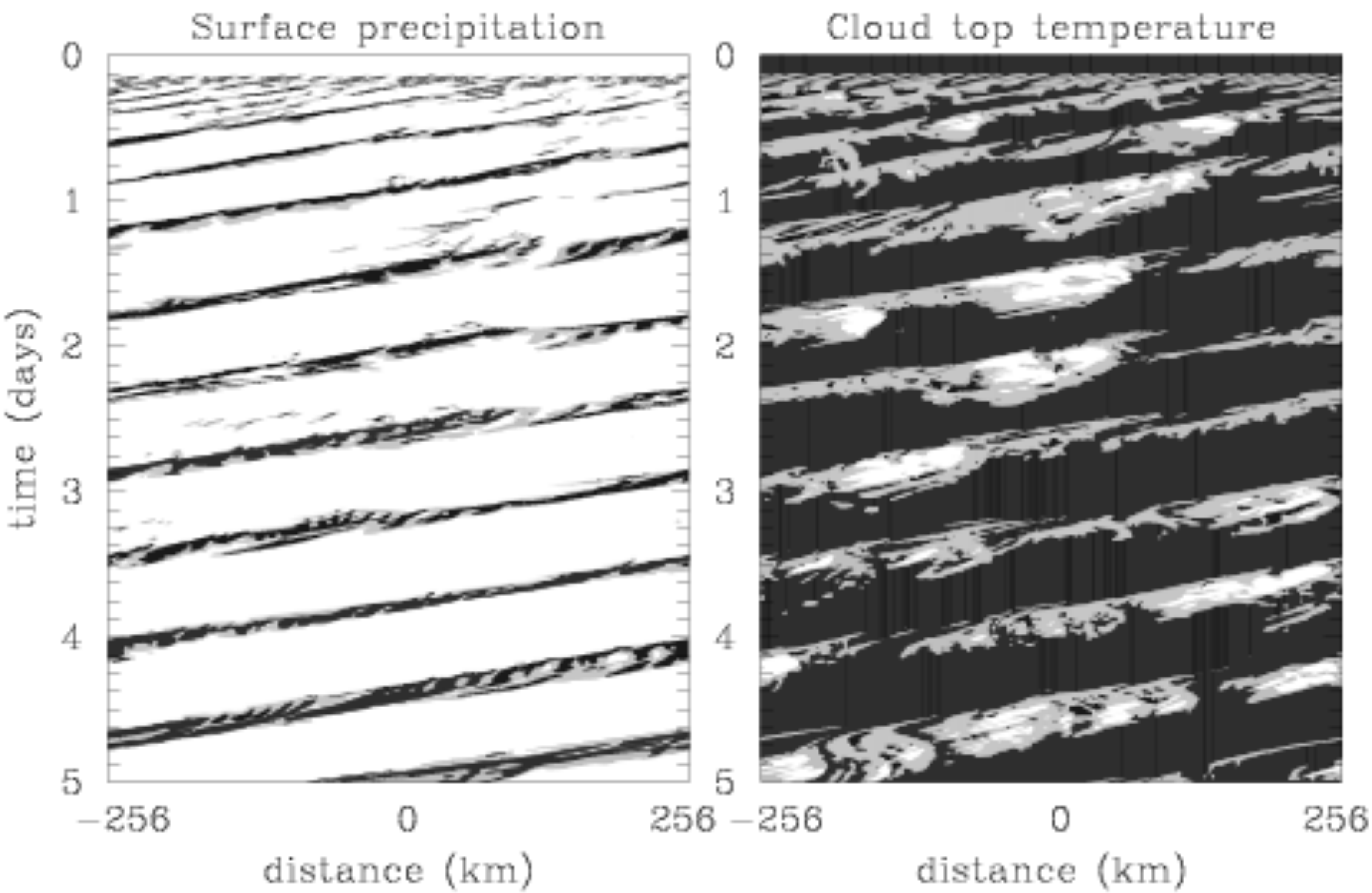
Hovmüller diagram of the surface precipitation

~ 4 m/s

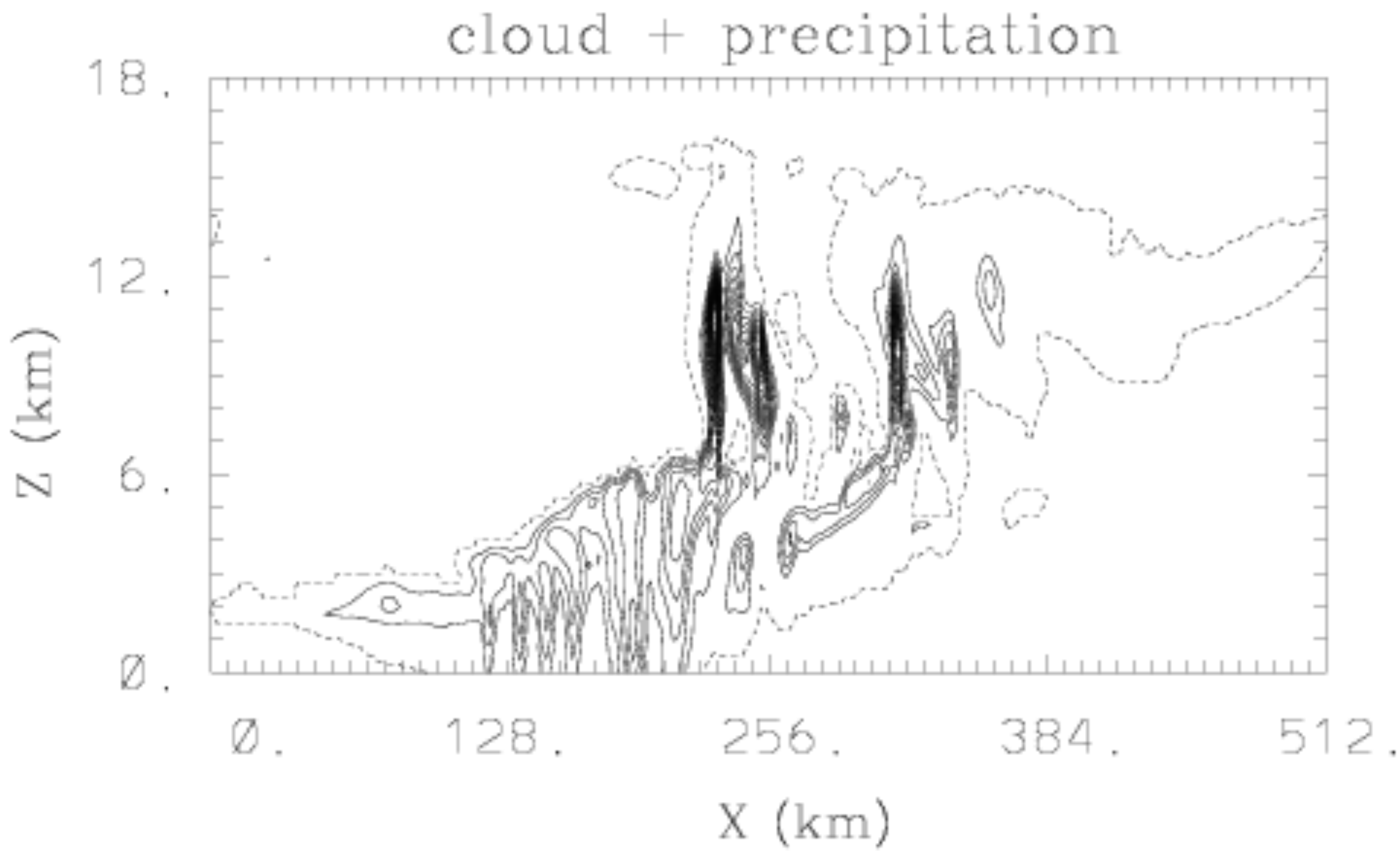


~ - 4 m/s

Hovmüller diagram of surface precipitation and cloud-top temperature for the shear case…



Snapshot of the sum of cloud and precipitation mixing ratio: a squall line



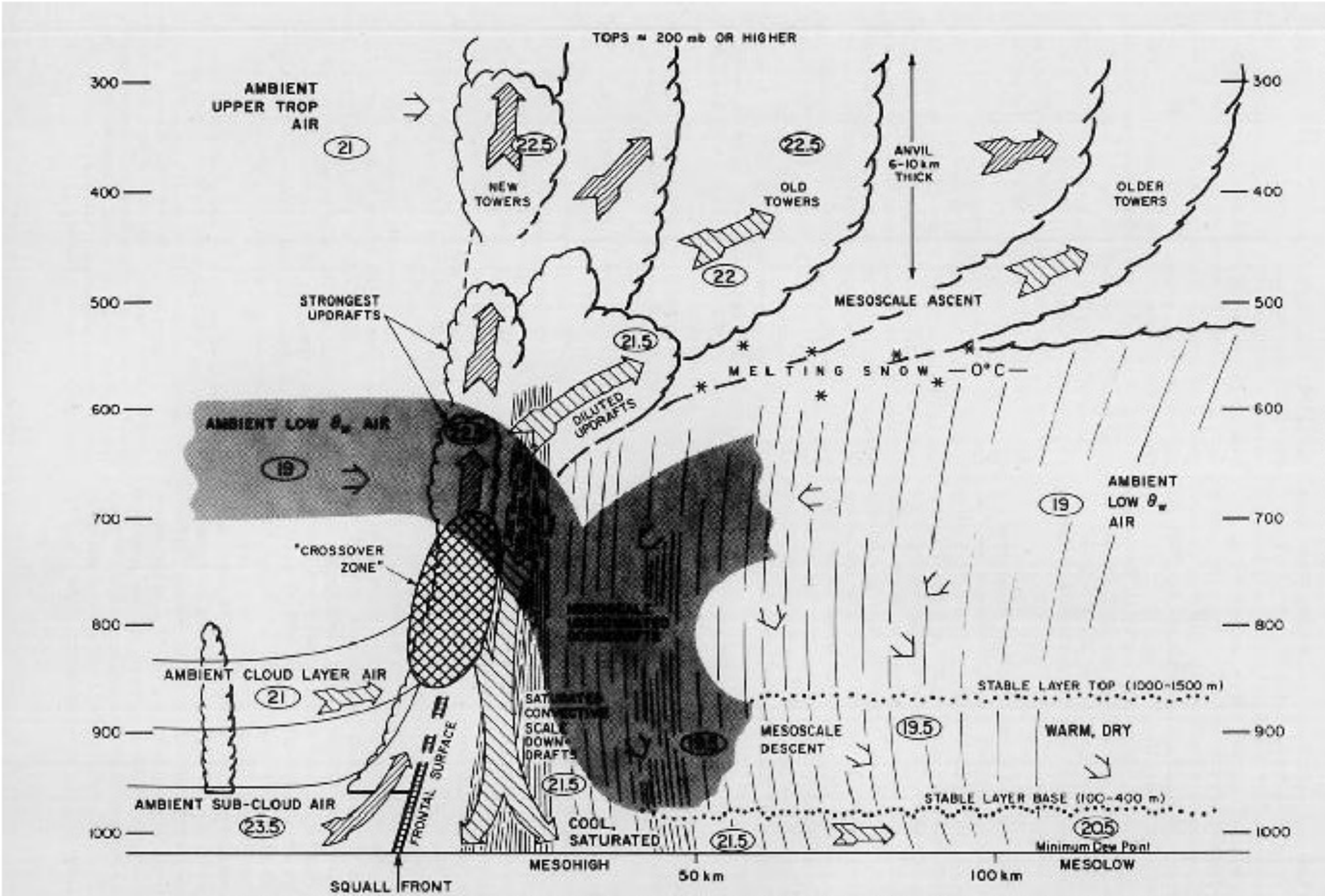


Fig. 13. Schematic cross section through a class of squall system. All flow is relative to the squall line which is moving from right to left. Circled numbers are typical values of θ_w in °C. See text for detailed discussion.

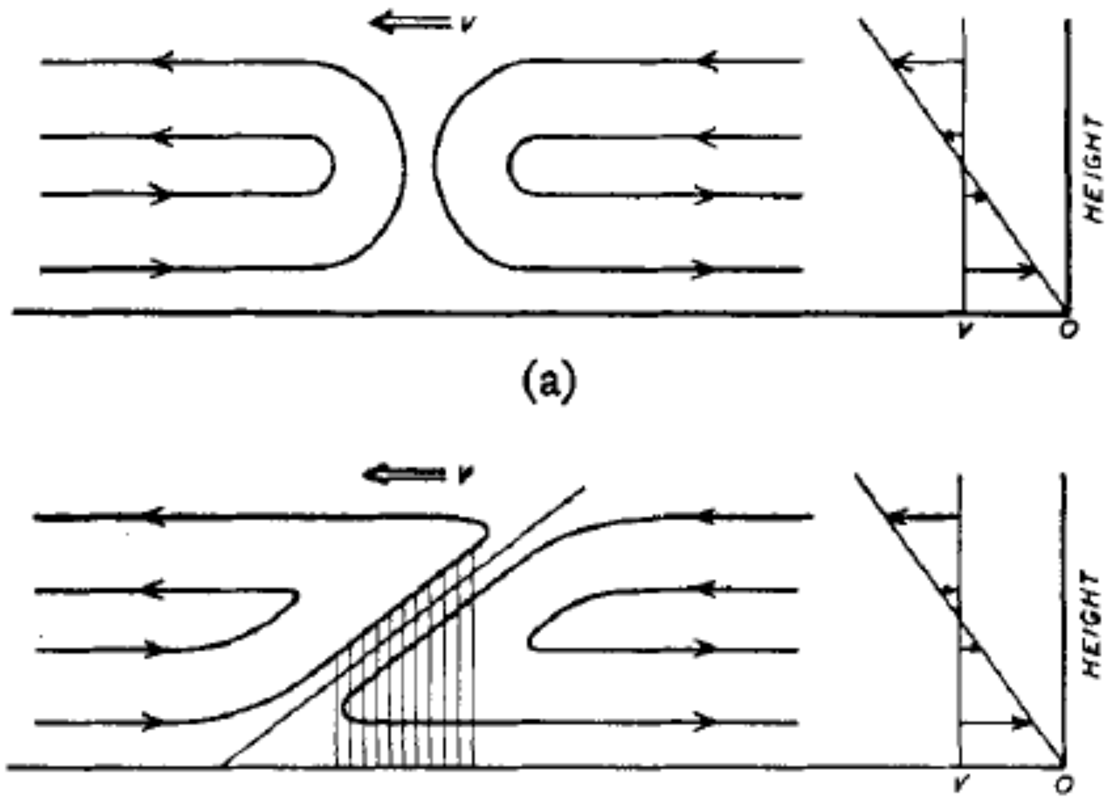
Zipser, *Mon. Wea. Rev.,* 1977 (observations in GATE)

Vol. 88 APRIL 1962 No. 376

551.501.81 : 551.515.4 : 551.578.7

Airflow in convective storms

By K. A. BROWNING and F. H. LUDLAM
Imperial College, London



(a)

(b)

Vol. 88 APRIL 1962 No. 376

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Airflow in convective storms

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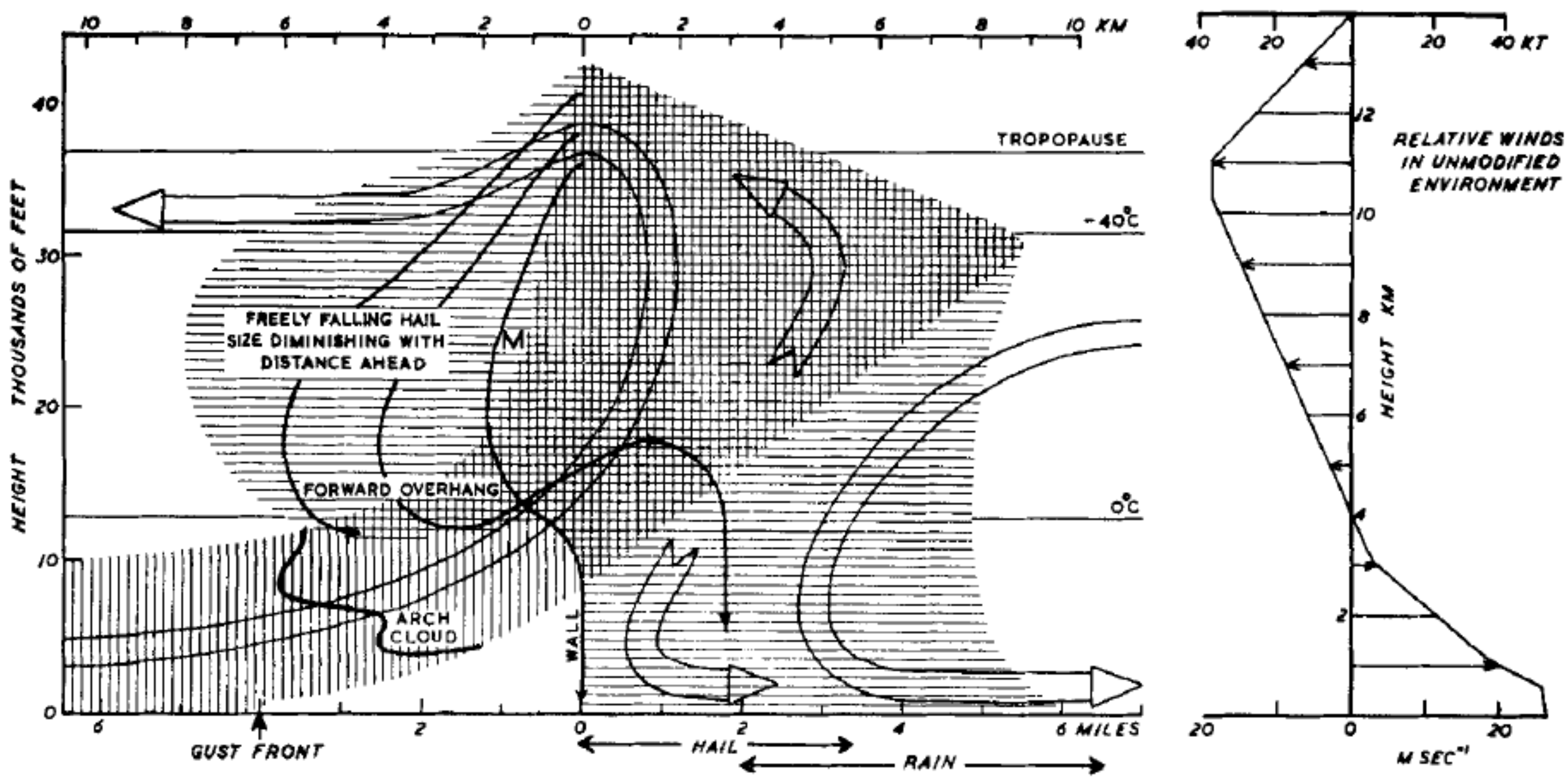
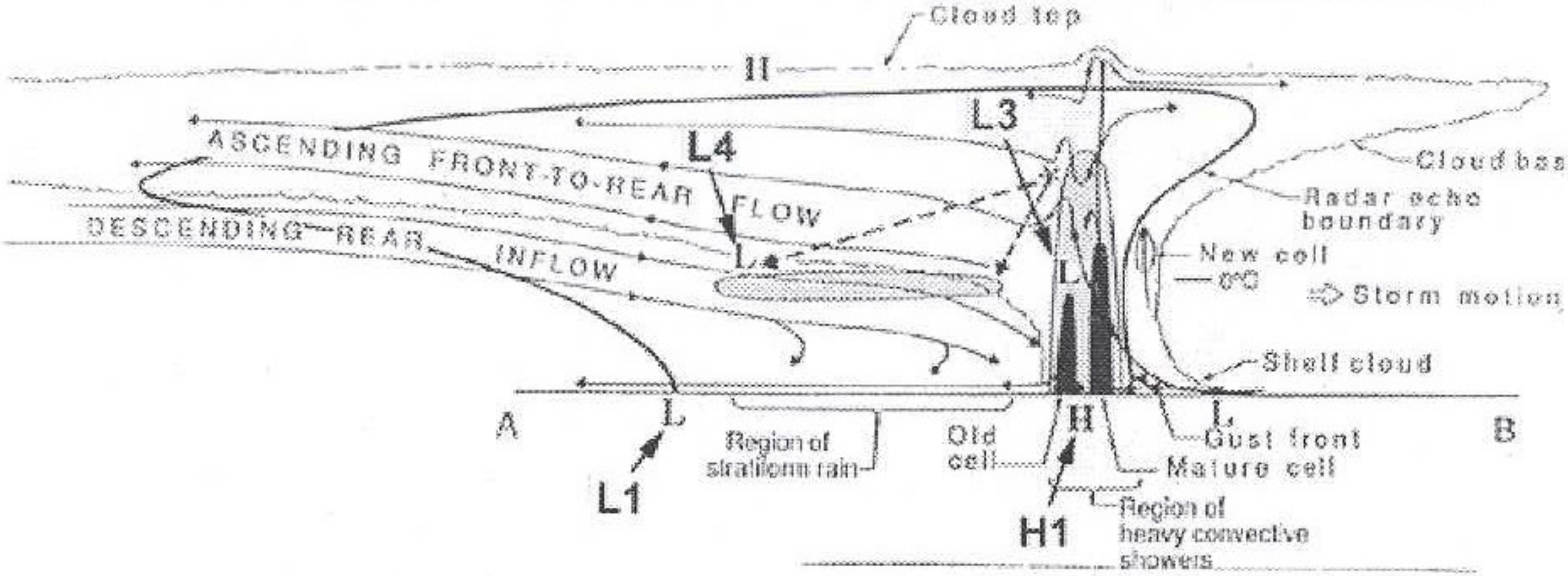
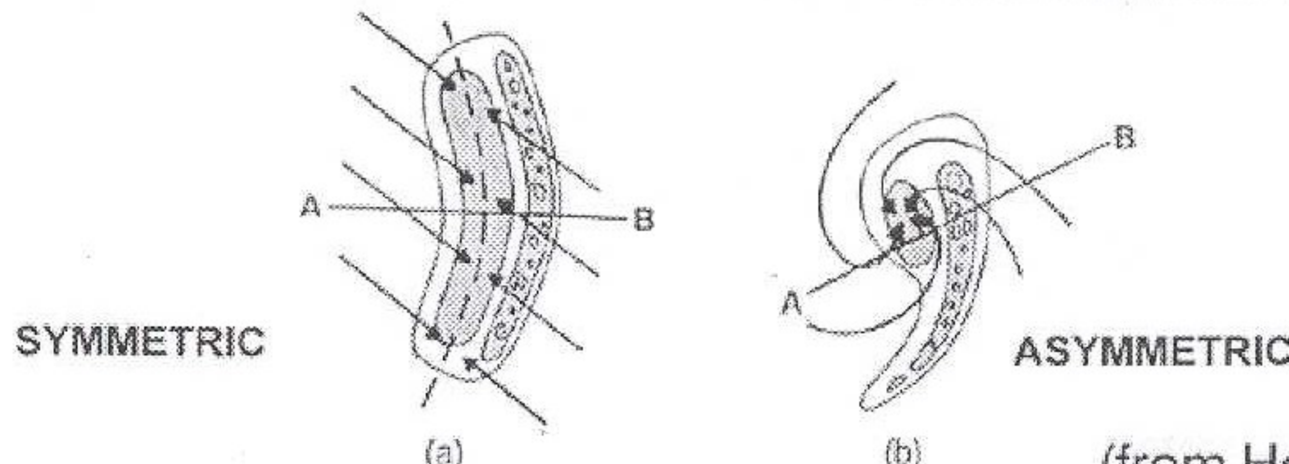
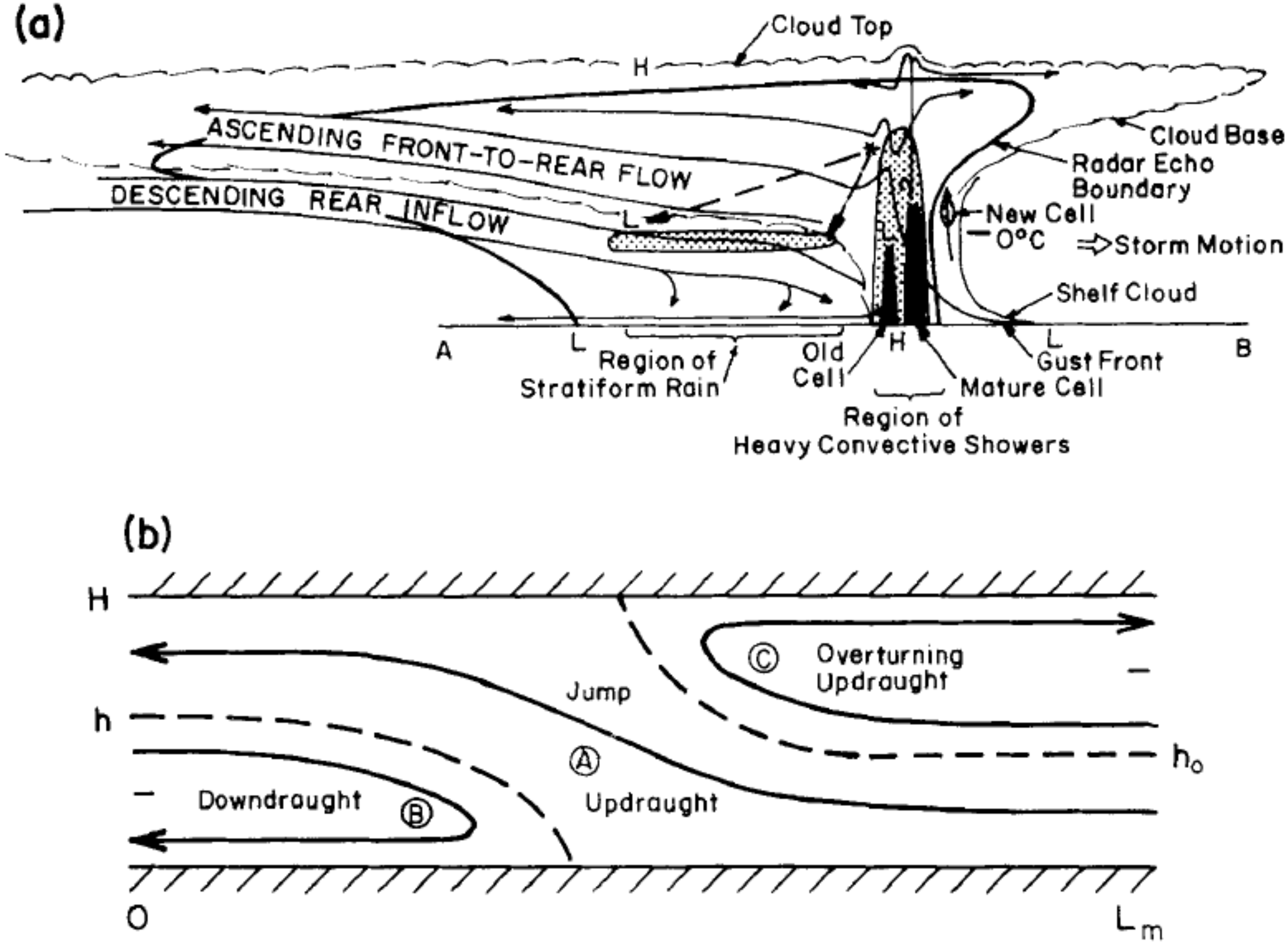


STORM CONCEPTUAL MODEL - MESOSCALE AIRFLOW STRUCTURE OF A LARGE - MATURE MCS





(from Houze et al. 1988)



Moncrieff QJ 1992

"RKW theory"

A Theory for Strong, Long-Lived Squall Lines

RICHARD ROTUNNO, JOSEPH B. KLEMP AND MORRIS L. WEISMAN

National Center for Atmospheric Research, Boulder, Colorado*

(Manuscript received 27 February 1987, in final form 7 September 1987)

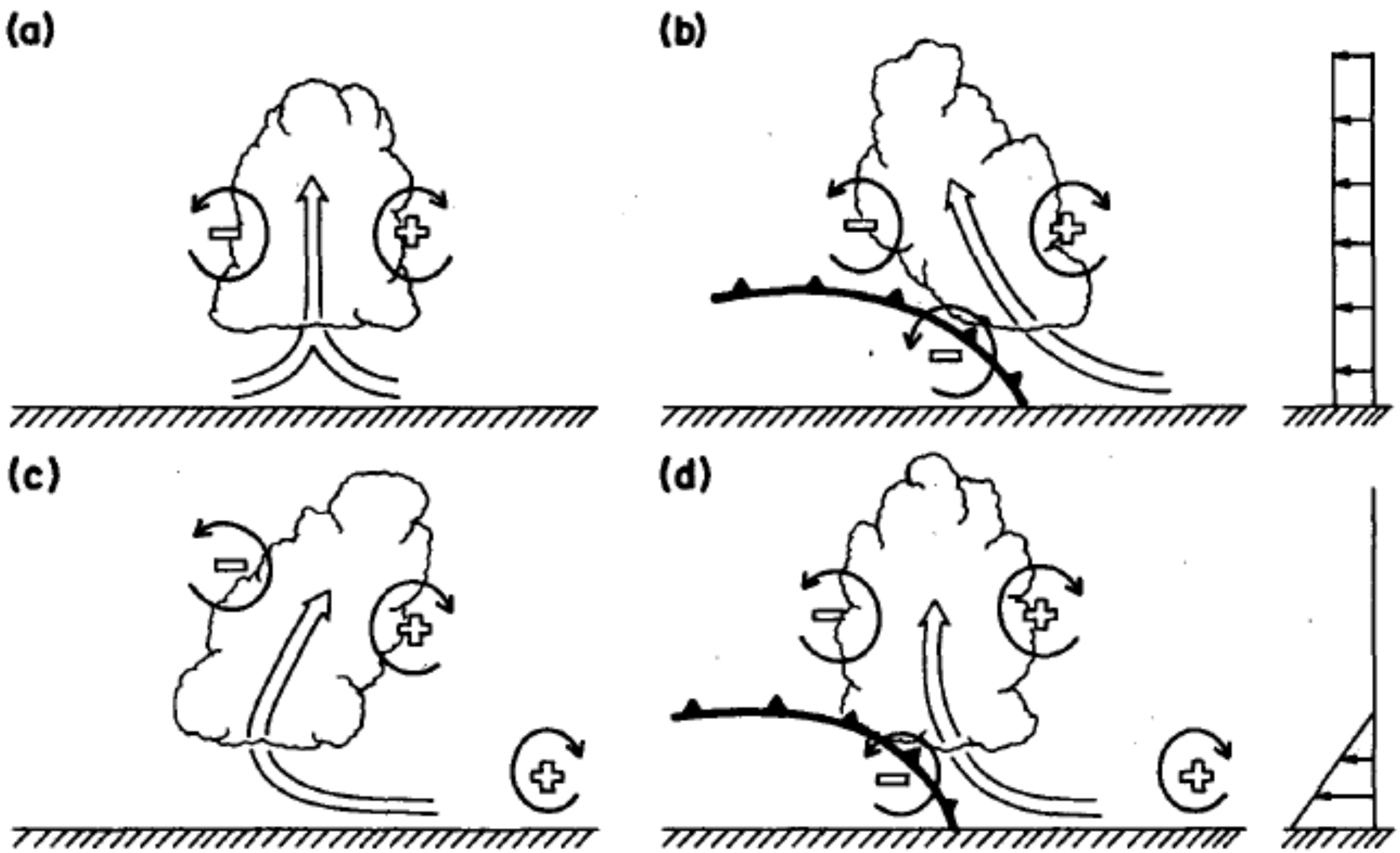


FIG. 18. Schematic diagram showing how a buoyant updraft may be influenced by wind shear and/or a cold pool. (a) With no shear and no cold pool, the axis of the updraft produced by the thermally created, symmetric vorticity distribution is vertical. (b) With a cold pool, the distribution is biased by the negative vorticity of the underlying cold pool and causes the updraft to lean upshear. (c) With shear, the distribution is biased toward positive vorticity and this causes the updraft to lean back over the cold pool. (d) With both a cold pool and shear, the two effects may negate each other, and allow an erect updraft.

Tornadic supercell – another example of organized convection…

Typically associated with high CAPE and thus occurring over summertime continents, especially N. America…

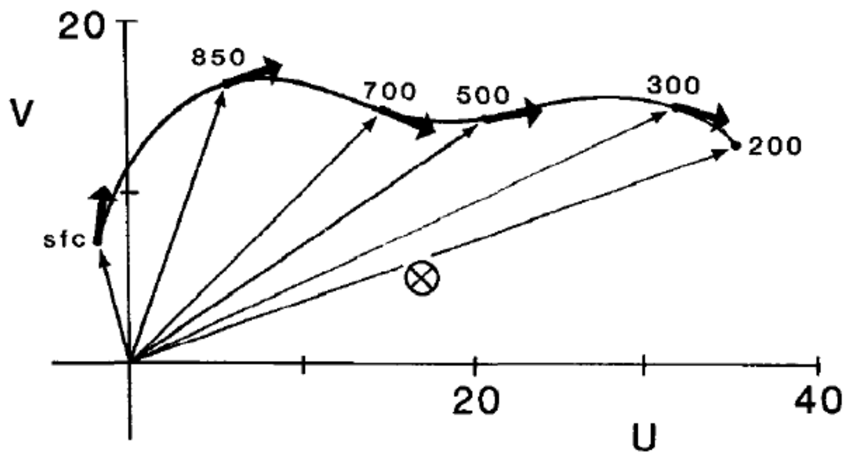
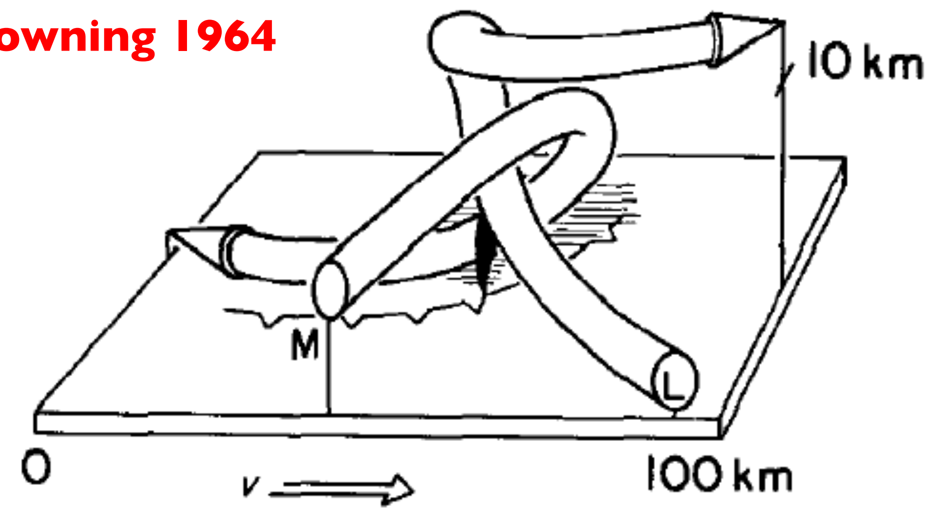
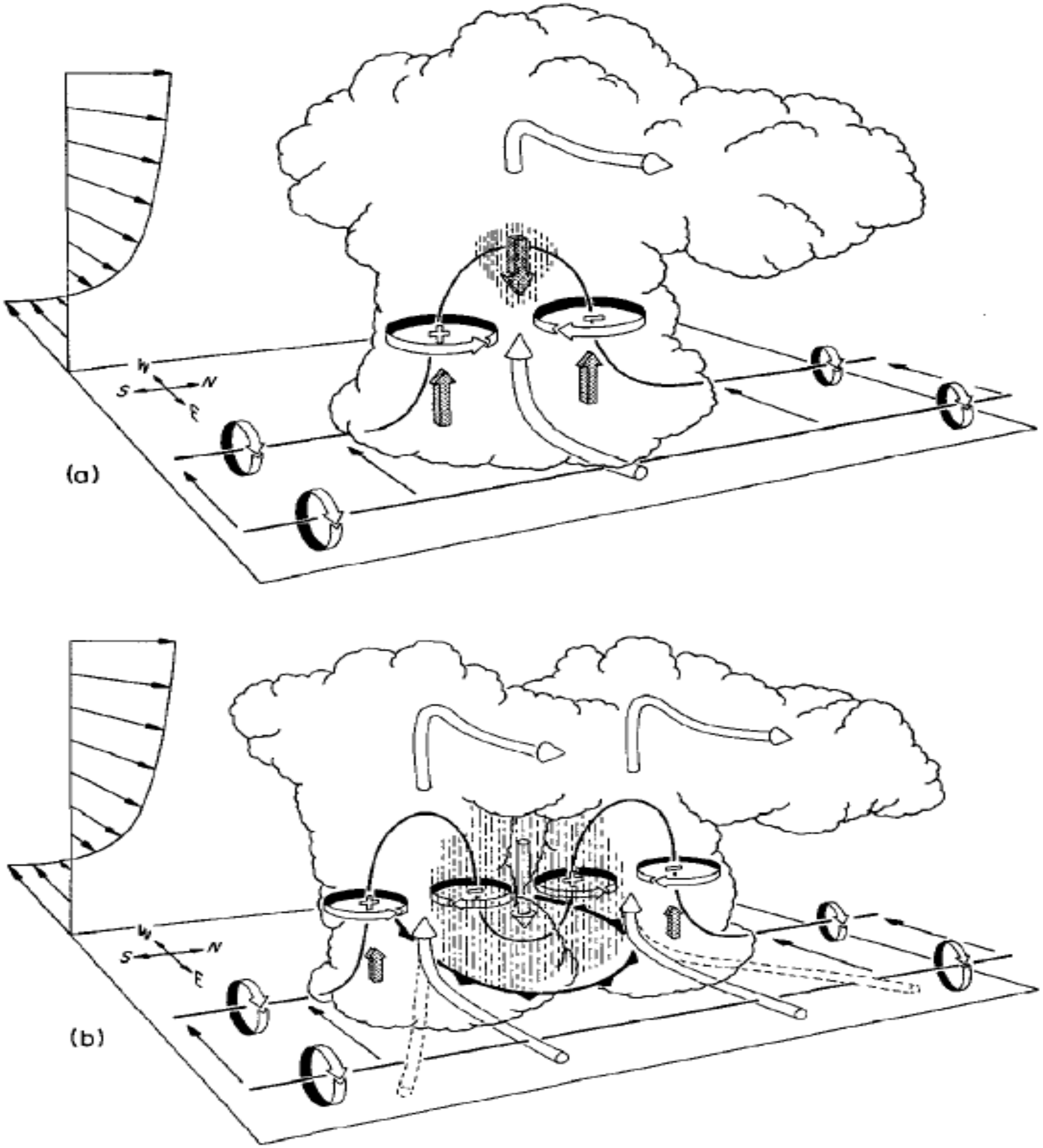


Figure 5 Mean wind sounding (in m s^{-1}) for 62 tornado outbreak cases. The soundings are composited by computing the winds at each level relative to the estimated storm motion. Heavy arrows indicate the direction of the shear vector at each level (labeled in mbar). The estimated mean storm motion is denoted by ⊗. (Adapted from Maddox 1976.)

Browning 1964



Klemp 1987



Rotunno 1981

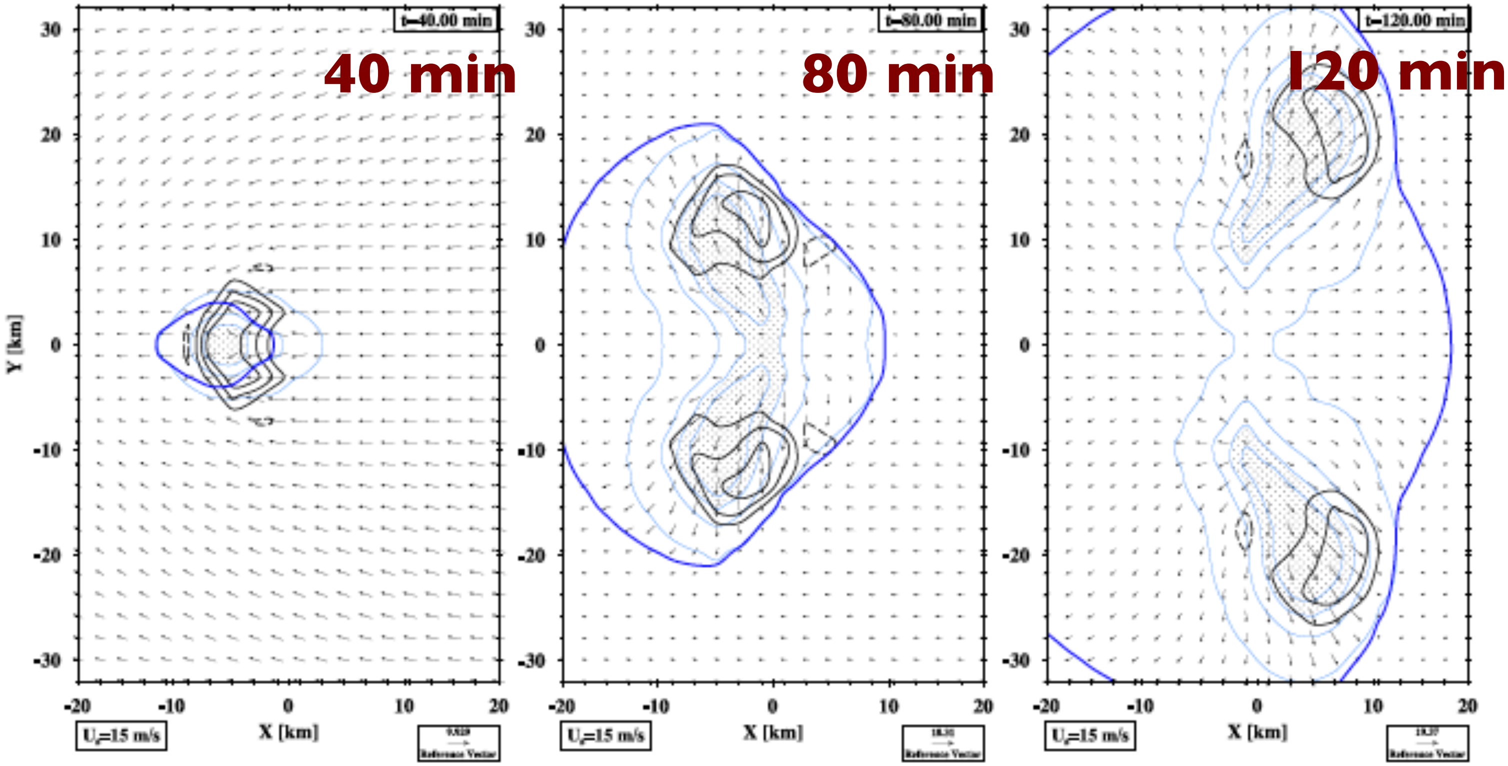
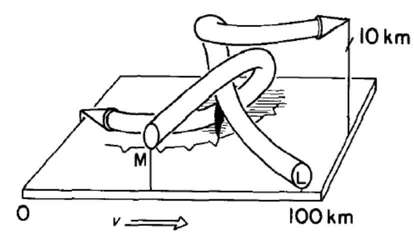


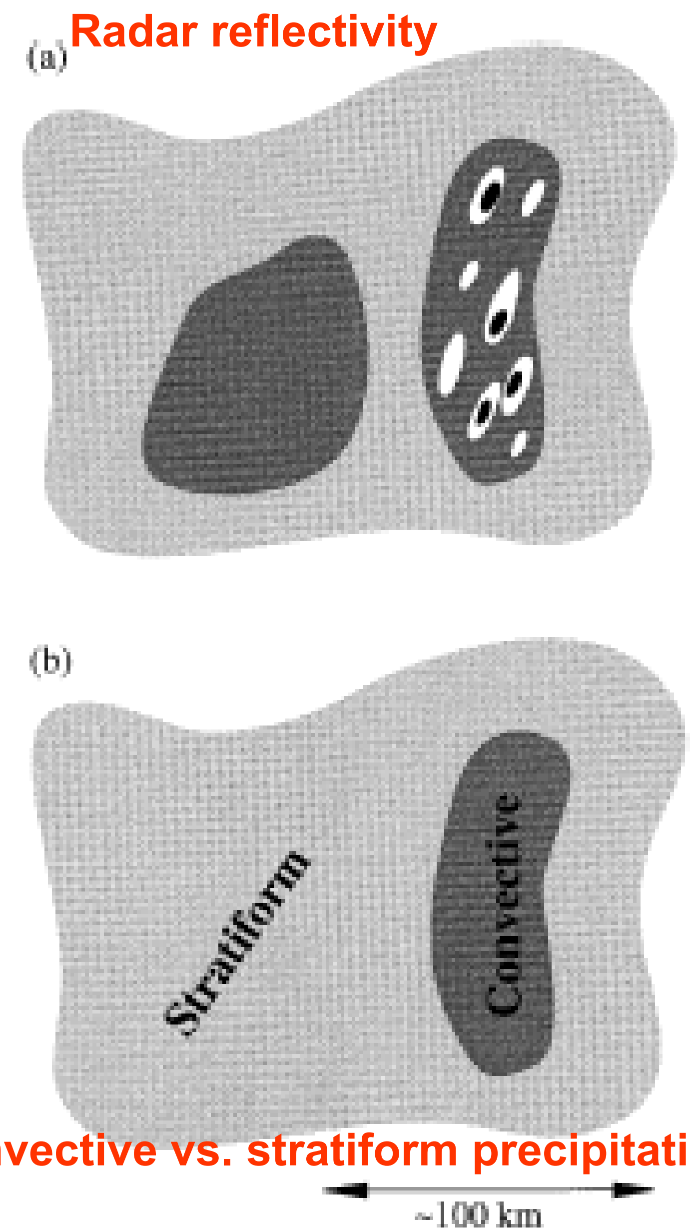
Fig. 10. Time evolution of horizontal flow at 75 m (black vectors), vertical velocity at 4900 m (black lines, dashed for negative values), surface precipitation (light blue lines), and a cold front defined as the edge of a cold pool ($\Delta\theta = -1$ K) at the surface (bold blue line). Dotted area marks region of $q_r > 2$ g/kg at the ground. Vertical velocity is contoured every 5 m/s for positive values and 2 m/s for negative values. Surface precipitation is contoured every 1 g/kg. The results are plotted for $U_s = 15$ m/s.



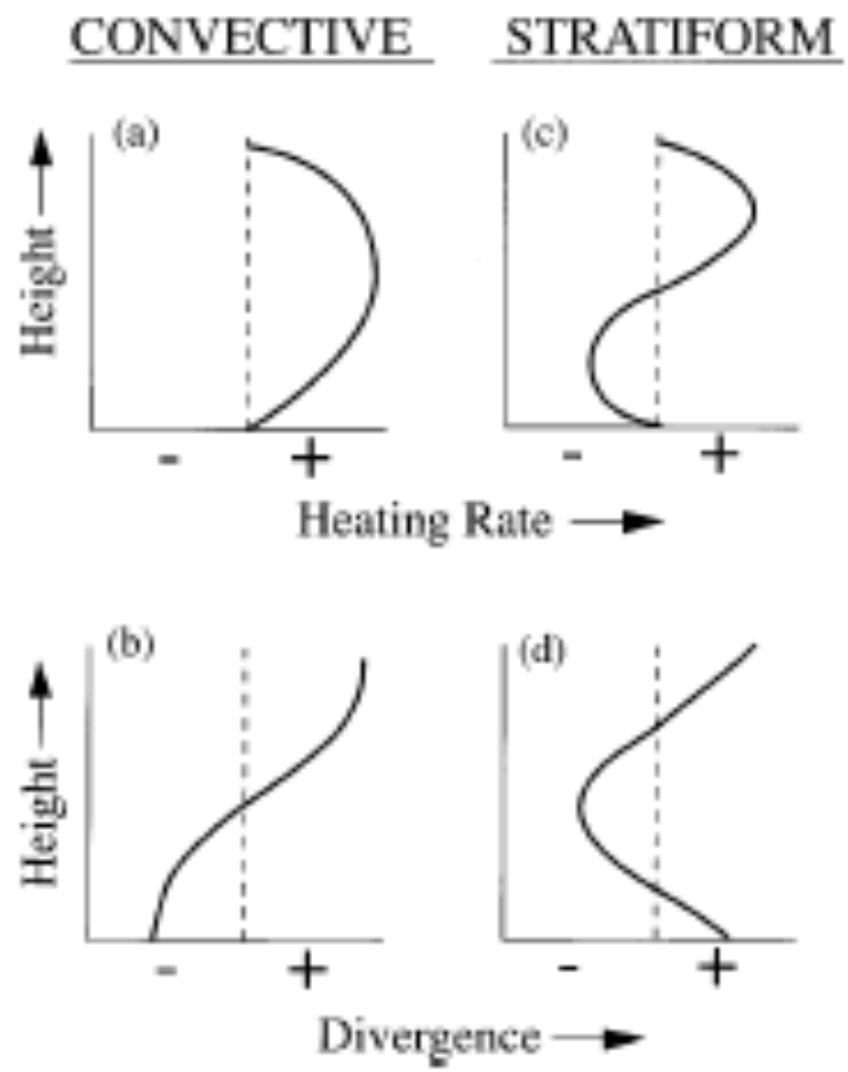
Kurowski et al. *AG* 2011

Impact of organized convection on its environment

Thermodynamic effect (mean heating: latent heating + convective heat transport)



Convective vs. stratiform precipitation

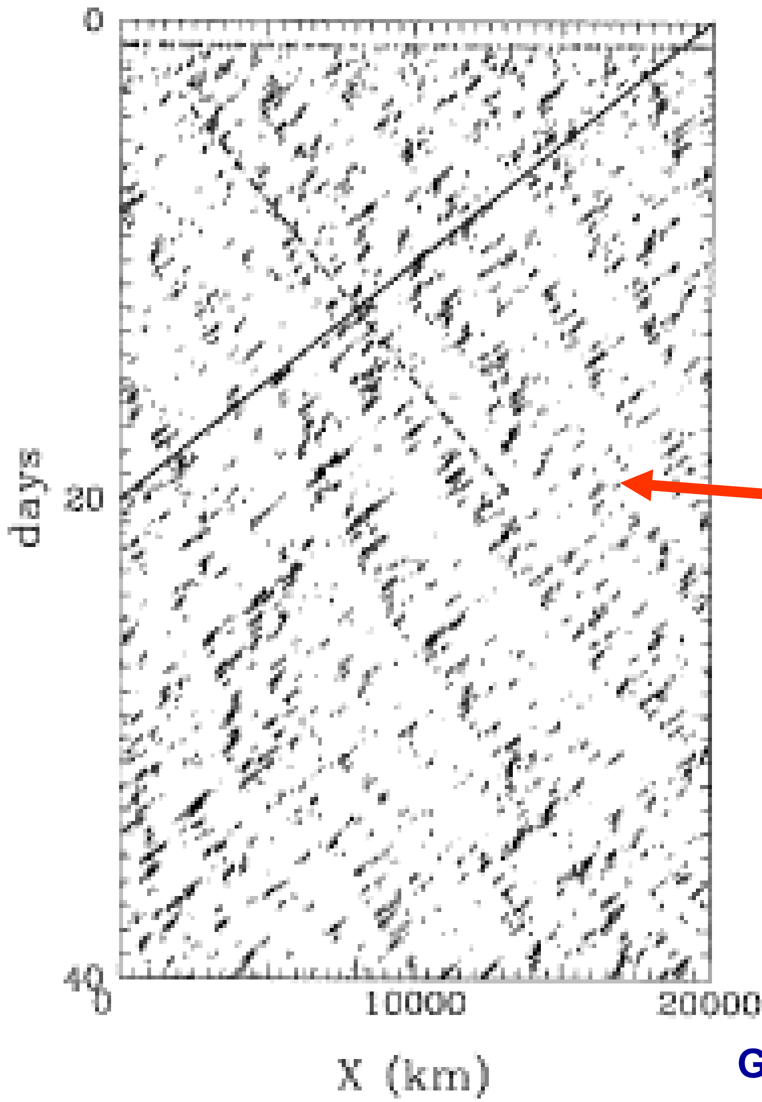


Houze, *BAMS*, 1997

Dynamic effect (convective transport of horizontal momentum)

Illustrated here by 2D cloud-resolving simulation of convective-radiative quasi-equilibrium in a very large computational domain

Prescribed radiative cooling (1.5 K/day across troposphere), prescribed surface conditions (ocean with constant SST), no *mean* large-scale shear

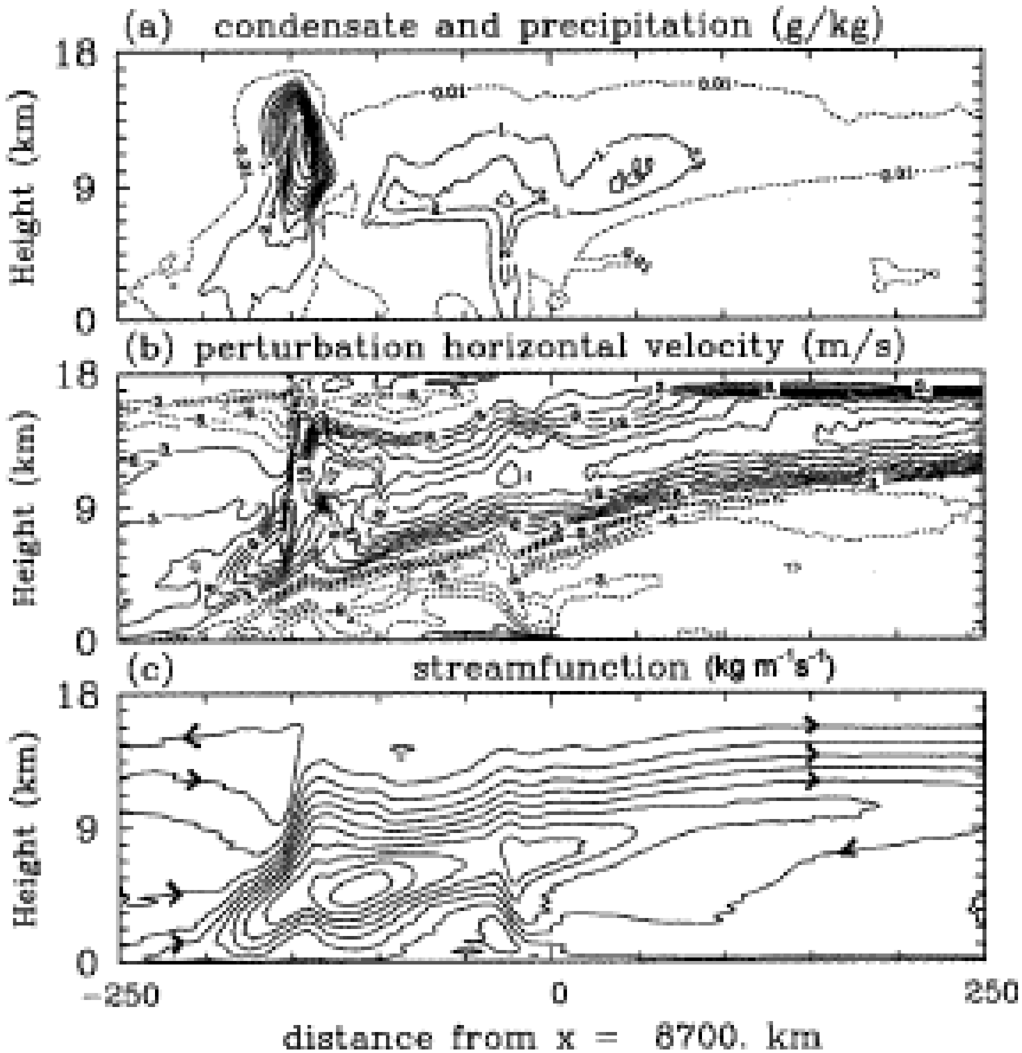


~ 3 km horizontal gridlength

Hovmüller diagram of surface precipitation

Grabowski and Moncrieff, *QJRMS*, 2001

Dynamic effect (convective transport of horizontal momentum), cont.

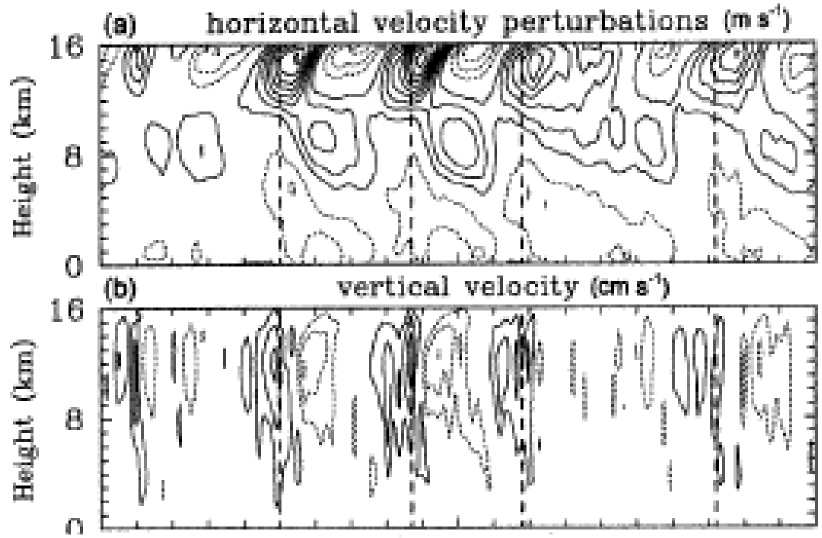


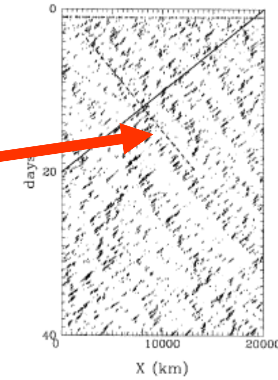
Convection takes the form of 2D squall lines, like in GATE small-domain simulations

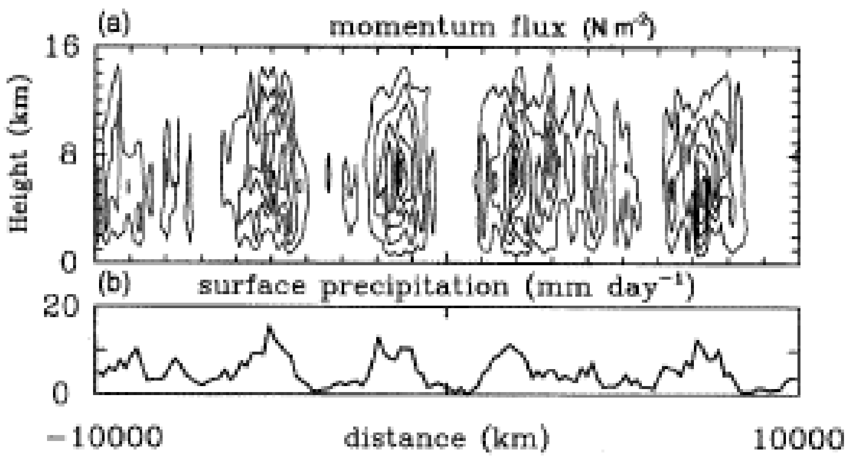
…there is no large-scale shear, but it does exist in parts of the domain…

Grabowski and Moncrieff, *QJRMS*, 2001

Dynamic effect (convective transport of horizontal momentum), cont.







convective flux of horizontal momentum, Λ

$$\Lambda = \rho u' w'$$

Grabowski and Moncrieff, *QJRMS*, 2001

Dynamic effect (convective transport of horizontal momentum), cont.

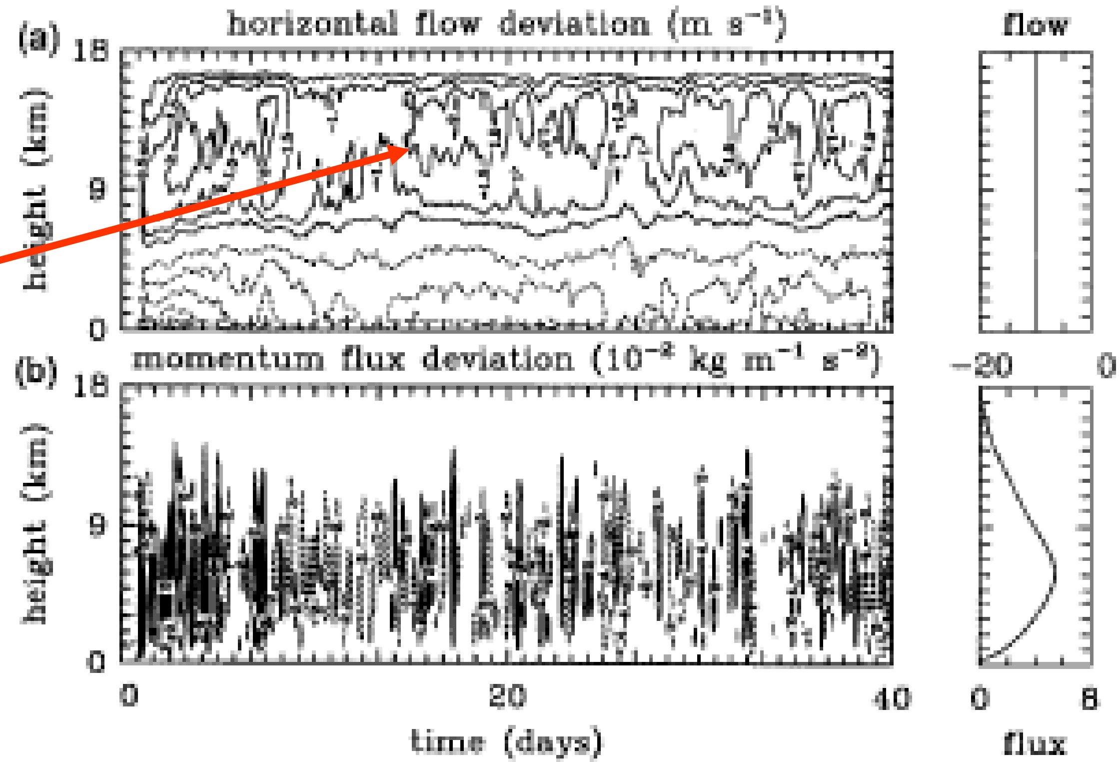
convective flux of horizontal momentum, Λ

$$\Lambda = \rho u' w'$$

domain-averaged flow

$$\frac{\partial \overline{u}}{\partial t} \approx -\frac{1}{\rho}\frac{\partial \overline{\Lambda}}{\partial z} - \frac{\overline{u} - U_o}{\tau}$$

τ **= 1 day, mean flow deviates ~ 1 m/s, so the momentum fluxes represent accelerations ~ 1 m/s/day**



Grabowski and Moncrieff, *QJRMS*, 2001

Is organized convection present in many places on Earth?

Organized convection in the tropics: part of the multi-scale convective phenomena…

Madden and Julian, JAS 1972

34 days

0 days, 45 days

12 days

22 days

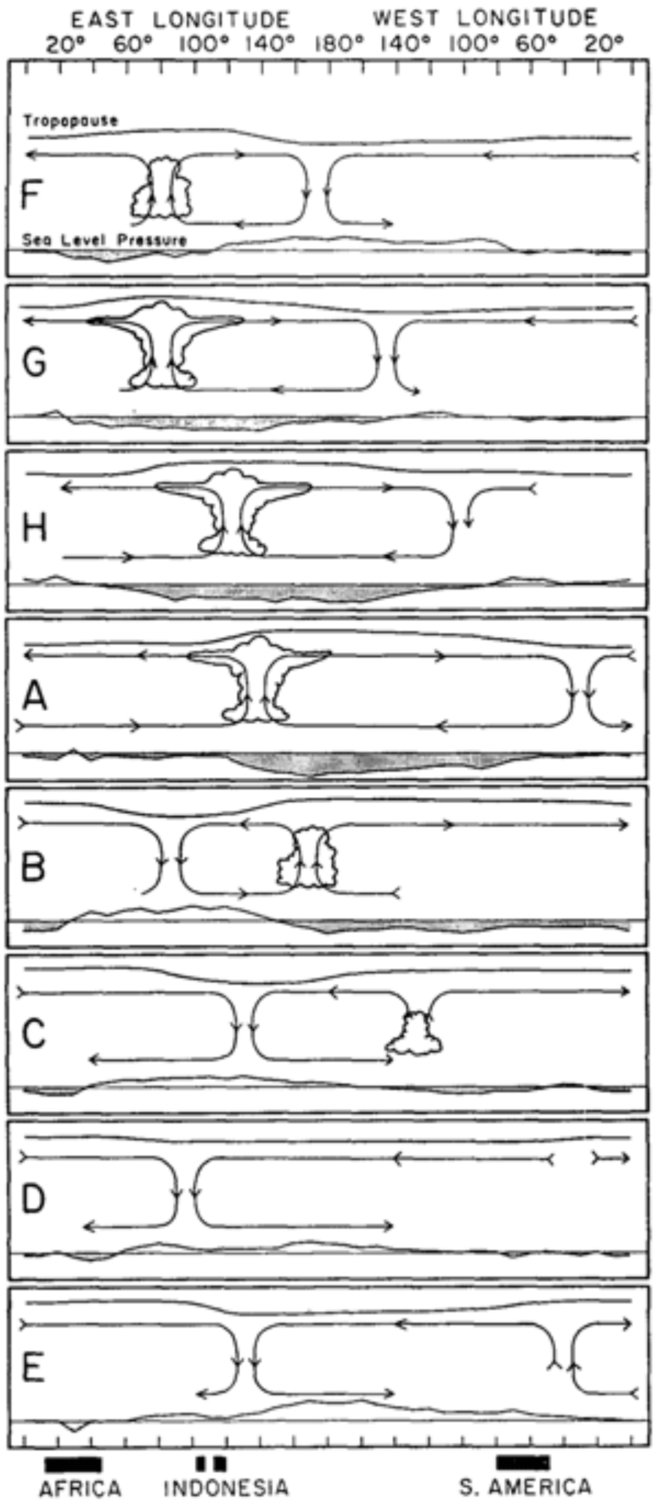


FIG. 16. Schematic depiction of the time and space (zonal plane) variations of the disturbance associated with the 40–50 day oscillation. Dates are indicated symbolically by the letters at the left of each chart and correspond to dates associated with the oscillation in Canton's station pressure indicated in Fig. 11. The mean pressure disturbance taken from Fig. 12 is plotted at the bottom of each chart with negative anomalies shaded. The circulation cells are based on the mean zonal wind disturbance presented in Fig. 13. Regions of enhanced large-scale convection are indicated schematically by the cumulus and cumulonimbus clouds. The relative tropopause height is indicated at the top of each chart.

Nakazawa, *JMSJ*, 1988

supercluster

organized convection

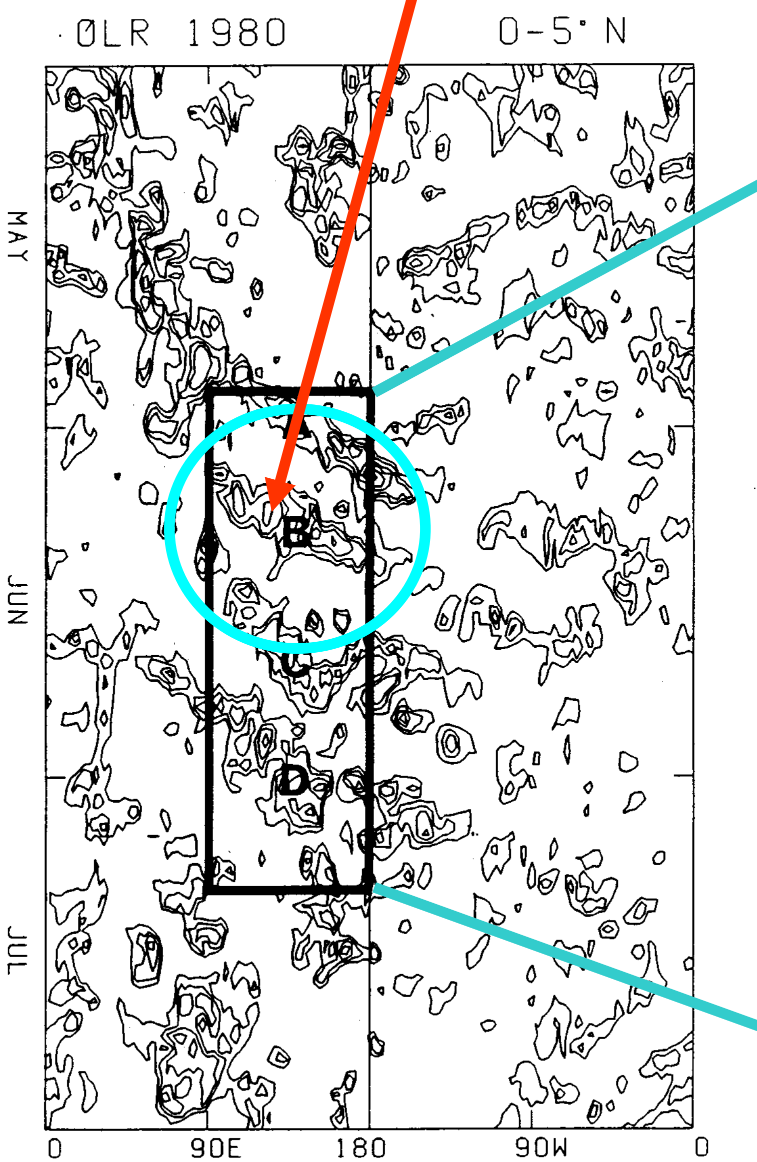


Fig. 1. Time-longitude section of transient (seasonal trend removed) OLR averaged between the equator and 5°N from May to July in 1980. Negative (active convective) regions are contoured. Contour interval decrements of 30 Wm^{-2} starting at -15 Wm^{-2}. Symbols A to D indicate super clusters.

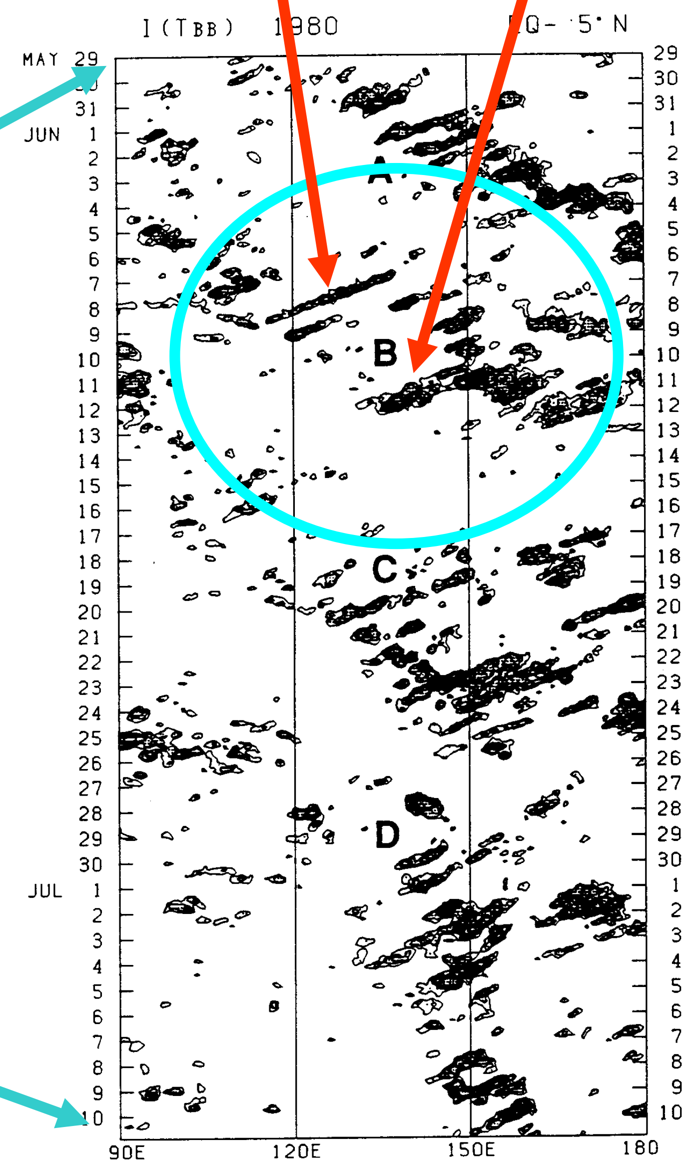


Fig. 2. Time-longitude section of T_{BB} index (I_{TBB}) integrated between the equator and 5°N obtained from the 3-hourly GMS IR data from 29 May 00Z to 10 July 21Z, 1980. Symbols A to D denote the same super cluster as in Fig. 1. Contour interval is 10, and shading denotes the region where values are greater than 20.

Nakazawa, *JMSJ*, 1988

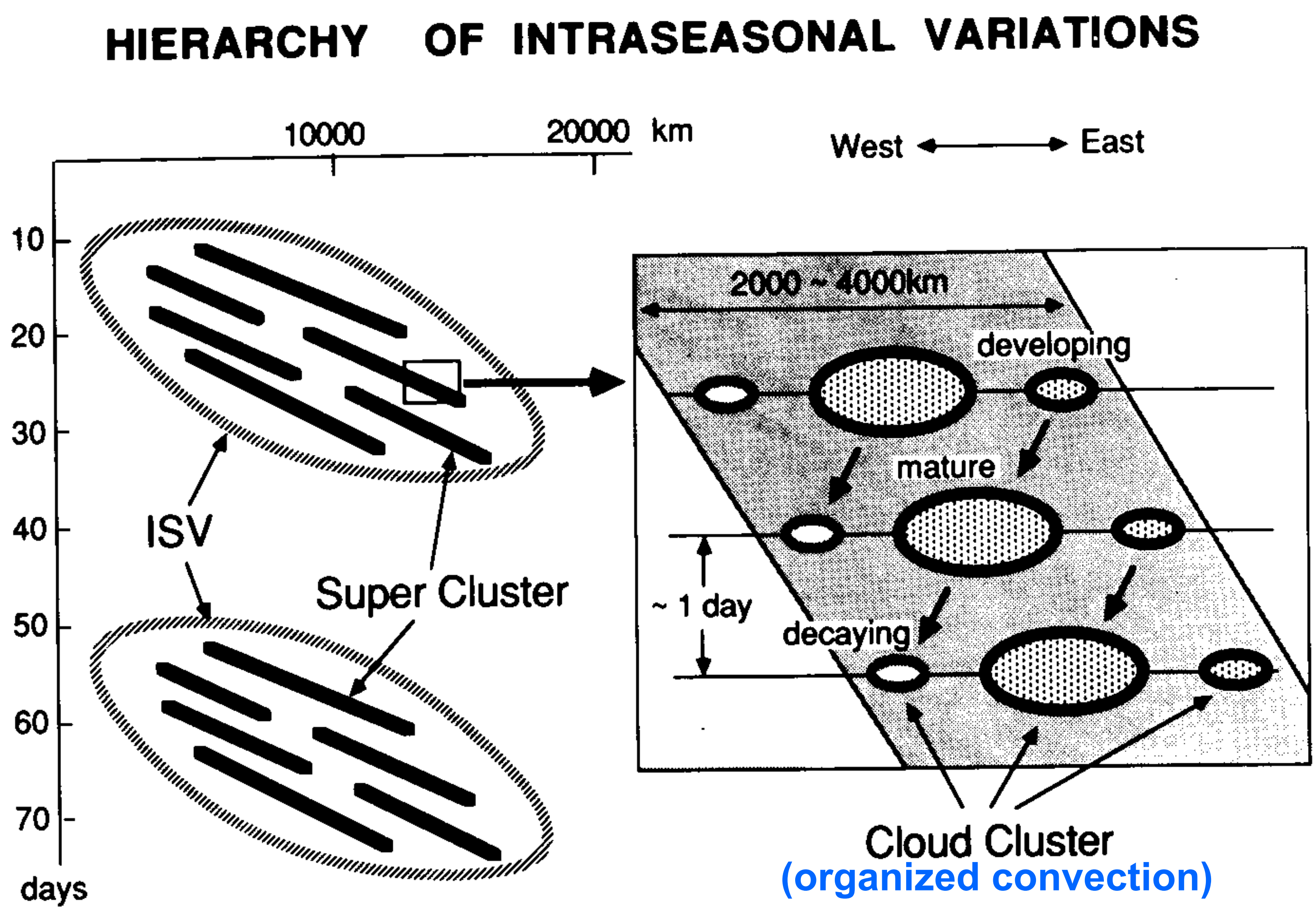
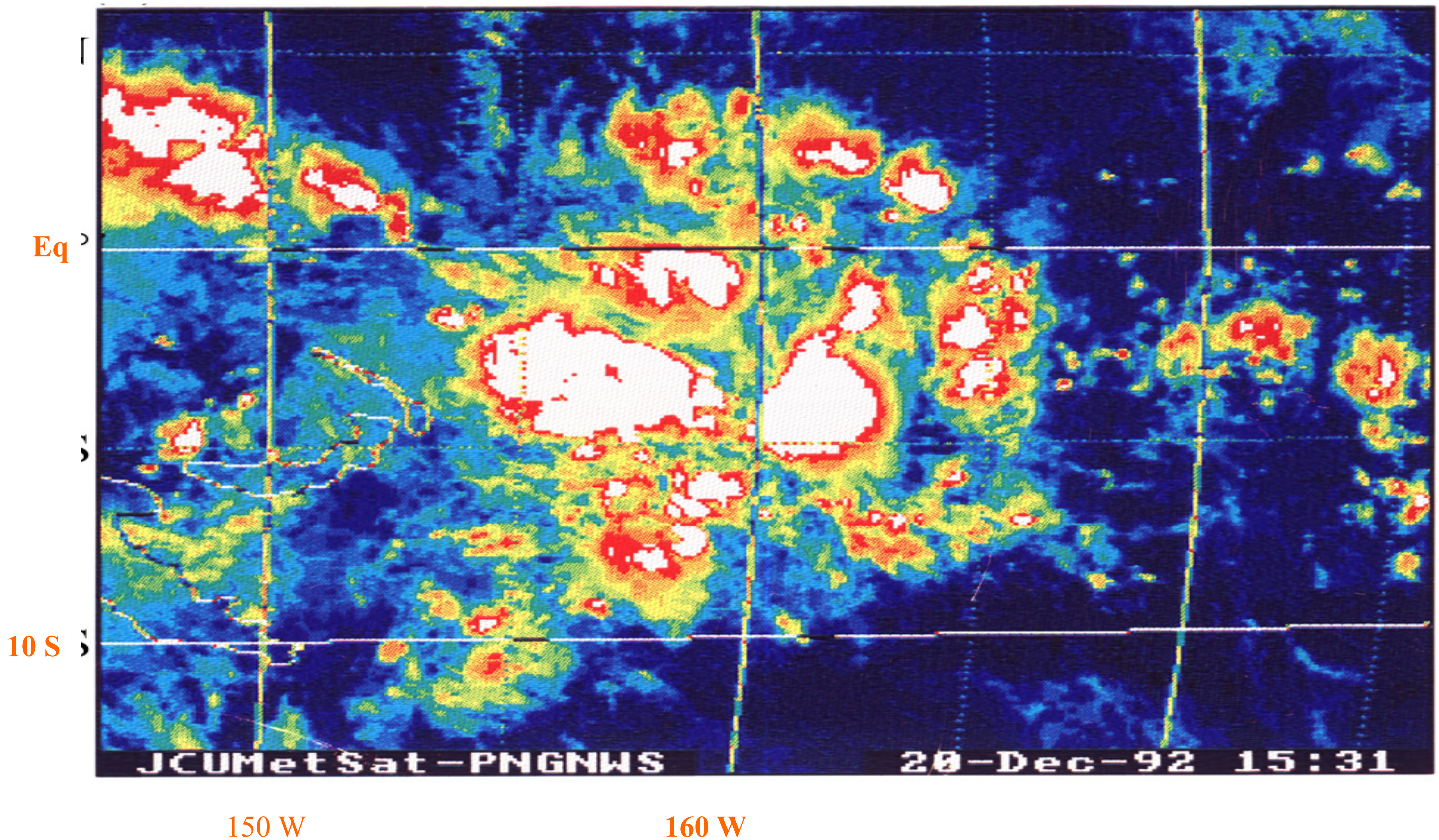
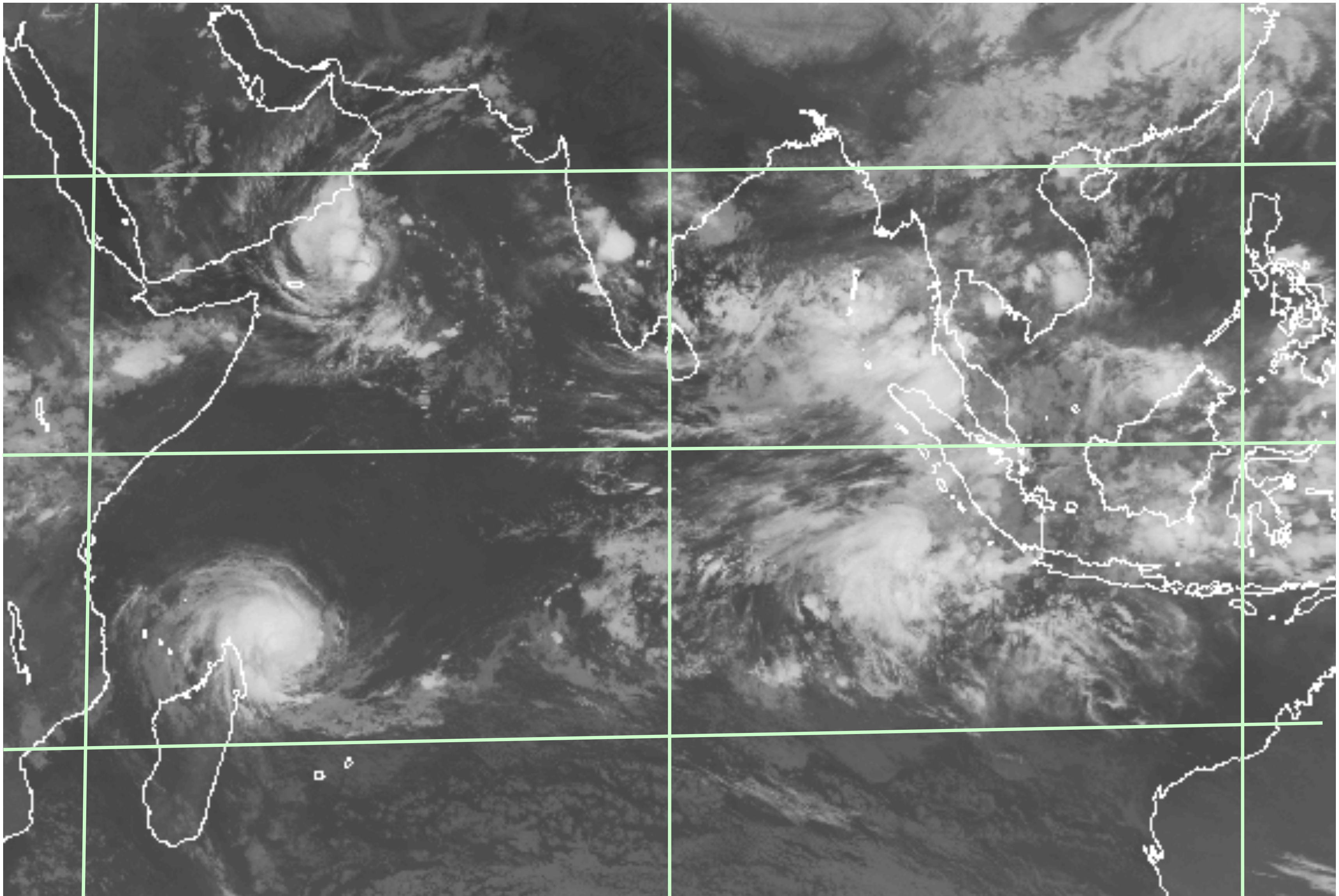


Fig. 5. Schematic diagram for the hierarchy of ISV.

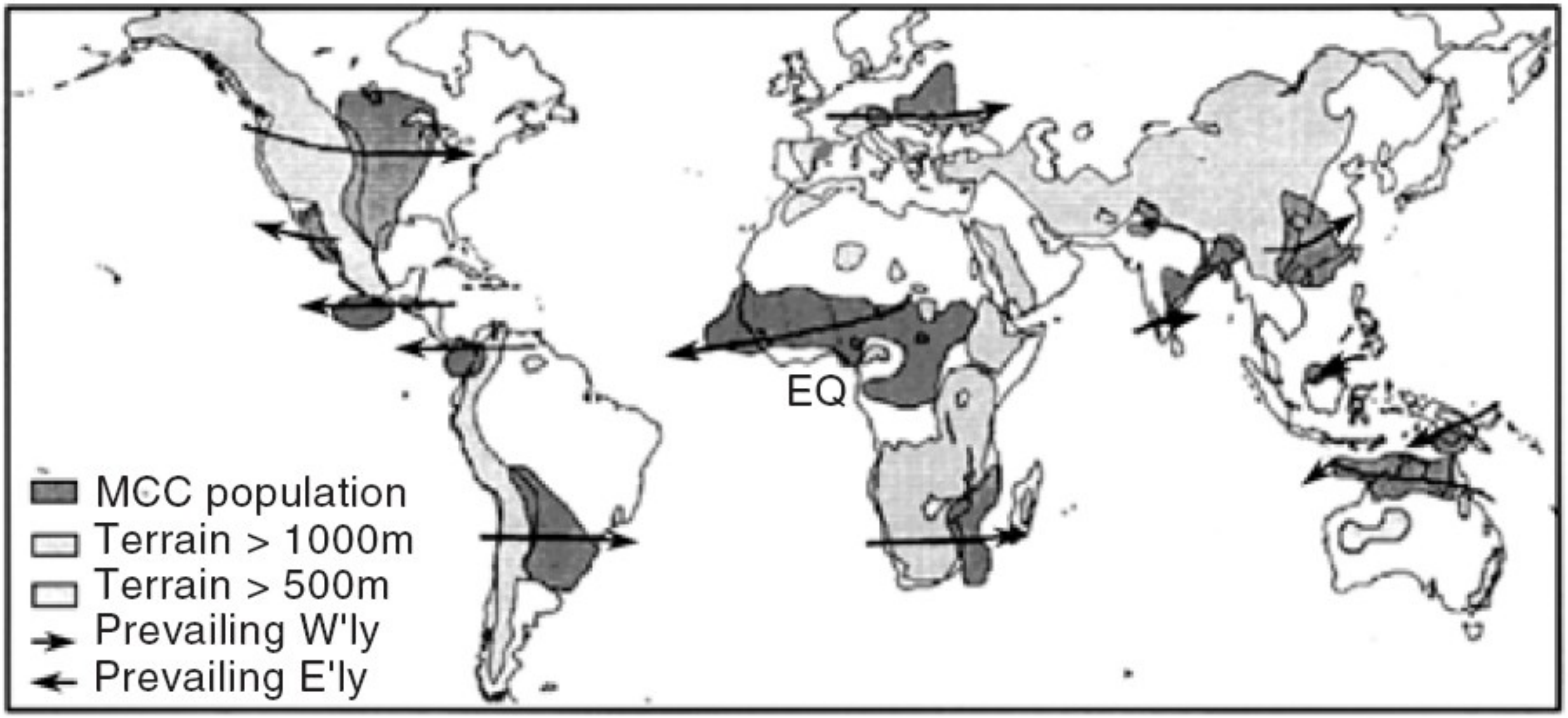

Eq
10 S
JCUMetSat-PNGNWS
20-Dec-92 15:31
150 W
160 W



MET-5 IR 8 MAY 02 21:00 UTC UW-CIMSS

Organized convection outside the tropics: mesoscale convective complexes (MCC) over subtropical and midlatitude summertime continents…

Mesoscale Convective Complex Locations

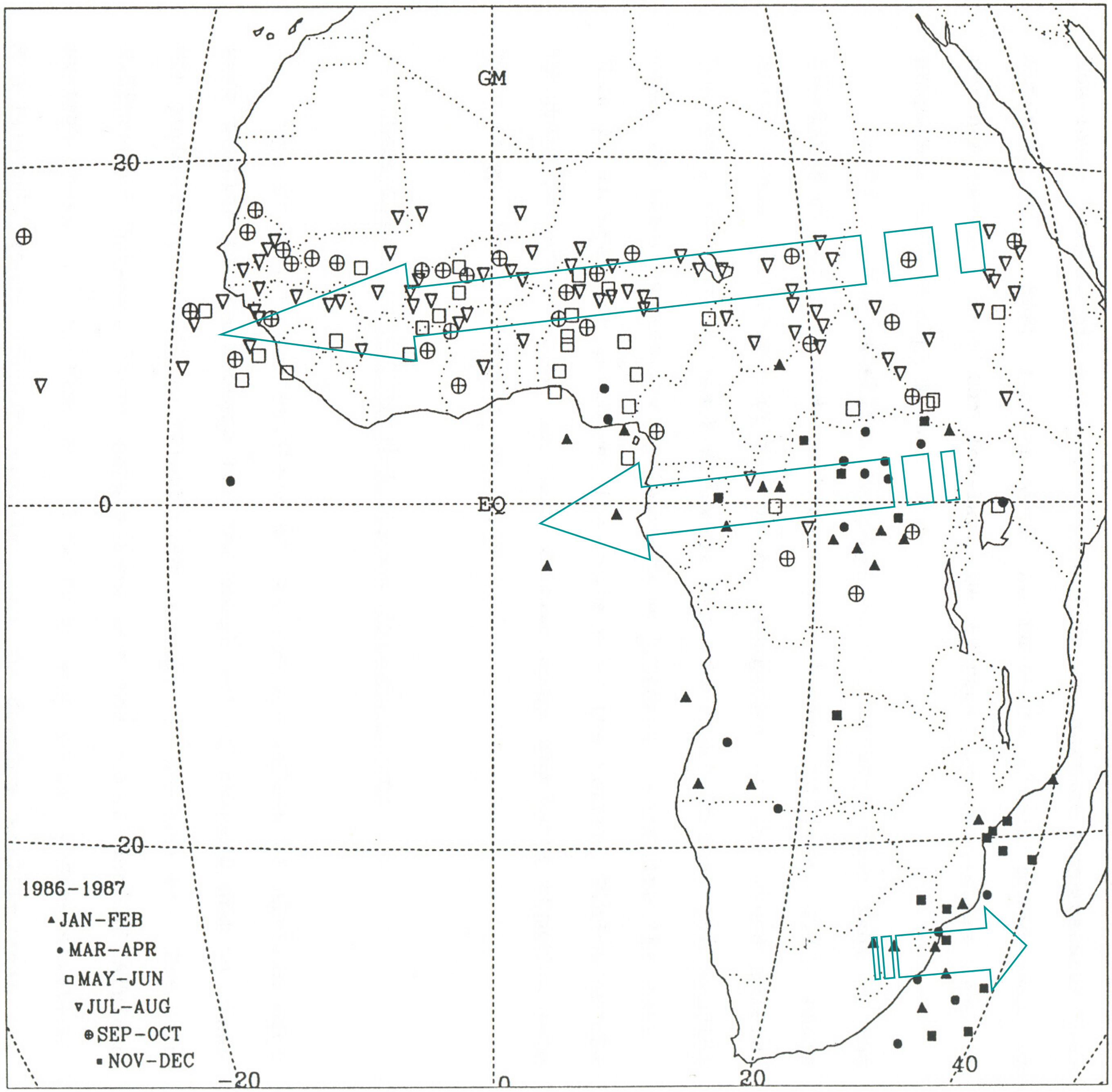


Relationship among mesoscale convective complex (MCC) population centers, elevated terrain, and prevailing midlevel flow (After Laing and Fritsch 1997)

Location	*Fraction of Global Population*
Land	91.6
Ocean	8.4
Northern Hemisphere	66.5
Southern Hemisphere	33.5

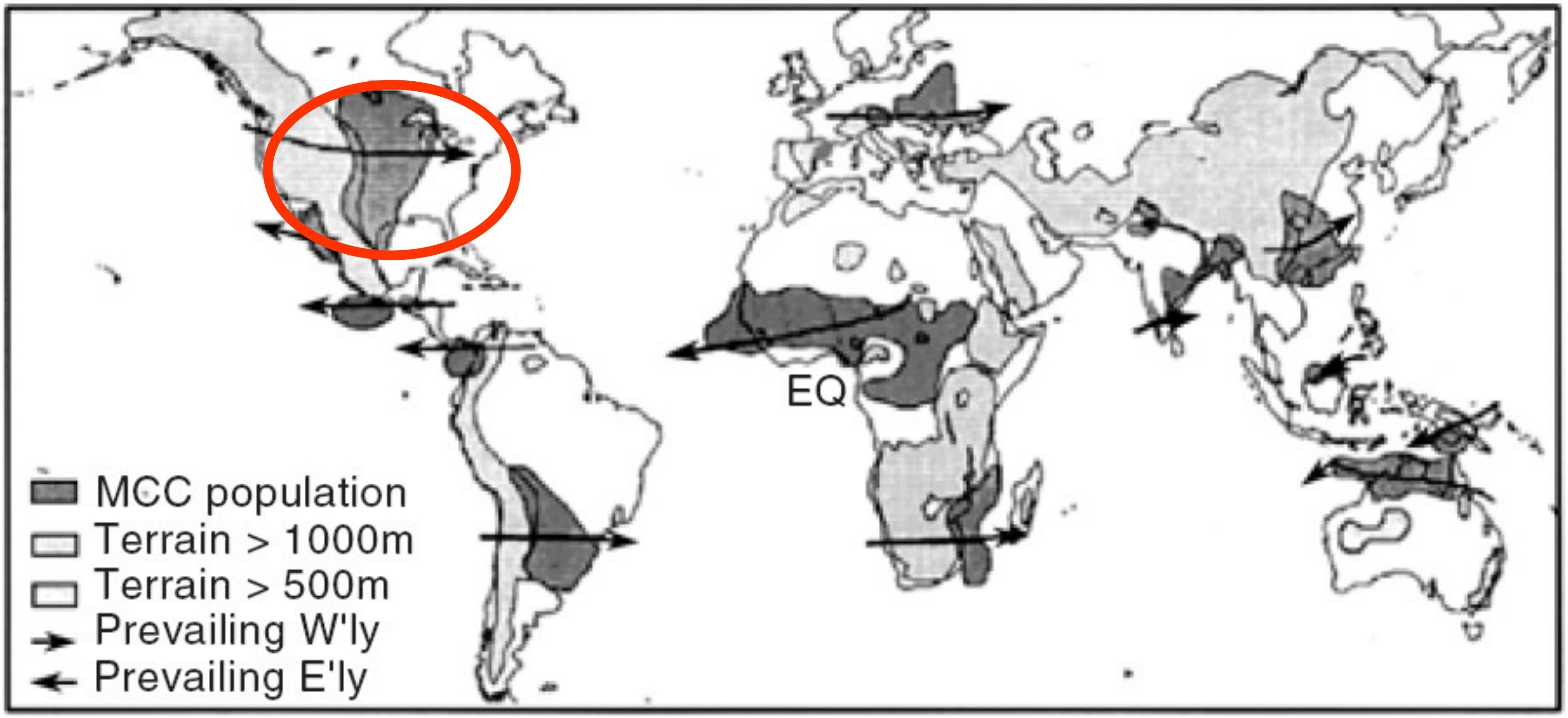
Laing 2006

Seasonal distribution of African MCCs



Laing 2006

Mesoscale Convective Complex Locations



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Location	*Fraction of Global Population*
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Southern Hemisphere	33.5

In US, availability of continental-scale continues-in-time radar data at 2-km horizontal resolution (from Weather Surveillance Radar – 1988 Doppler; WSR-88D) allows unprecedented analysis of summertime precipitation "episodes" associated with the presence of the organized convection…

Carbone et al. *JAS* 2002; and subsequent papers…

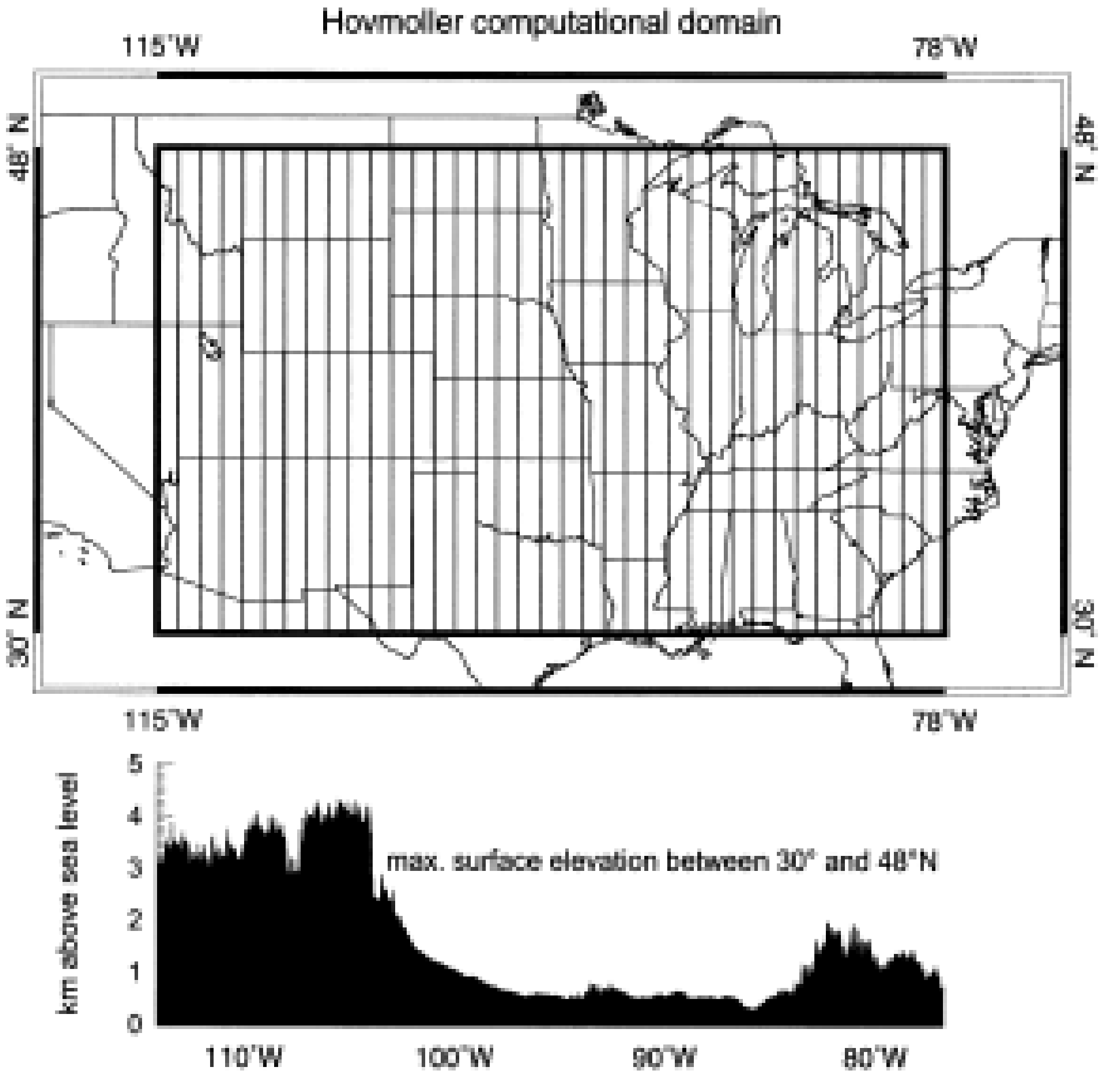


FIG. 1. Computational domain for radar–rain rate Hovmöller diagrams. For clarity, subdivisions are shown with 1° vertical stripe whereas, in actuality, there are 740 stripes of width 0.05° (~4 km). Diurnal echo frequency diagrams use a similar domain with a western boundary at 110°W.

Carbone et al. *JAS* 2002

diurnal cycle

Propagating precipitation “episodes”

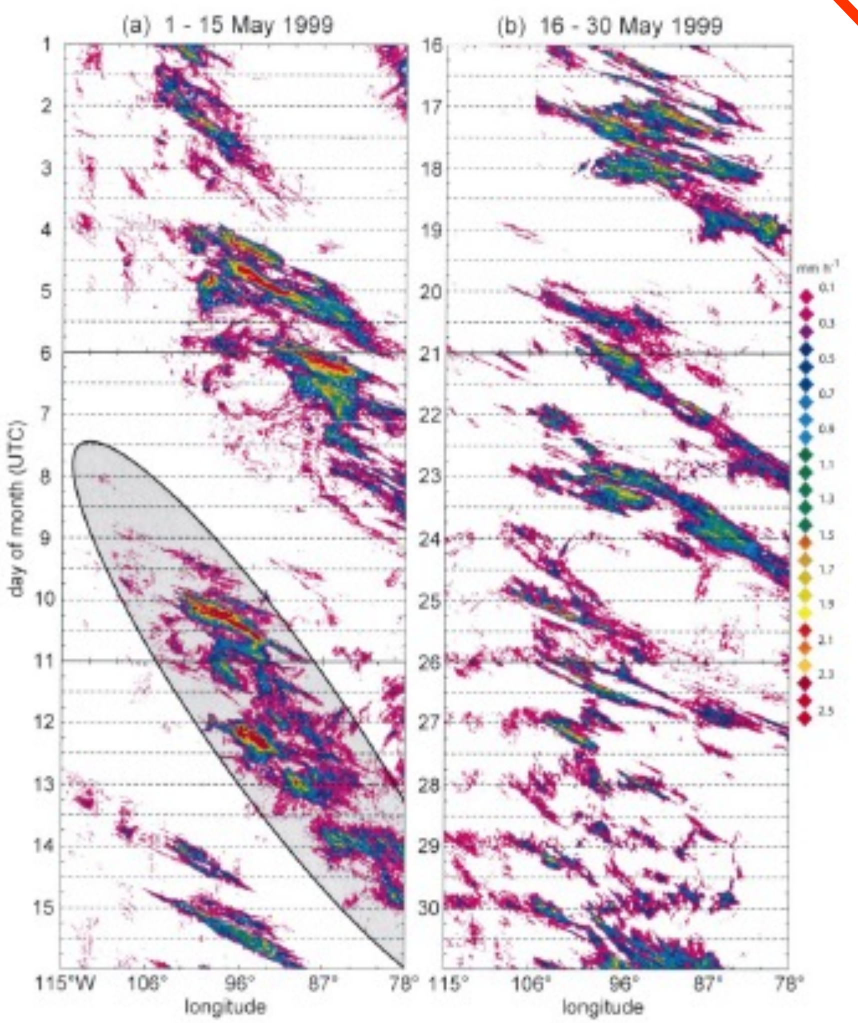


FIG. 3. Radar-derived rain-rate Hovmöller diagram for (a) 1–15 May 1999, and (b) 16–30 May 1999. Note the slow eastward propagation of precipitation envelopes in (a), within which there are faster propagating rain streaks. The shaded, elliptical area denotes one such envelope. In (b), there are mixed regimes including a more obvious component of diurnal modulation late in the period.

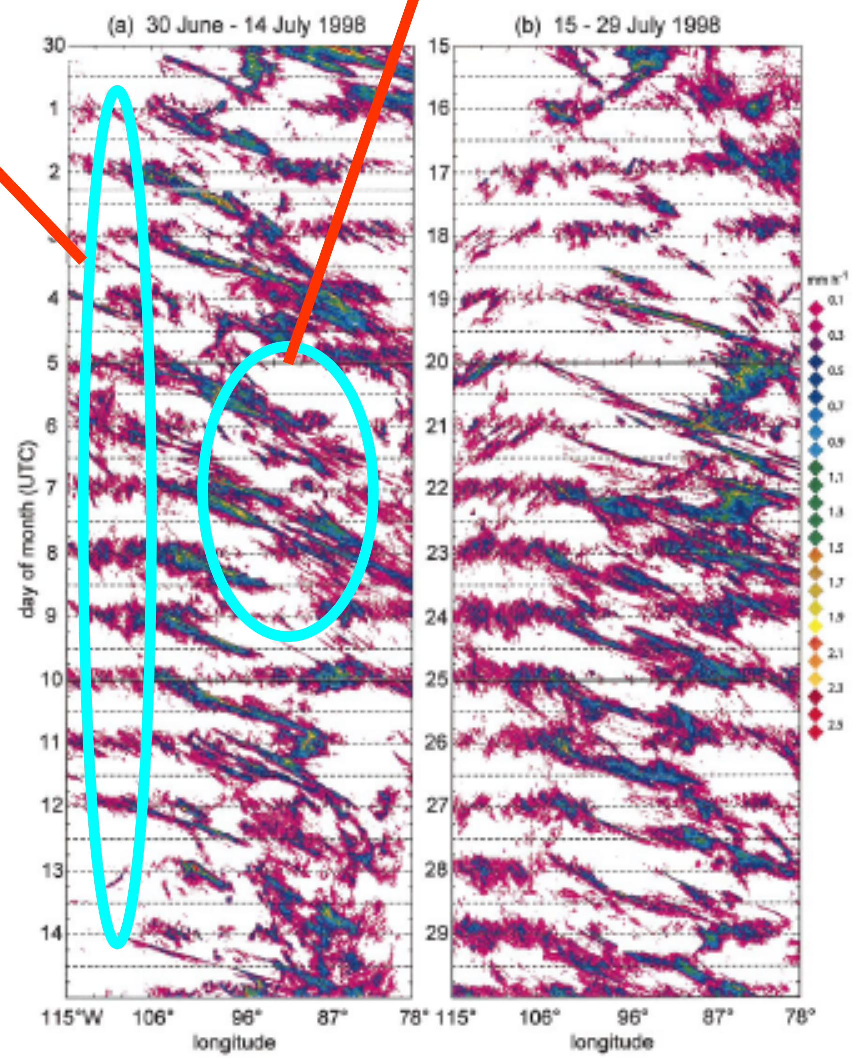
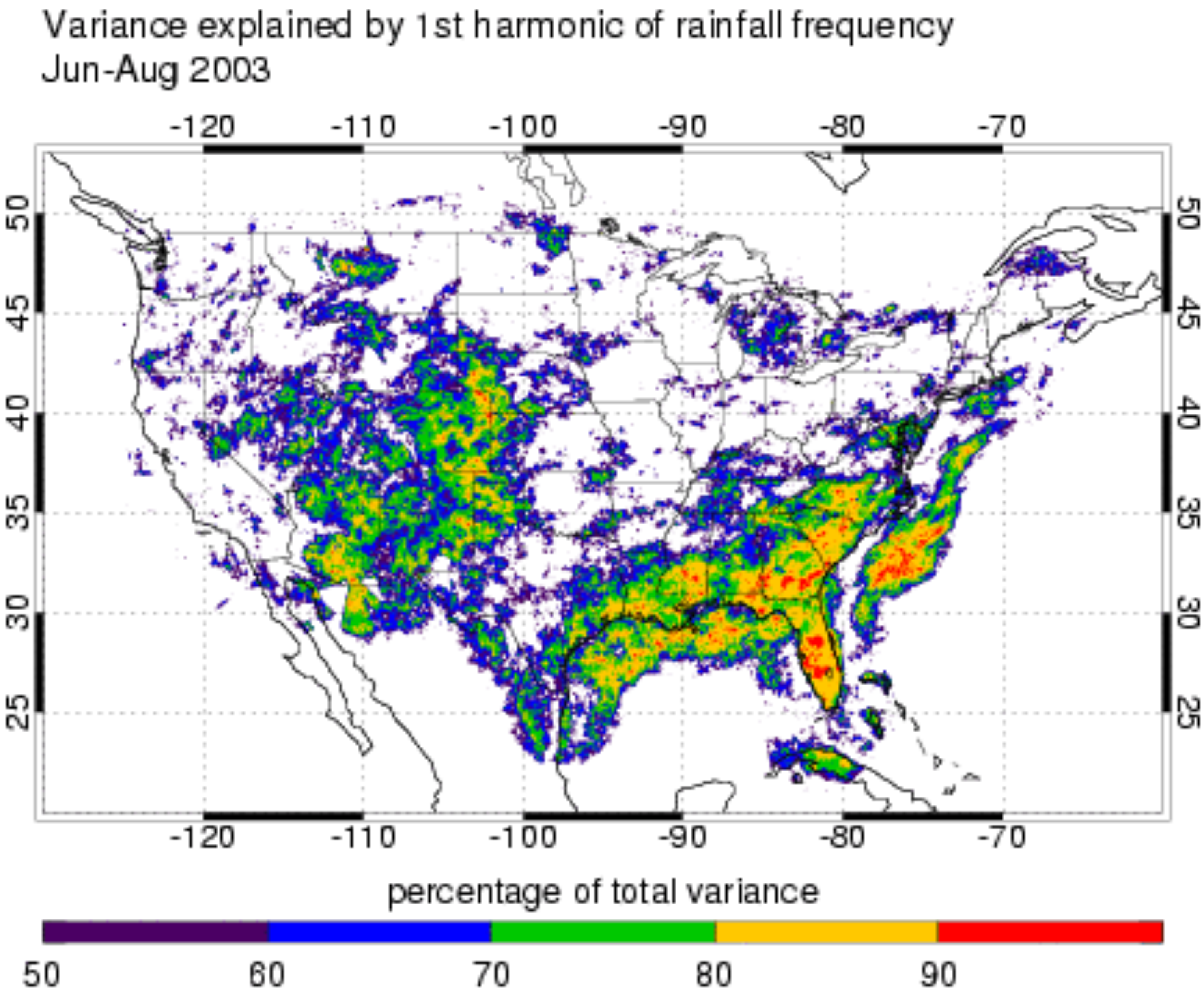


FIG. 6. As in Fig. 3, but for 30 Jun 1998–29 Jul 1998. See text for explanation.

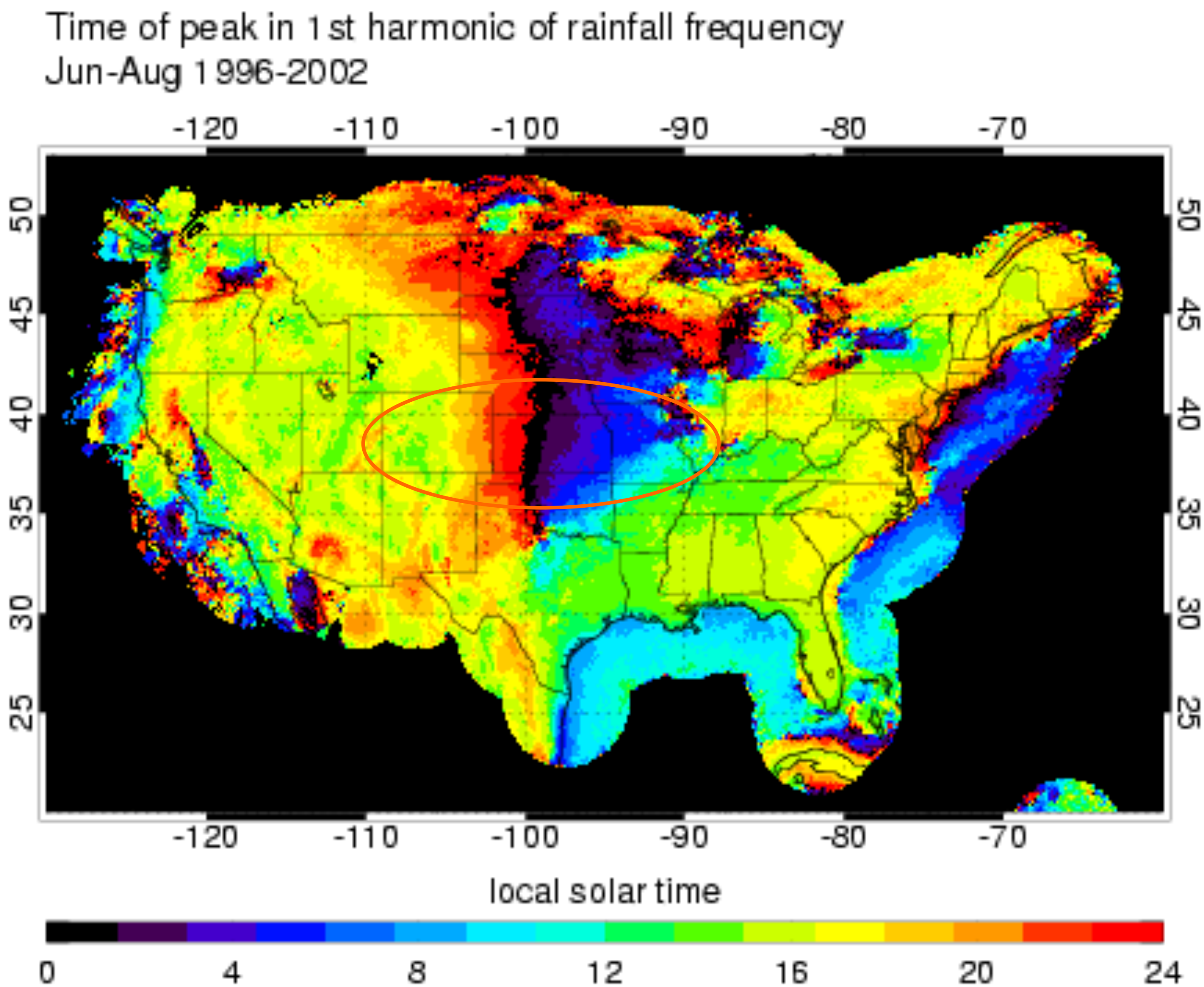
Carbone et al. *JAS* 2002

Amplitude of diurnal cycle:



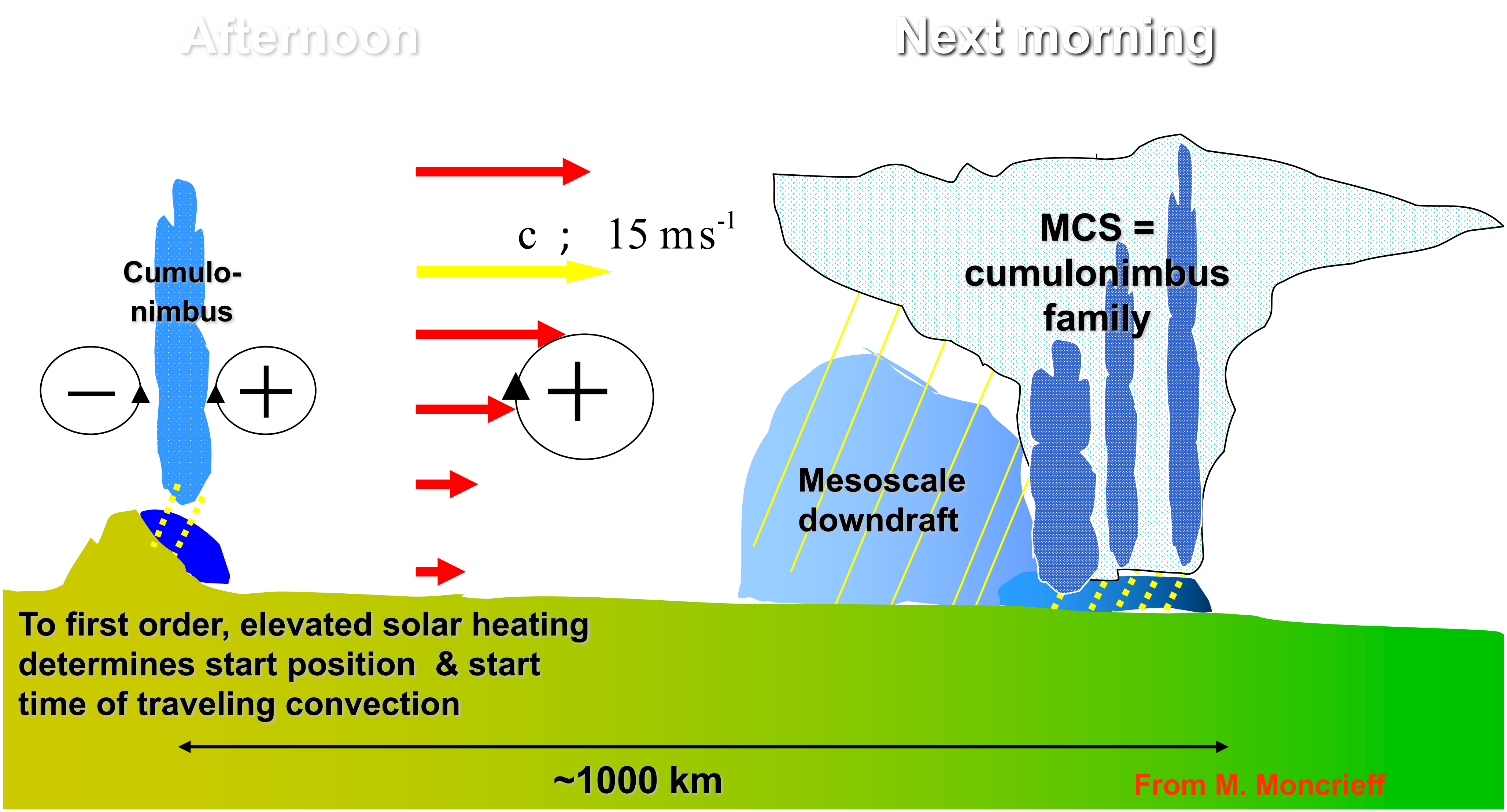
Knievel et al. (2004)

Phase of diurnal cycle: getting it right means getting traveling convective systems right …

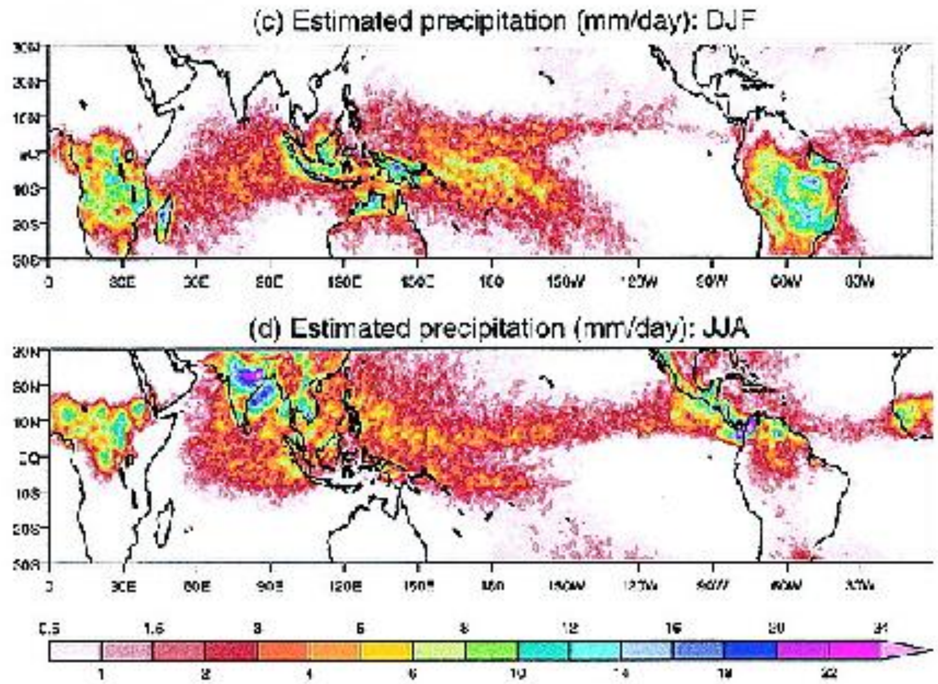


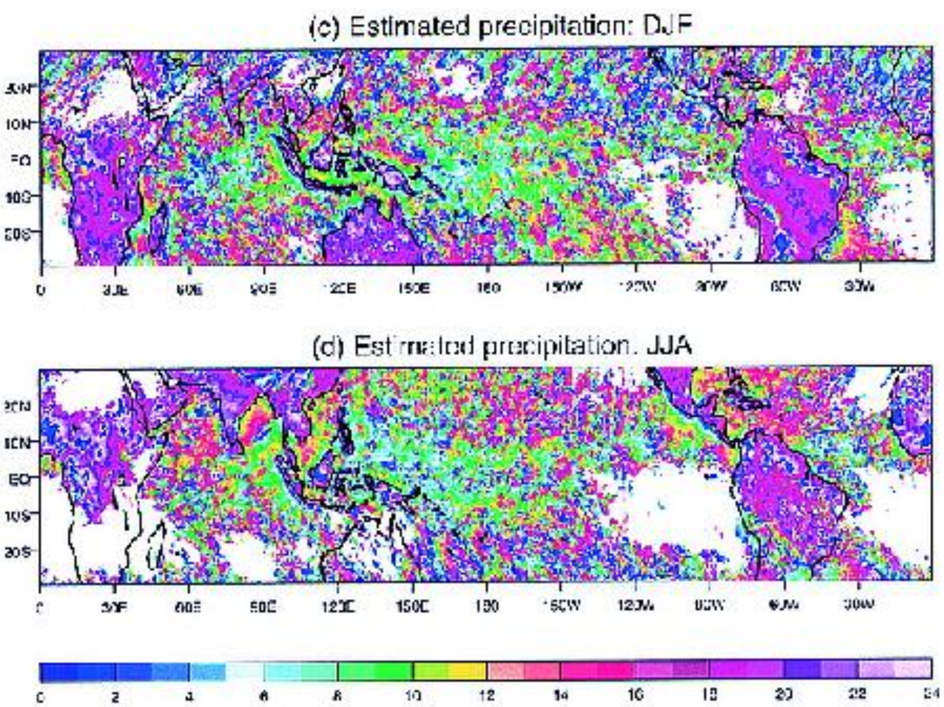
Knievel et al. (2004)

A problem of interaction among elevated solar heating, environmental shear & traveling convection



Diurnal cycle of deep convection in global observations and large-scale models





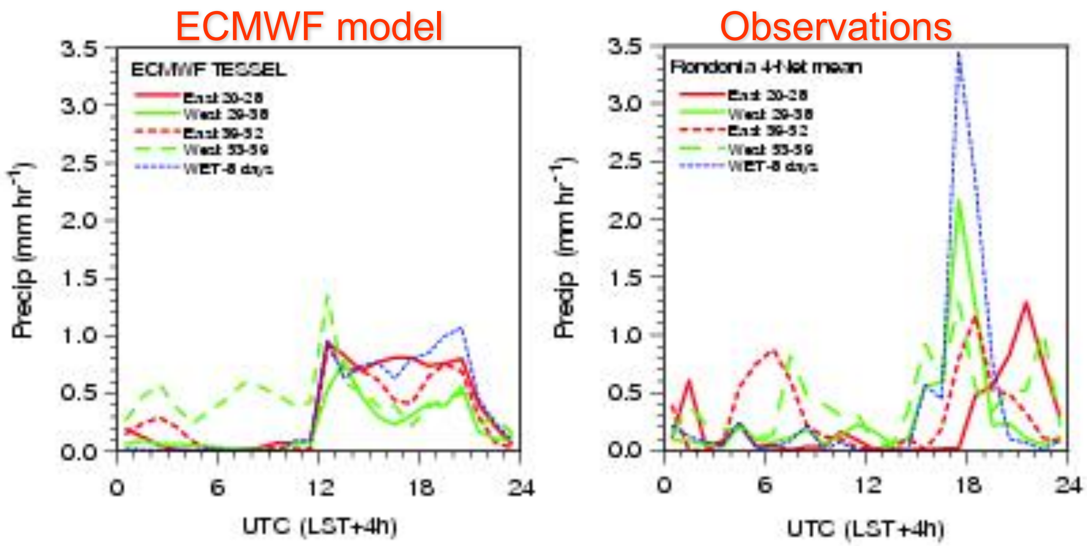
Observations:

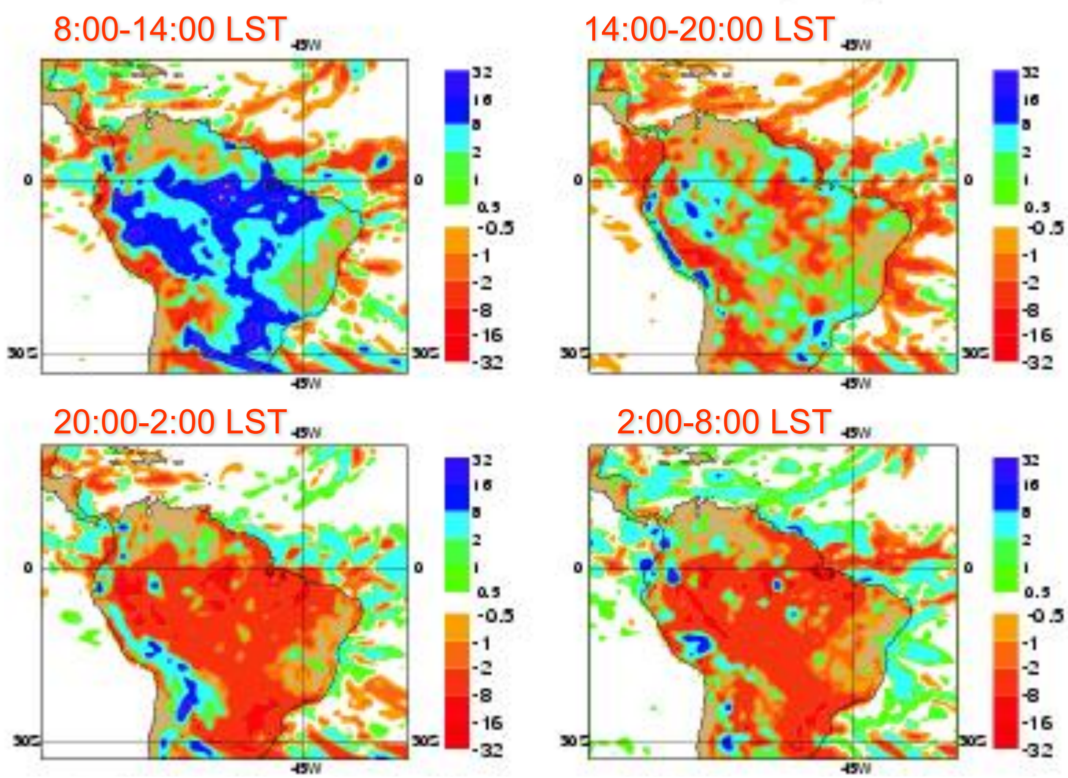
Amplitude of the diurnal cycle: larger over land than over ocean

Phase of the diurnal cycle: early evening over land, early morning over ocean

Yang and Slingo, *Mon. Wea. Rev.*, 2001

Betts and Jakob, *J. Geophys. Res.*, 2002

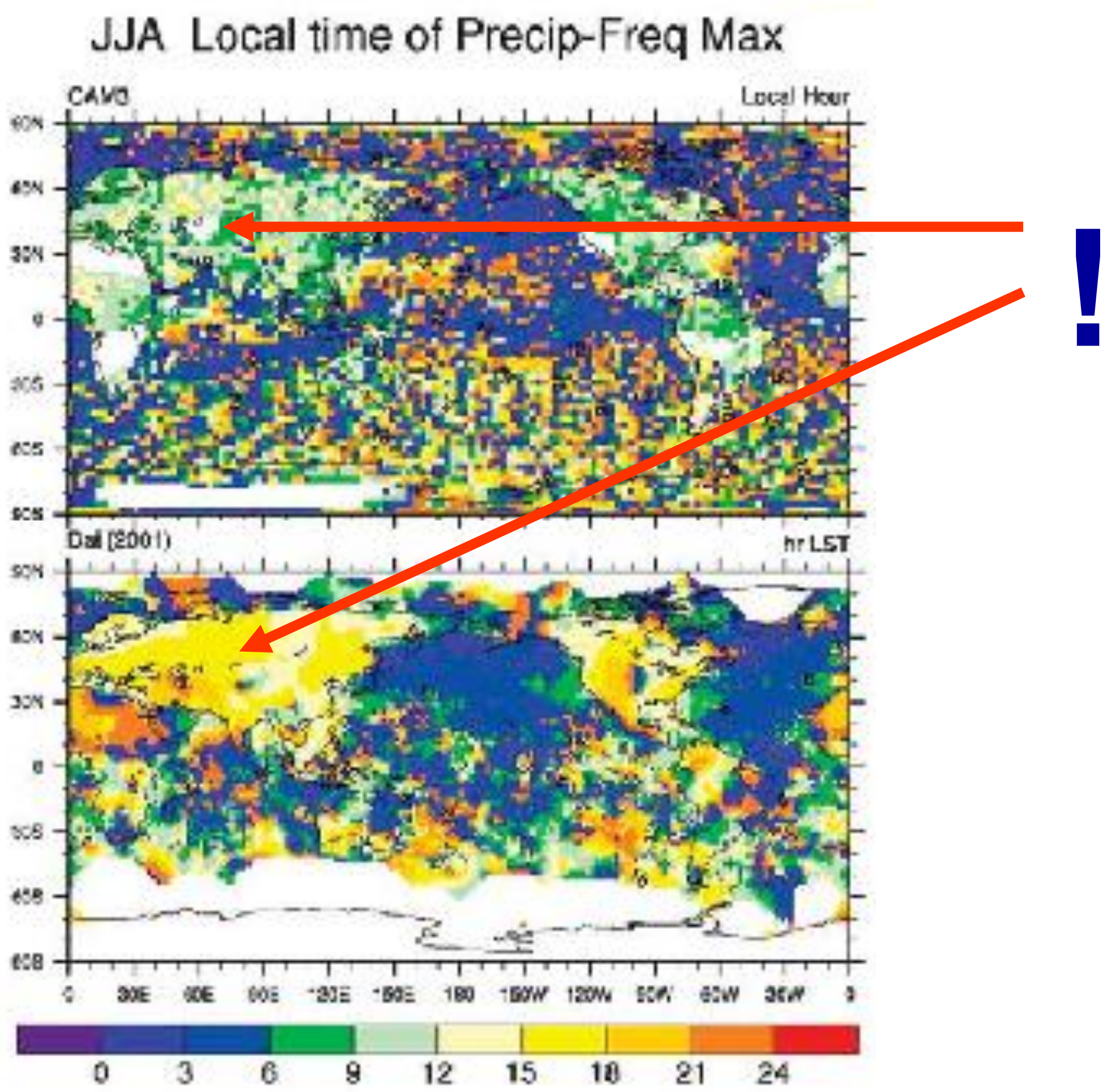




Analysis of one week simulation using ECMWF model (February 1999)

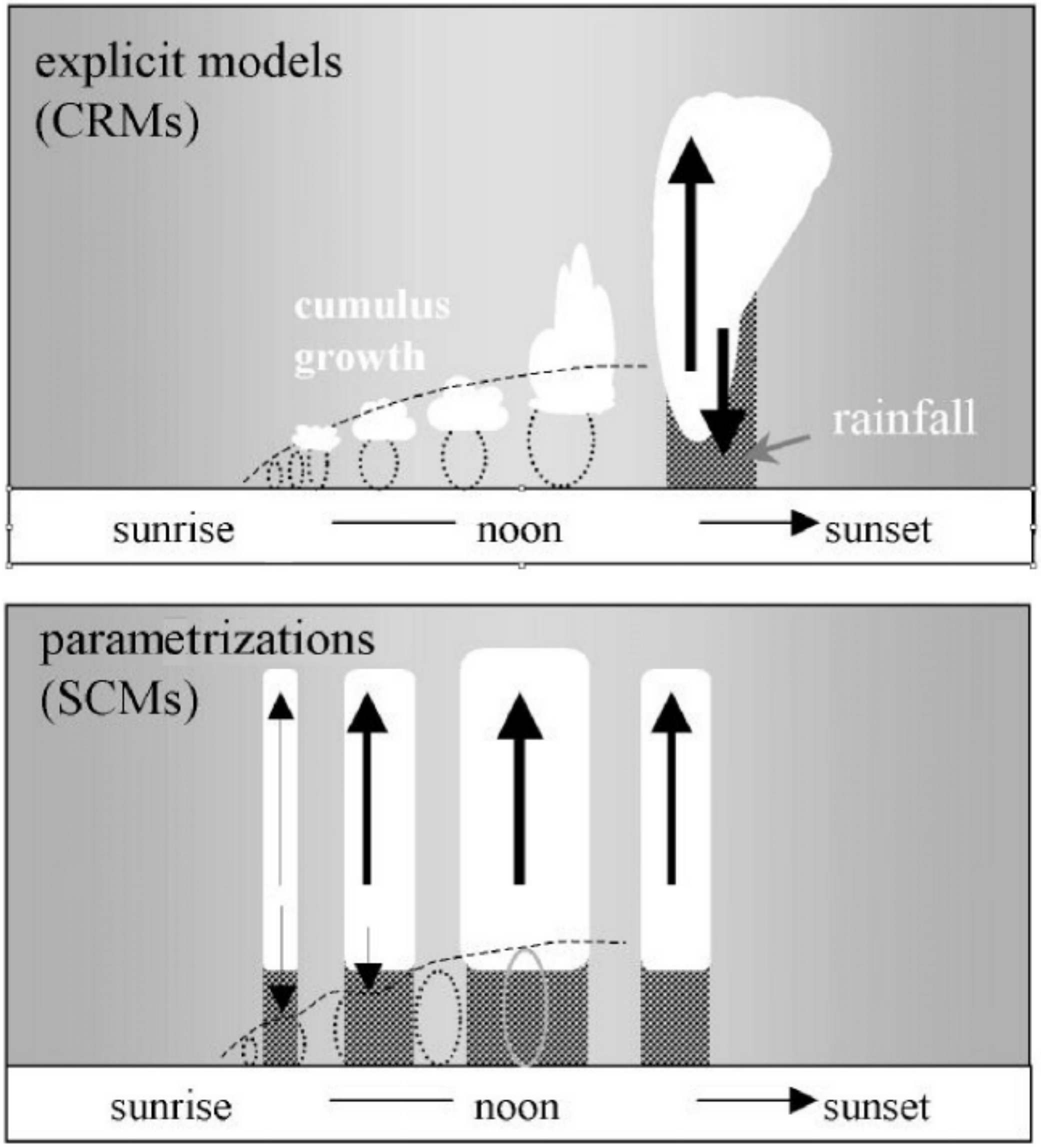
A global NWP model

CAM (Community Atmosphere Model from NCAR's Community Climate System Model)



Observations

A global climate model



Cloud-resolving models are capable in representing boundary-layer and convective development when appropriate boundary layer scheme is used…

Deep convection is triggered prematurely when traditional convective parameterization is used…

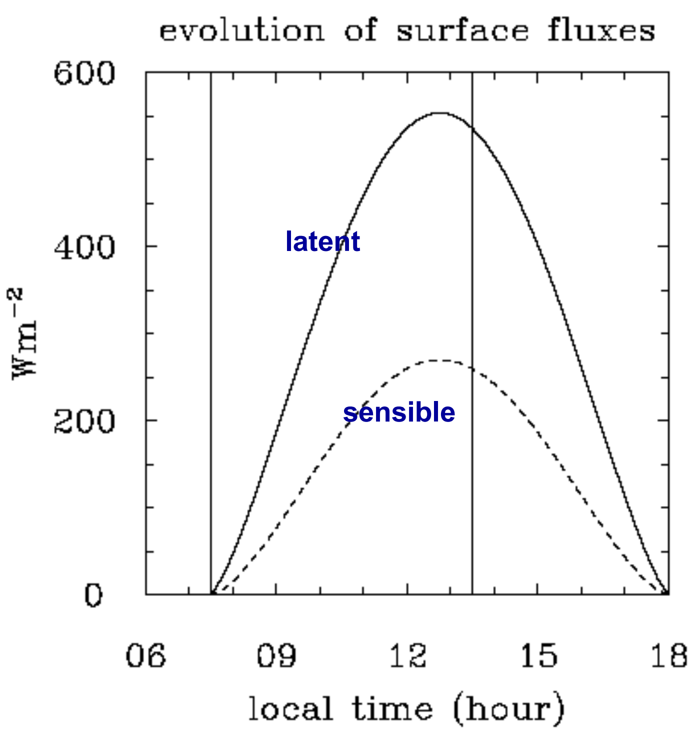
Guichard et al. *QJRMS* 2004

Grabowski et al. *QJRMS* 2006

Typical evolutions of surface sensible and latent heat fluxes over summertime continents

Tropical Rainfall Measuring Mission (TRMM) Large-scale Biosphere Atmosphere (LBA) Experiment,

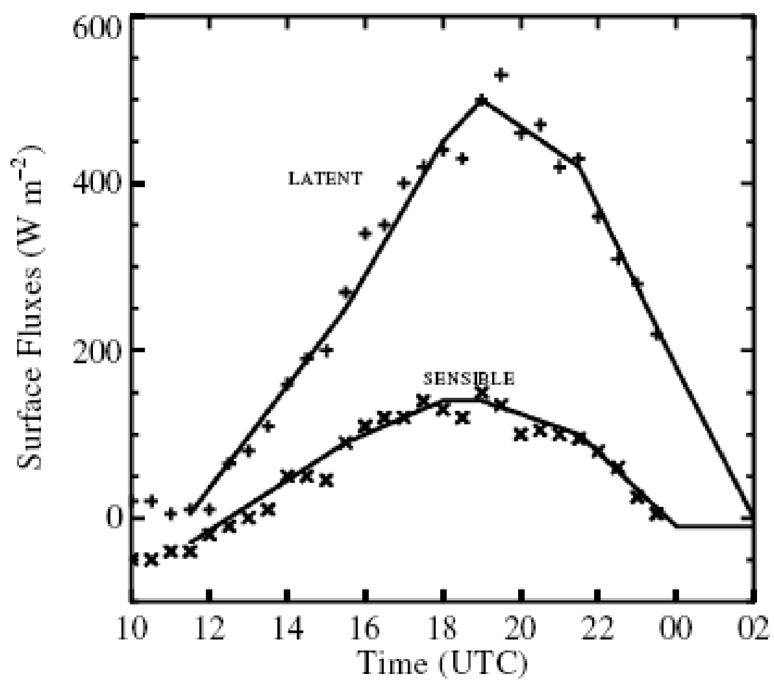
Rondonia, Brazil



(as applied in a study by Grabowski et al. *QJRMS* 2006)

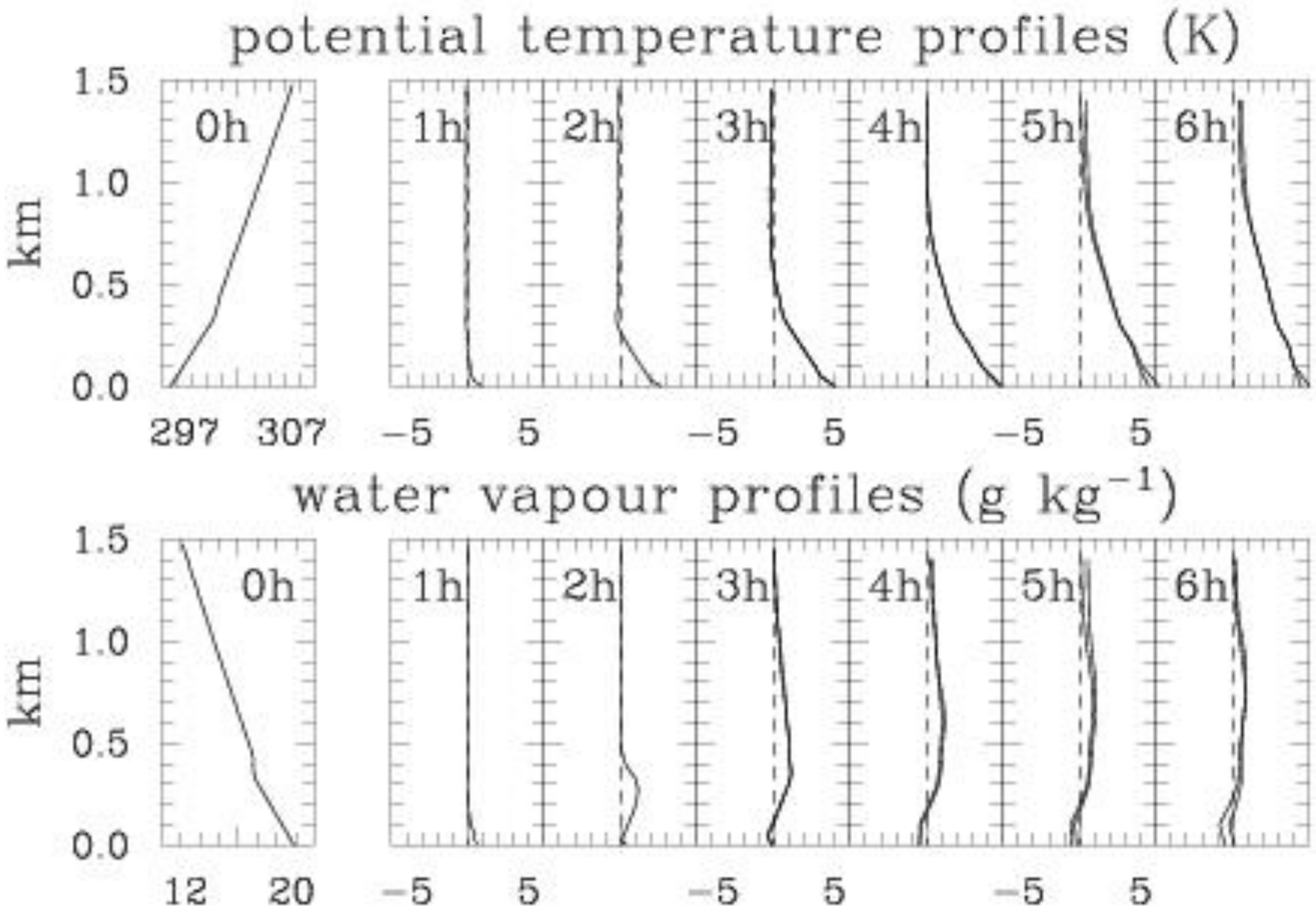
Atmospheric Measurement Program (ARM) Southern Great Plain (SGP) Site,

Oklahoma, USA

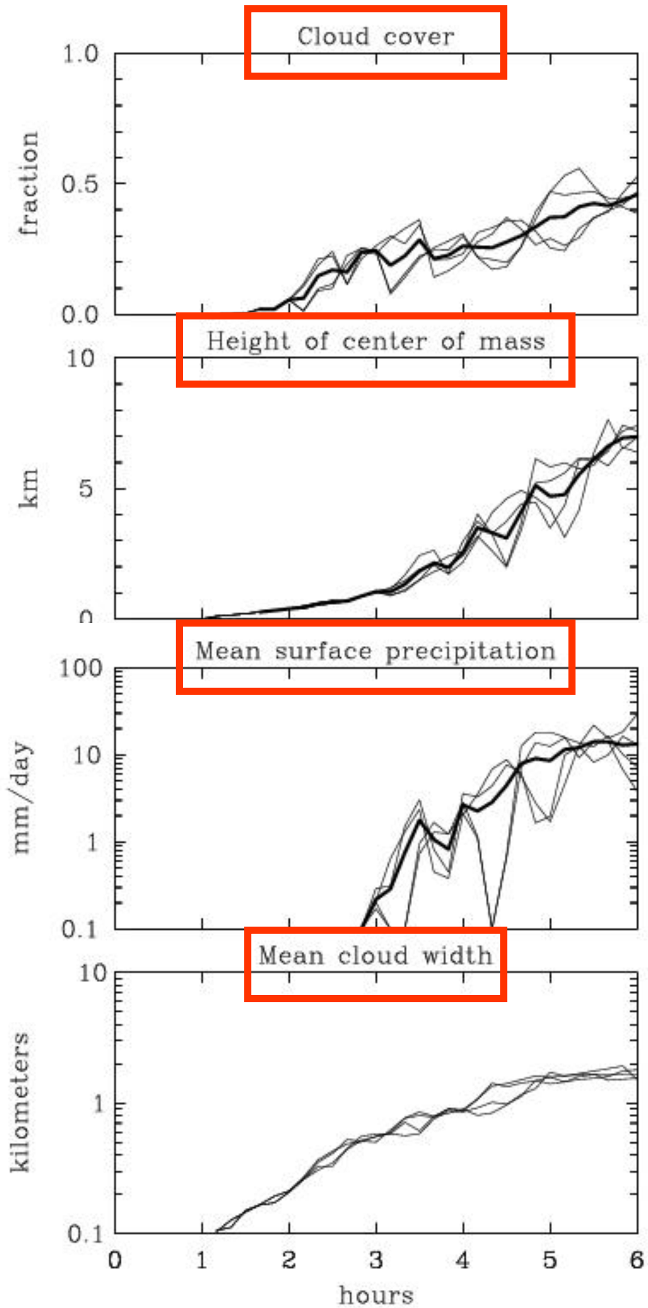


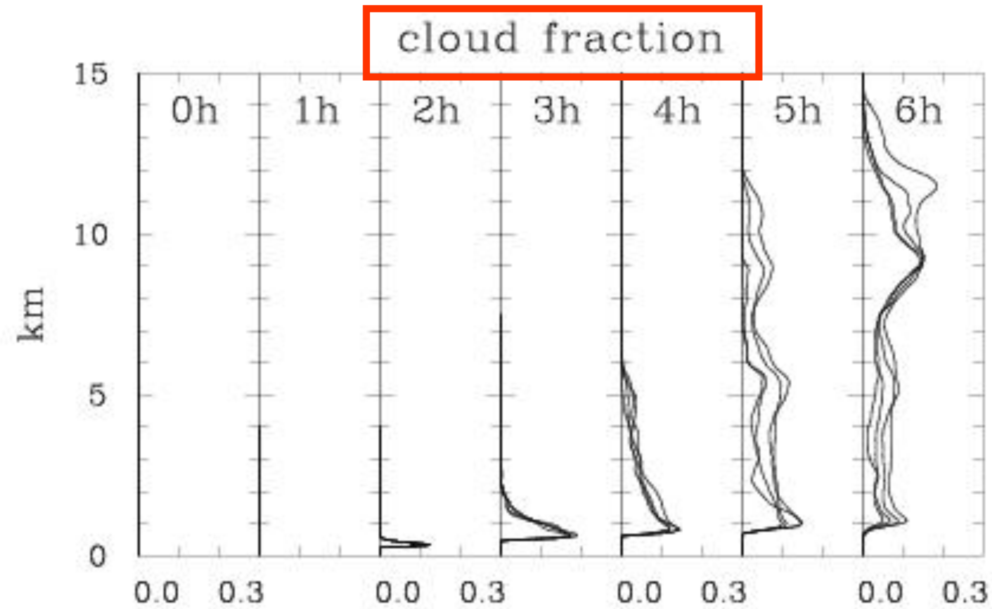
(as applied in a study by Brown et al. *QJRMS* 2002)

Deviations from initial (0h) profiles…



Grabowski et al. *QJRMS* 2006





Evolution of various cloud characteristics in a small ensemble of custom-designed LES/CRM simulations as the day progresses…

Grabowski et al. *QJRMS* 2006

Summary:

Deep convection is often organized into mesoscale convective systems. These system are typically built from individual convective cells that undergo classical life cycle, i.e., through development, mature, and dissipations stages. The classical example is the squall line system. The supercell is another example of organized convection.

The key to mesoscale organization is the vertical shear of the horizontal wind, in addition to (obviously!) CAPE.

Organized convection is poorly represent in large-scale models in weather and climate. There is virtually no convection parameterization that includes physics of convection organization as typically shear is not consider in the parameterization.

Convection-permitting (i.e., nonhydrostatic) large scale models is an obvious way forward.