Numerical Weather Prediction (NWP)

Parameterization and physical processes:

Basic concepts of Planetary boundary layer, Land surface processes, Convection (Deep cumulus and shallow convection), Large scale condensation, Radiation (short wave and long wave parameterization), Cloud Radiation interaction, Dry and moist convective adjustment processes, Cloud microphysical parameterization

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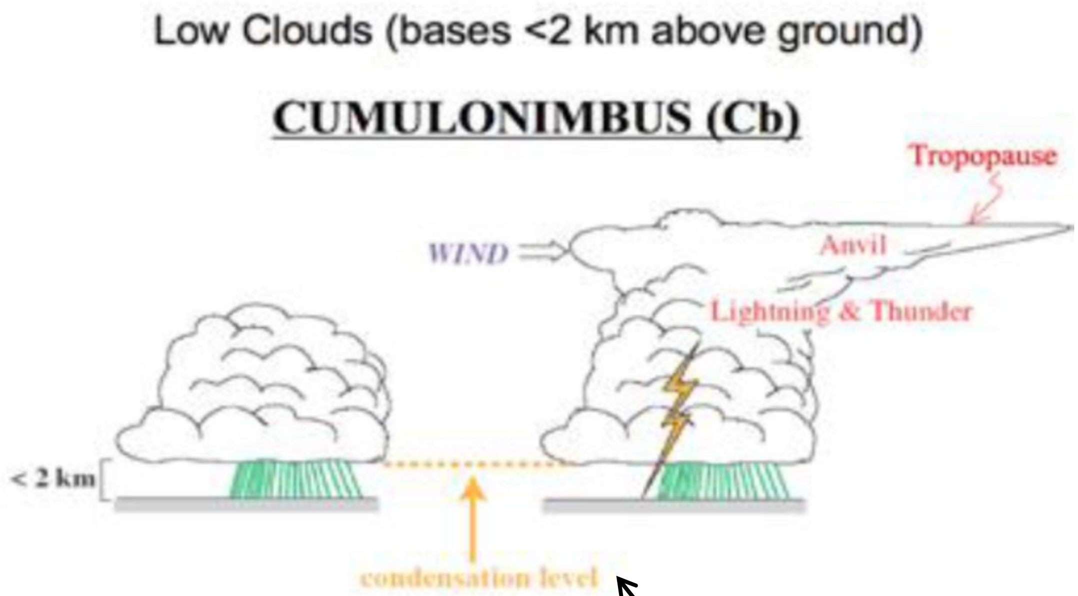
Forecasters Training Course (FTC) Batch No. 192



Cumulonimbus clouds are menacing looking multi-level clouds, extending high into the sky in towers or plumes. The base of the cloud is often flat, with a very dark wall-like feature hanging underneath, and may only lie a few hundred feet above the Earth's surface.

Questions from last class: Is it convective condensation level or lifting condensation level?

The Convective Condensation Level (CCL) is the level at which condensation will occur if sufficient afternoon heating causes rising parcels of air to reach saturation. The CCL is greater than or equal in height than the lifting condensation level (LCL). The CCL and the LCL are equal when the atmosphere is saturated.

The primary difference between LCL and CCL has to do with the surface temperature. A LCL occurs when forced lifting occurs. A surface parcel, with its temperature and dewpoint are forced into the vertical by a trigger mechanism such as a front, convergence boundary, mountain, and so forth. This air cools at the dry adiabatic lapse rate until the temperature equals the dewpoint. When the air parcel becomes saturated, the LCL is reached.

Now onto the CCL, the CCL is not found by forced lifting, but by rather a warming of the earth's surface. The air does not rise until the surface temperature warms and reaches a critical value with this process. The CCL is generally higher than the LCL because the air must first warm before the air can rise to the CCL. The CCL will be higher than the LCL. The LCL and CCL are found by the same process except from the CCL the surface temperature must rise to a critical value before a surface parcel will begin the ascent in the vertical due to positive buoyancy. Use the CCL for pre-monsoon thunderstorms and daytime heating lifting and the LCL for any dynamical lifting (vorticity, frontal, convergence uplift).

Sample questions:

1) Why does CCL is higher than LCL?
2) What is the basic difference between CCL and LCL?

Why is it important and what are the types of moist convection?

Moist convection is important to the prediction of atmospheric circulation for many reasons.

Large scale horizontal gradients of latent heating produced by deep moist convection help to drive large scale vertical circulations e.g. Hadley cell, Walker cell.

Deep convection also is a major component in ENSO and it can influence the seasonal climate in the northern hemisphere. The SST in the tropical eastern Pacific are warmer than normal, during ENSO. Associated with this, deep convection develops, releasing latent heating in a deep atmospheric column and producing upper level divergence. The upper level divergence excites Rossby waves that alter the hemispheric flow (Tribbia 1991).

Deep Convection: Thermally driven turbulent mixing, where vertical motions take parcels from lower atmosphere above 500 hPa

Generally requires:

- Low Level Convergence
- Upper level divergence
- Relative Humidity in excess of 70% lifted above 500 hPa
- Unstable Layer.
- Triggering Mechanism

Shallow convection

In contrast to deep convection, shallow cumulus clouds are the most frequently observed tropical cloud (Johnson et al.1999).

Shallow convection modifies the surface radiation budget, influences the structure and turbulence of the PBL and thereby also affect the global climate (Randall et al 1985).

Shallow convection also occurs in mid-latitude particularly when cold air moves over warm water. Shallow cumulus cloud develop over water which commonly align themselves in the form of bands (Houze 1993)

Shallow Convection: Thermally driven turbulent mixing, where vertical lifting is capped below 500 hPa

Generally requires:

- Low Level Convergence
- Mid Level Cap
- Relative Humidity in excess of 70% lifted no higher than 500 hPa
- Unstable Layer.
- Triggering Mechanism

Stratiform convection

Deep convection can be further sub divided into convective and stratiform components (Houze, 1997, Chattopadhyay etal, 2009). The convective components refer to convection associated with individual cells, horizontally small regions of more intense updrafts and down drafts in association with young and active convection.

The stratiform component refers to convection associated with older, less active convection with vertical motion generally less than 1 ms^{-1}.

Multi-scale nature

- **Essentially moist convection is comprised of two components namely convective and stratiform which has different spatio-temporal scale. This is the reason why convection is a multi-scale process.**

- **The present day challenge is to devise a scheme (parameterization) that can resolve the multi-scale nature of convection in a realistic way.**

What is parameterization and why is it necessary?

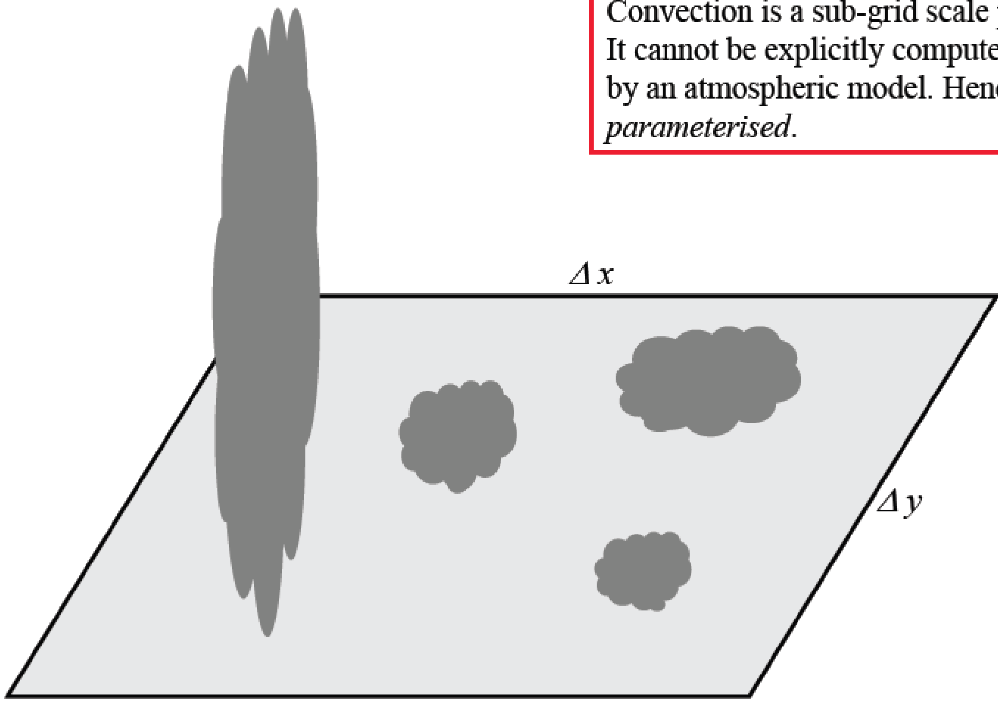
The basic physical equations describe the behaviour of the atmosphere on small scales. From these we derive equations that describe the behaviour of the system on larger scales.

The large-scale equations contain terms that represent the effects of smaller-scale processes.

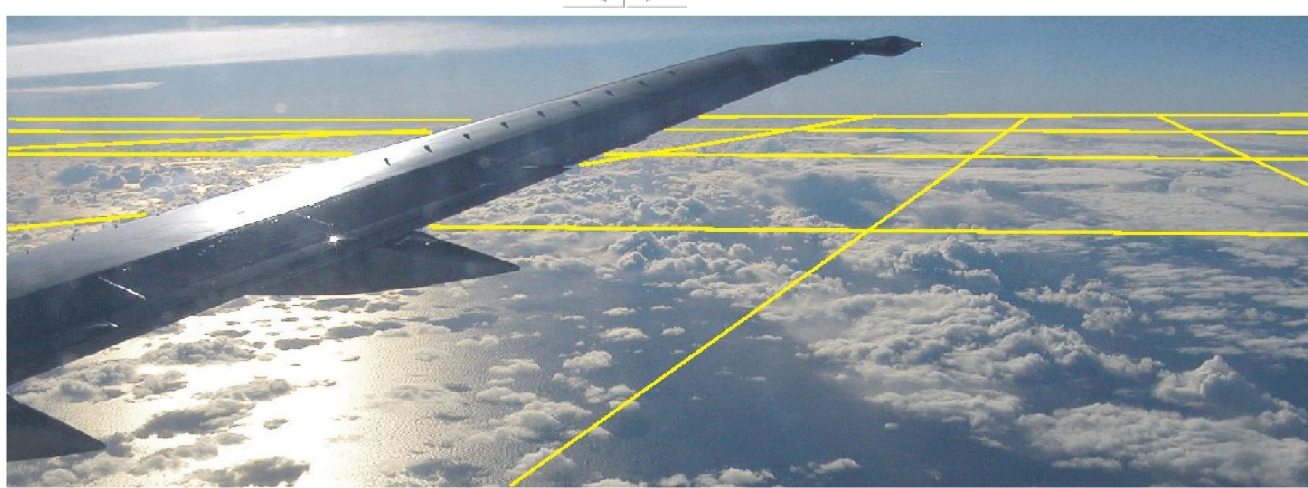
A “parameterization” is designed to represent the effects of the smaller-scale processes in terms of the large-scale state.

The Need for a Parameterisation

Convection is a sub-grid scale phenomenon. It cannot be explicitly computed (resolved) by an atmospheric model. Hence, it should be *parameterised*.



Is it possible to have a numerical model without convective parameterization ?



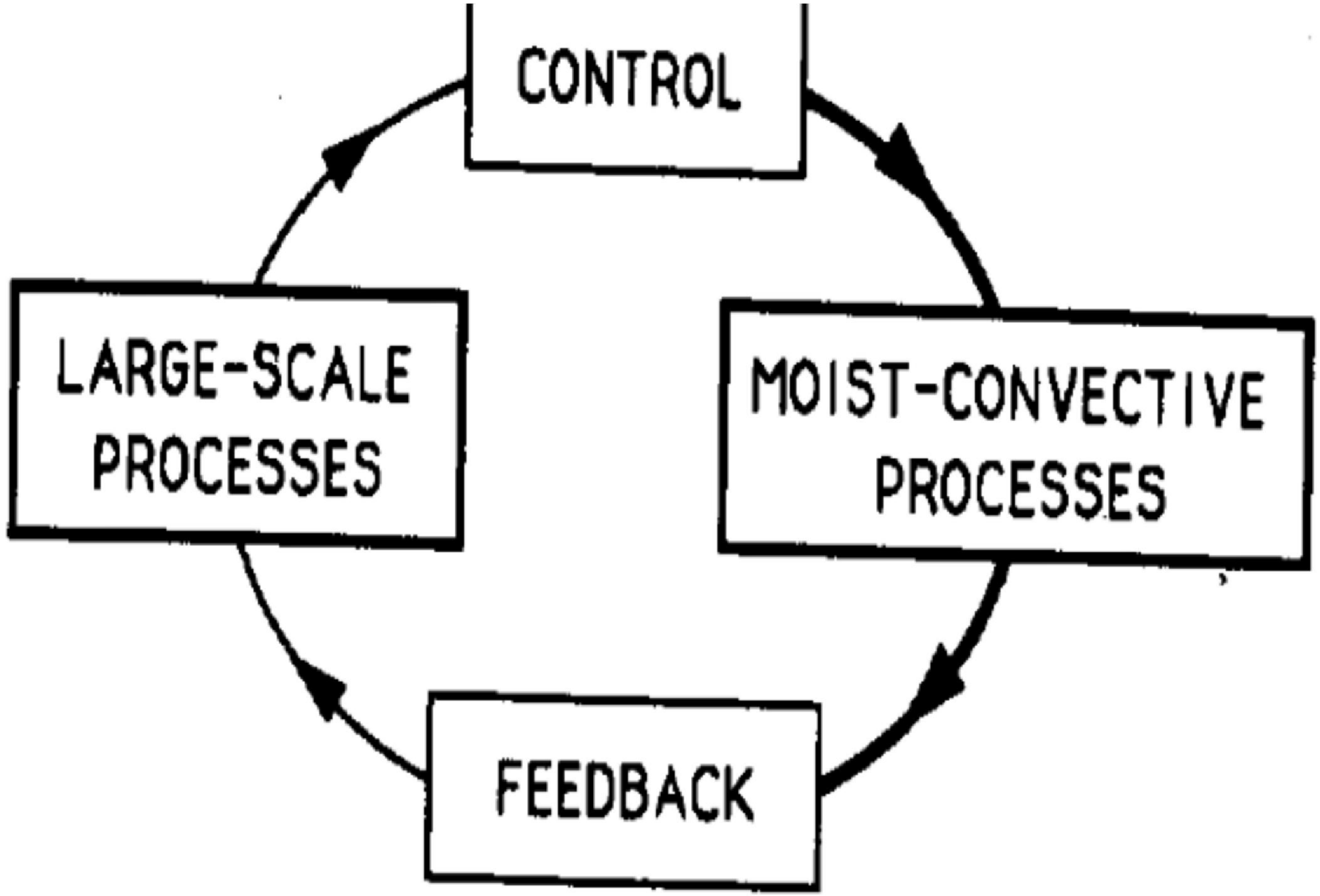


FIG. 1.1. A schematic figure showing the interaction between large-scale and moist-convective processes.

Arakawa, Met. Mono. No.46, 1993

Key features of Parameterization scheme

Since convective parameterization represents the effects of sub-grid scale processes on the grid variables, it is called an implicit parameterization

- Convection can be viewed as driven by buoyancy. From this instability view point local buoyancy is the key variable required to determine the convective response. Buoyancy is a key components of many convective parameterization schemes.

- Hence **Buoyancy** and **moisture** both are crucial for convective parameterization. Moisture is key component in the sense that convective parameterization is a method to account for the effects of sub-grid scale saturation. Moisture content should drive the behaviour of convective scheme by controlling amount of convection produced in an unstable environment based on available moisture that can be removed from the atmosphere.

- **Closure assumptions** are used to define where and when convection is activated. Closure assumptions also determine the amount and intensity of the convection and a separate set of criteria are used to determine convective development which is called "**Trigger functions**". Trigger functions determine how convection evolves over time

- Minimally, one needs to derive 3 parameters from convective parameterization scheme.
    a) Vertical distribution of heating
    b) vertical distribution of moistening
    c) Rainfall rates

Point of uncertainties

There are a number of uncertainties in modeling clouds and their associated processes such as those shown below fig.

- we do not adequately understand what determines the rate of entrainment of “environmental” air into the updrafts, or how entrainment affects the evolution of a convective cloud system.

- Cumulus entrainment entails the dilution of convective updraft by dry, cool environmental air.

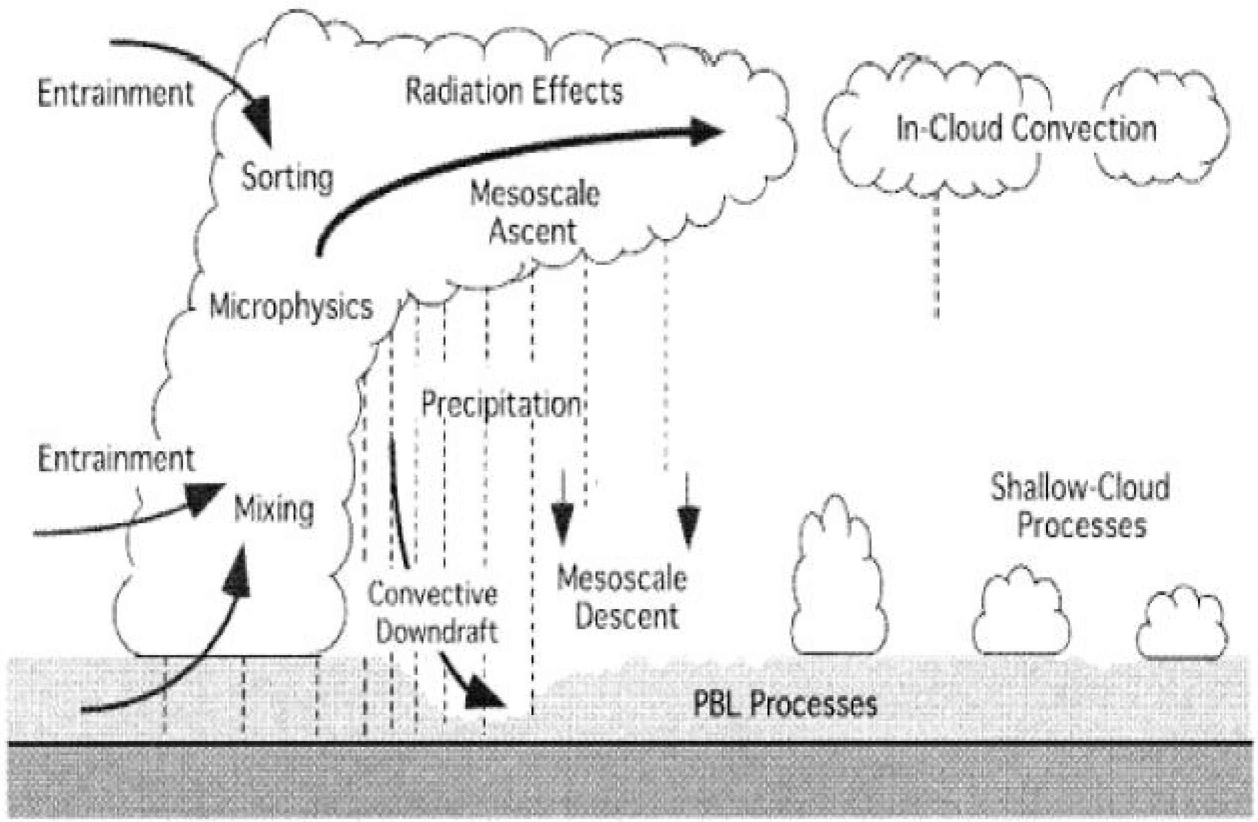
- Current parameterizations incorporate the effects of entrainment through simple assumptions (e.g., Lin and Arakawa 1997a, b)

- The environment of the hot towers is typically assumed to be uniform, but in reality its properties vary on unresolved scales, due in part to the humid corpses of deceased cumuli.

- The properties of the entrained air must, therefore, depend on which part of the variable environment in which an updraft happens to find itself. In addition, the representation of microphysical processes is extremely crude.

- The cloud dynamics is highly simplified in large-scale models.

UNCERTAINTIES IN FORMULATING CLOUD AND ASSOCIATED POCESSES



Arakawa 2004, Jour. Of Climate

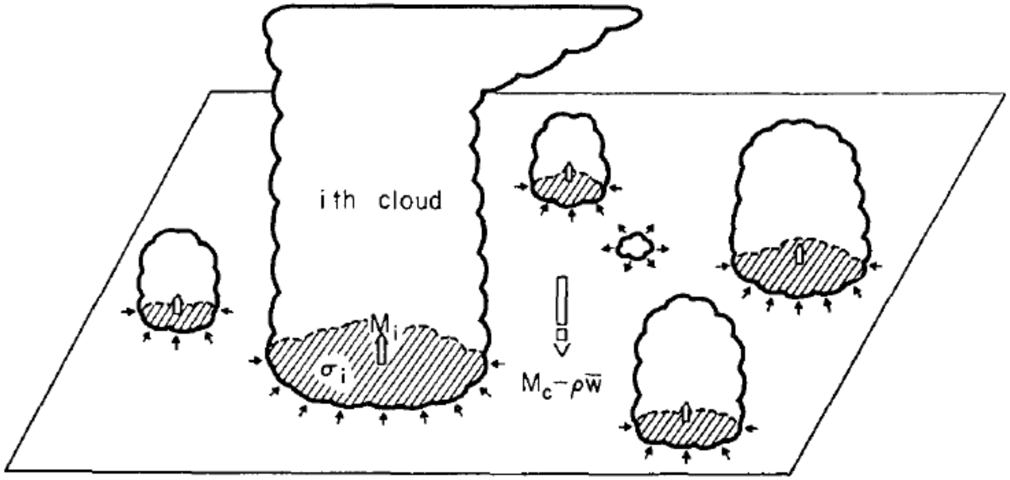
Arakawa-Schubert convection parameterization scheme

Arakawa-Schubert , 1974, JAS, 674-701

AS scheme attempts to quantify the effect of cumulus convection on the large-scale environment.

A spectrum of cloud ensemble of different sizes is considered. Each cloud is characterized by a parameter λ, where λ varies from 0 to λ_{max}.

- Within the cloud layer, multiple individual clouds are allowed to form. The sum of the individual clouds in a column makes up a cloud ensemble.
- The cloud ensemble occupies a horizontal area much smaller than the horizontal area of a grid cell.
- Each cloud in this ensemble has its own entrainment rate and vertical mass flux across the cloud base.
- It is assumed that each cloud in the ensemble has the same cloud base. However, their cloud tops may vary.



A unit horizontal area at some level between cloud base and the highest cloud top. The taller clouds are shown penetrating this level and entraining environmental air. A cloud which has lost buoyancy is shown detraining cloud air into the environment.

The horizontal area must be large enough to contain an ensemble of cumulus cloud but small enough to cover only a fraction of large scale disturbance. The existence of such an area is one of the basic assumptions of this paper

- Entrainment is considered to take place at all the levels below the cloud top; detrainment is assumed to occur only from the top of the clouds.
- The cloud ensemble is divided into subensembles, which consists of clouds with similar fractional entrainment rates (μ) which is defined as the entrainment rate per unit height divided by the vertical mass flux. The μ can be used to determine all the properties of the cloud subensemble.
- These properties include the precipitation rate, the rate of destruction of the convective instability of the environment, the work done by the buoyancy force, the speed of the updraft within the cloud, the cloud-top height and the total mass of cloud air that is detrained at the cloud top.
- Equations are derived for each subensembles and summed over all subensembles to obtain the net effect of the ensemble on the model-scale environment.

How does cloud ensembles affect the model-scale environment?

- When saturated air containing liquid water detrains from cloud tops and evaporates, it cools the model-scale environment. Evaporation increases the water vapor content in the environment. Rates of detrainment differ for different cloud types and cloud-top heights

- Cumulus convection, which occurs when clouds grow vertically, induces subsidence between clouds. During subsidence, the model-scale temperature increases and relative humidity decreases.

Trigger:

To trigger convection, the scheme requires some boundary-layer CAPE.

Although it varies in specific implementations, the general formulation requires the presence of large-scale atmospheric destabilization with time. The process by which the scheme attempts to assess destabilization is complex; for example, it must account for the effects of entrainment and clouds of various depths.

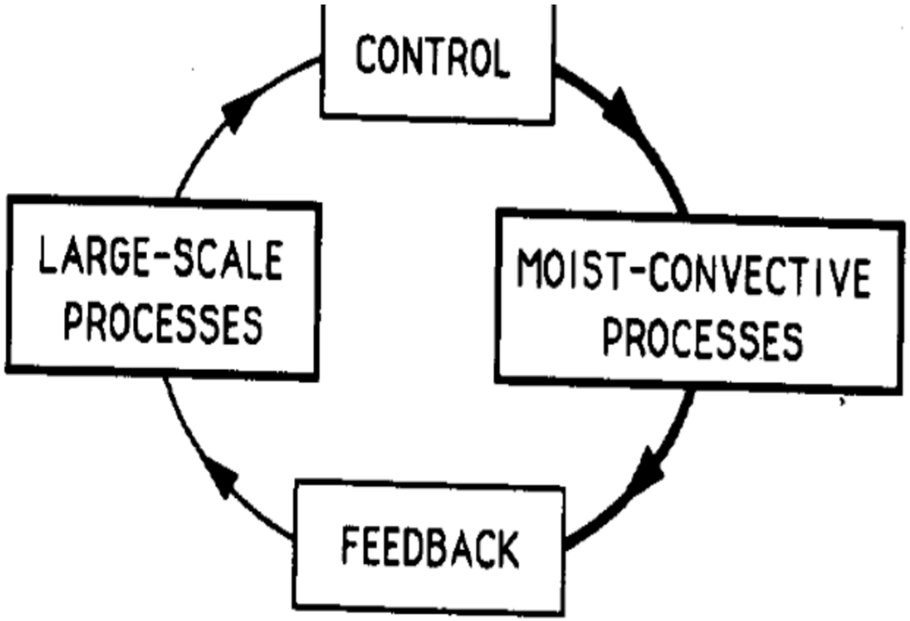


FIG. 1.1. A schematic figure showing the interaction between large-scale and moist-convective processes.

Dynamic control : deals with how the convective clouds are influenced by the large-scale environment. It is determines the spectral distribution of the clouds.

Static control: determines cloud thermodynamics properties and is often linked to the dynamical control.

Feedback: determines the effect of convection on the environment.

In other words, the static control is a way of communication between the feedback and the dynamical control. The dynamical control determines the effect of the environment on the cumulus clouds & the feedback determines the effects of cumulus clouds on the environment.

The **cloud work function**, A(λ) is a measure of the buoyancy force in the clouds, is defined for each sub-ensemble, and under the assumption that it is in quasi-equilibrium.

A is a measure of the kinetic energy generated by the buoyancy force for the sub-ensemble λ. A(λ) >0 indicates environment has moist convective instability.

The **closure** of the scheme is based on a **quasi-equilibrium hypothesis** that states that the production of moist convective instability by large-scale forcing and their destruction by the cumulus-scale forcing are in a state of balance over the timescale of the large-scale synoptic systems.

As discussed in the Introduction, a closure assumption is needed to complete any cumulus parameterization. In the Arakawa-Schubert parameterization, the closure takes the form of a balance between the generation of moist convective instability by the large-scale processes and its destruction by clouds as shown schematically in Fig. 1. Cloud-scale kinetic energy is the manifestation of a moist convective instability in the environment.

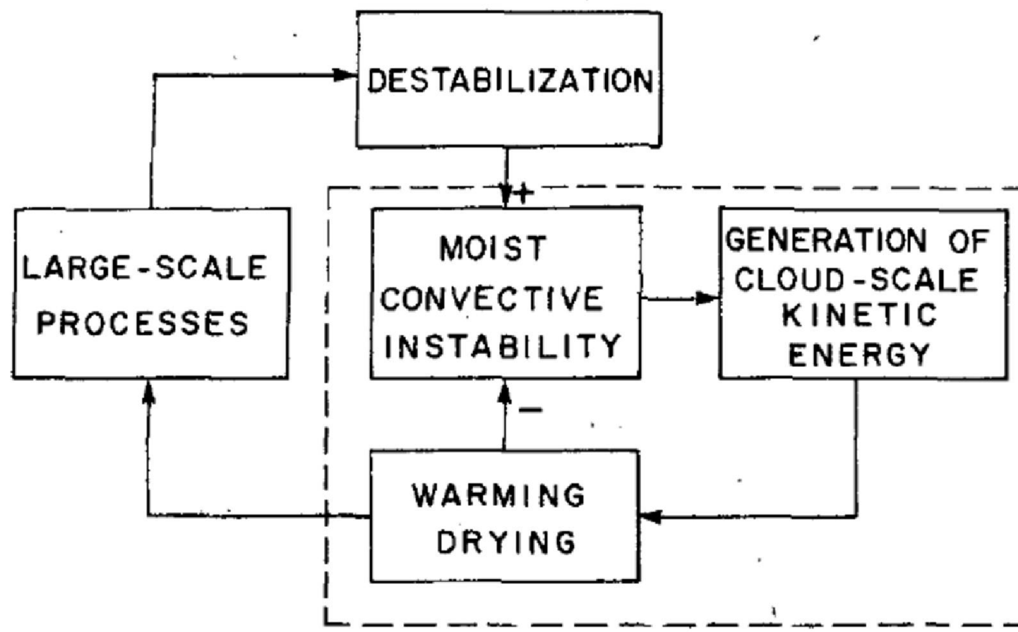


FIG. 1. A schematic diagram of the Arakawa-Schubert closure assumption. The dashed box represents the cumulus parameterization.

Arakawa-Schubert Scheme: Strengths & Limitations

Strengths

- Accounts for the influences of entrainment, detrainment, and compensating subsidence around clouds
- Can account for cap, depending on the specific implementation details
- This is a complex scheme that deals with a variety of cloud depths and is capable of providing complex sounding changes corresponding to many forecast situations

Limitations

- May not sufficiently stabilize the model atmosphere
- May produce rain later(not immediately) or result in a prolonged period of weak convection, especially if destabilizing advection or surface fluxes counteract the modest convective scheme stabilization
- May result in grid-scale convection! Many serious negative forecast impacts can occur, including dramatic changes to the model's mass fields
- Is not designed for elevated convection
- Assumes that convection exists over only a very small fraction of the grid column, which may not be appropriate at today's higher-resolution models
- Assumes that convective updrafts entrain through the sides, whereas observations of cumulus and towering cumulus indicate entrainment mainly through cloud top. This affects scheme rainfall and heating profiles, which feedback on to the resolved motions
- Takes longer to run than other schemes