CONVECTION

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DEFINITIONS

Convection

- Small-scale, thermally direct circulations which result from the action of gravity upon an unstable vertical distribution of mass ([Emanuel (1994)])
- Moist deep convection (precipitating cumulonimbus)
  Horizontal scale ≈ vertical scale ≈ depth of the troposphere
  Typical vertical velocities several metres per second
  Turbulent mixing of cloudy and clear air
- Shallow convection (non-precipitating stratocumulus)
  Small vertical scale
  Moderate vertical velocities

Stratiform condensation, clouds and precipitation

- Horizontal scale >> vertical scale
  Saturation in gentle upward motion

INFLUENCE OF THE LARGE SCALE ON CONVECTION

Observations show correlation between convection and large scale

- convergence of mass and moisture
- low level ascending motion $\sim \omega$
- magnitude of instability
- vertical wind shear

INFLUENCE OF CONVECTION ON THE LARGE SCALE

Vertical transport of mass, heat and moisture

- Warming and drying of middle troposphere connected with adiabatic compression in subsiding environment of clouds
- Detrainment of cloud water and transport of heat and moisture in moist downdrafts

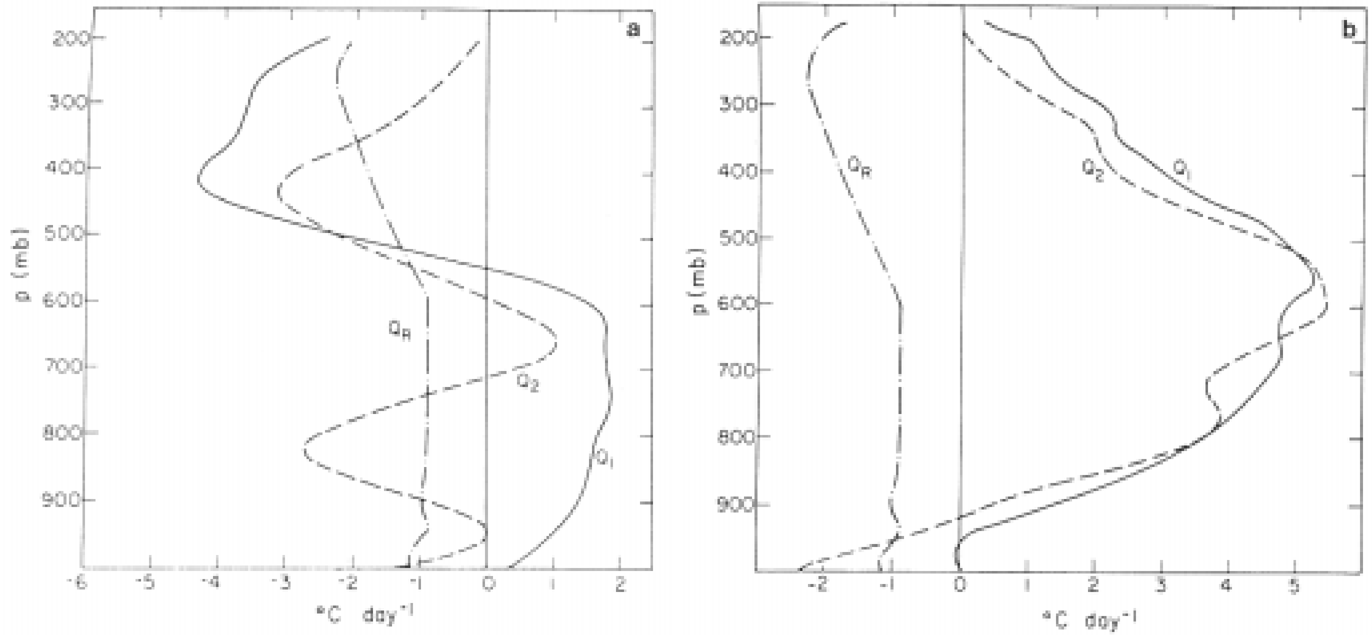

Fig. 6.27. (a) Apparent heat source Q_1, apparent moisture sink Q_2, and radiative heating rate Q_R profiles for undisturbed conditions over a 3-day period of GATE. (b) Same as (a) except for disturbed period. [From Cho *et al.* (1979).]

Figure 1: Influence of tropical convection on large-scale flow

([Cotton and Anthes (1989)])

TASKS OF CONVECTION PARAMETRIZATION

Parametrization of convection in a NWP model is possible if there is a physical relationship between the controlling large-scale processes and small-scale circulations.

A convection parametrization scheme aims to answer the questions:

1. How much convection is there?

2. How convection influences the large-scale processes?

3. What triggers the convection?

PARAMETERS GIVEN BY CONVECTION PARAMETRIZATION

- amount of convective cloudiness
- amount and phase of convective cloud condensate
- amount and phase of convective precipitation
- mass, heat and moisture transports in convective updrafts and downdrafts

SCALE DEPENDENCIES AND SCALE SEPARATION

Variable	GCM	HIRLAM	Cloud model
	$\approx 300km$	$10 - 50km$	$\approx 1km$
cloud-scale circulations	P	P	R
meso-scale circulations	P	R(P)	R
circulations connected with stratiform cloudiness	R	R	R

Scale separation principle:

Distinct separation between the horizontal and time scales of individual convective clouds and the resolved processes is necessary for the convection parametrization to success.

CLOSURES

Adjustment schemes

- Convection tends to adjust the virtual temperature to an equilibrium state nearly neutral to convection
- Needed: reference profiles of temperature and moisture
- Cloud model not used
- e.g. Betts-Miller-scheme (1986)

Quasi-equilibrium closure

CAPE produced by large scale	=	CAPE consumed by convection

- CAPE=Convective Available Potential Energy
- convection results from instability
- e.g. Arakawa-Schubert-scheme (1974)

Closure based on moisture budget

moisture produced by large scale convergence	$\sim$	moisture consumed by convection

- conditions for convection: instability + moisture convergence
- e.g. Kuo-scheme (1969), mass flux scheme of Tiedtke (1989)
- possible violation of scale-separation: grid size structures created
- underprediction of rainfall amount in mesoscale models observed

Closure based on CAPE

amount of convection $\sim$ amount of CAPE

- convection results from instability
- triggering of convection: removal of capping inversion
- e.g. Kain-Fritsch-scheme (1990)

CLOUD MODEL

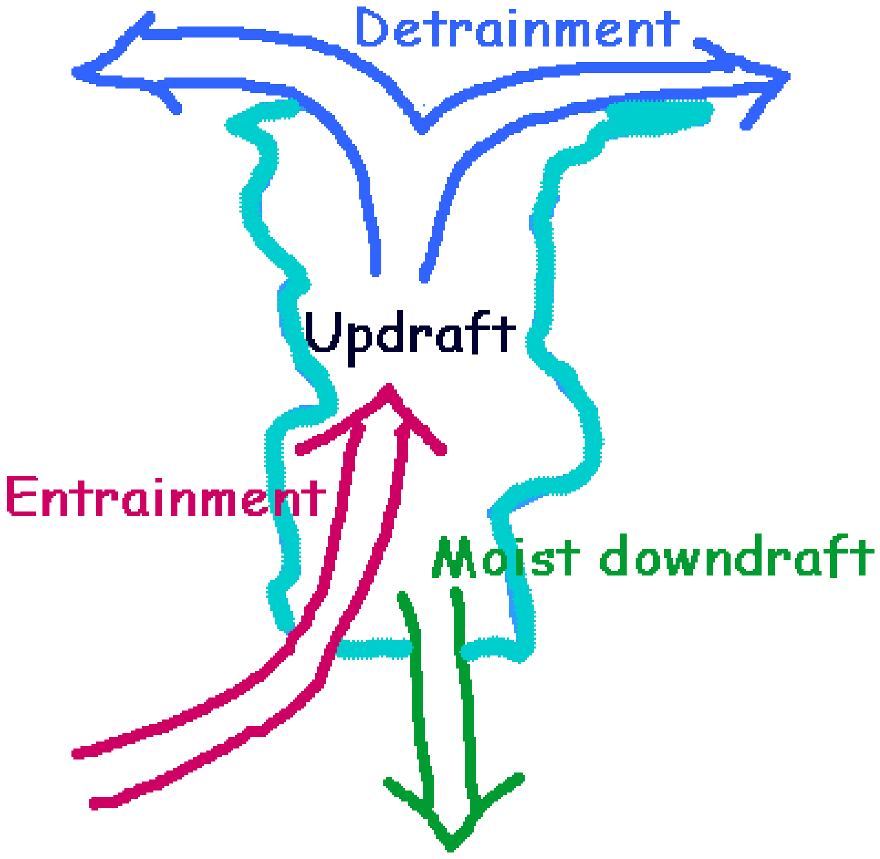

Figure 2: Processes described by the cloud model

Processes described by the cloud model:

- condensation and evaporation
- updrafts: entrainment of environmental air, detrainment of cloudy air
- moist downdrafts

In a mass flux-type schemes these are given by:

- mass flux in the cumulus cloud
  = compensating subsidence in the environment
- detrainment of cloudy air

Cloud model determines the vertical structure of the mass flux

- vertical structure of the mass flux
- properties of the detrained air

Cloud models

- entraining plume
- buoyancy sorting

c.f. [Bister (1998)]

TRIGGERING

Onset of deep convection in a conditionally unstable environment
$\leftarrow$ Disappearing of the capping inversion caused by

- surface heating (or moistening)
- differential vertical advection
- ascending vertical motion

Triggering is needed by schemes using CAPE-based closure.

Parcel theory is used to test whether a parcel can rise to its level of free convection. To remove a capping inversion positive vertical velocity or thermal perturbation is necessary.

KUO SCHEME

water vapour produced by large-scale convergence	=	water vapour consumed by convection

Based on observations of tropical deep convection, e.g. [Malkus and Williams (1963)].

Needed: CAPE + moisture convection

Problems, possibly leading to grid-point storms:

1. Spurious growth of CAPE
2. Feedback: moisture convergence $\rightarrow$ moist convection $\rightarrow$ moisture convergence

Available moisture is divided between

1. moistening of the air

2. heating by condensation

according to a tunable parameter.

Vertical structure

- of heating $\sim T - T_{cloud}$ (T_{cloud} given by moist adiabat of a parcel rising from boundary layer)

- of moistening $\sim q - q_s$

Problems:

- no heating or cooling below cloud base $\rightarrow$ no moist downdraft

- vertical profile of heating $\neq$ observed

PRESENT CONVECTION SCHEMES OF HIRLAM

Kuo-type schemes

- KUO: the original formulation from HIRLAM-1 without cloud condensate
- CONVEC: modified formulation within the original Sundqvist parametrization from HIRLAM-2
- STRACO: recoded formulation within the Sundqvist parametrization from HIRLAM-4

Tiedtke mass flux scheme

- MFX: a formulation from HIRLAM-4

At the moment there are technical and numerical problems connected with the implementation of the CONVEC and MFX schemes.

EXAMPLES FROM JULY,9,1996

Synoptic situation

- Surface map
- Satellite picture
- Composite radar picture

Examples of HIRLAM runs using the existing schemes

- KUO+COND
- CONVEC
- STRACO
- MFX

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