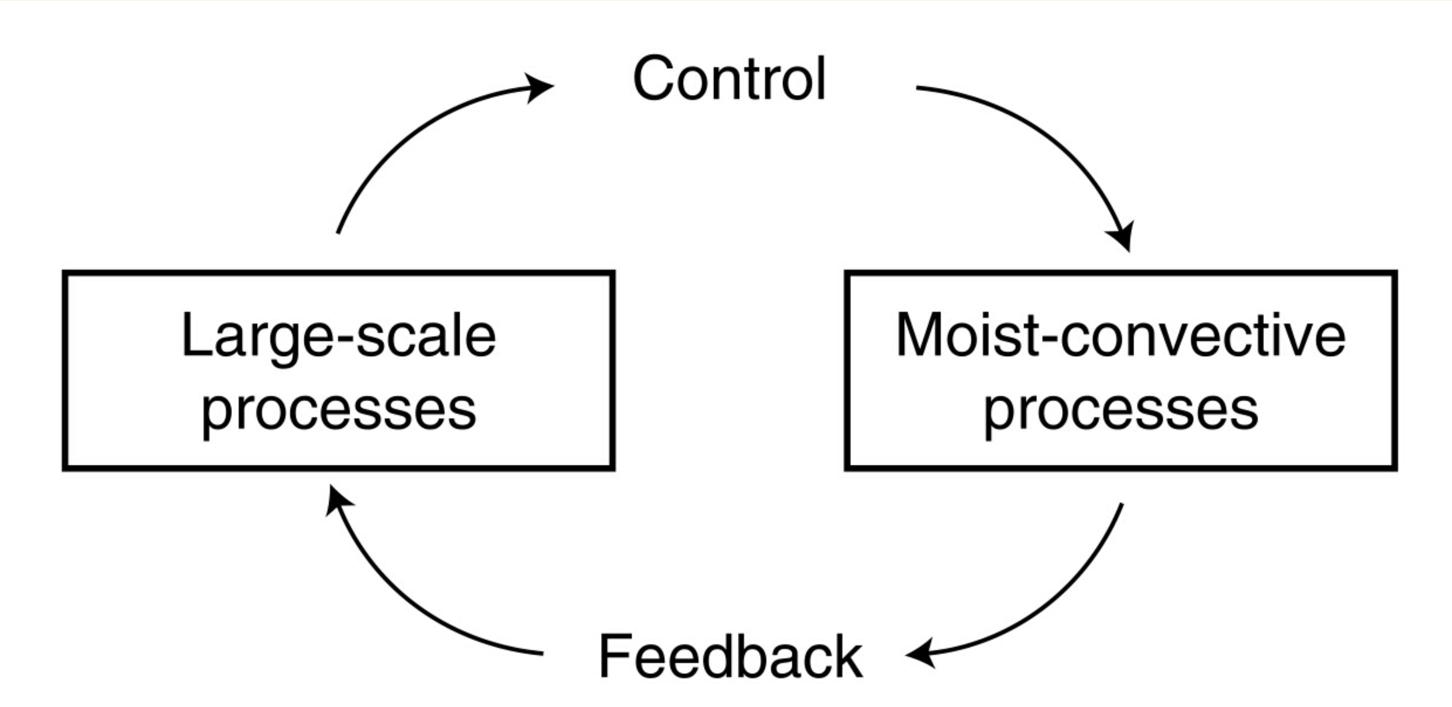
Tiedtke Convective Parameterization Scheme

Ariele Daniel

Why is this important?



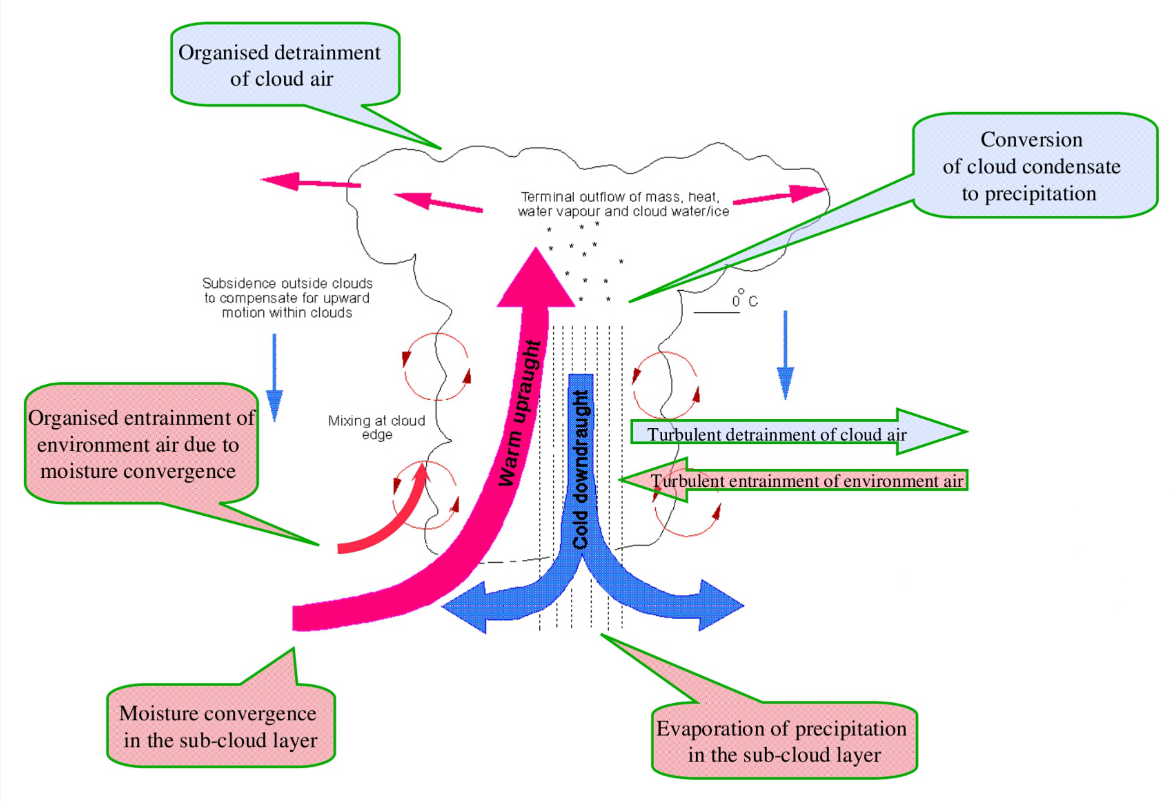
Why is this Important?

- Intense moist convection can influence small scale phenomena such as flash flooding, gust fronts, tornadoes, and concentrated intense rainfall events.
- Models generally can’t resolve convection processes on the specified grid scale
- Main objective is to define convection at the right place at the right time with the correct evolution and intensity

Overview of Tiedtke Scheme

- Mass flux scheme
- Uses 1-D bulk model
- Entraining and Detraining plume model
- Considers 3 different types of convective parameterizations
- Cloud base and cloud tops determined by use of parcel method
- Highly simplified microphysical parameterizations
- Both organized and turbulent entrainment and detrainment considered

Cloud Model



Organised detrainment of cloud air
Conversion of cloud condensate to precipitation
Terminal outflow of mass, heat, water vapour and cloud water/ice
Subsidence outside clouds to compensate for upward motion within clouds
0° C
Warm upraught
Cold downdraught
Mixing at cloud edge
Organised entrainment of environment air due to moisture convergence
Turbulent detrainment of cloud air
Turbulent entrainment of environment air
Moisture convergence in the sub-cloud layer
Evaporation of precipitation in the sub-cloud layer

Cause of Convective Clouds

- Convective cloud formation
  - detrainment of cloud air from convective updrafts into environmental air
- Dissipation
  - adiabatic and diabatic heating, formation of precipitation, turbulent mixing of cloud air and drier environmental air at cloud edges
- There is no difference between the way convective clouds and other cloud forms are handled in parameterization of precipitation processes.

Thermodynamic Energy Budget Equations

- Tiedtke Scheme only concerned with thermodynamic forcing by cumulus convection

$$\frac{\partial \bar{s}}{\partial t} + \bar{\mathbf{v}} \cdot \nabla \bar{s} + \bar{w} \frac{\partial \bar{s}}{\partial z} = -\frac{1}{\bar{\rho}} \frac{\partial}{\partial z} (\bar{\rho} \overline{w's'}) + L(\bar{c} - \bar{e}) + \overline{Q_R} \quad (1)$$

$$\frac{\partial \bar{q}}{\partial t} + \bar{\mathbf{v}} \cdot \nabla \bar{q} + \bar{w} \frac{\partial \bar{q}}{\partial z} = -\frac{1}{\bar{\rho}} \frac{\partial}{\partial z} (\bar{\rho} \overline{w'q'}) - (\bar{c} - \bar{e}), \quad (2)$$

$$M_{ui} = \bar{\rho} a_{ui} (w_{ui} - \bar{w}), \quad M_{di} = \bar{\rho} a_{di} (w_{di} - \bar{w}), \quad (4)$$

$$\frac{\partial \bar{s}}{\partial t} + \bar{\mathbf{v}} \cdot \nabla \bar{s} + \bar{w} \frac{\partial \bar{s}}{\partial z} = -\frac{1}{\bar{\rho}} \frac{\partial}{\partial z} [M_u s_u + M_d s_d - (M_u + M_d) \bar{s}] + L(c_u - e_d - \tilde{e}_l - \tilde{e}_p) - \frac{1}{\bar{\rho}} \frac{\partial}{\partial z} (\bar{\rho} \overline{w's'})_{\mathrm{tu}} + \overline{Q_R} \quad (5)$$

$$\frac{\partial \bar{q}}{\partial t} + \bar{\mathbf{v}} \cdot \nabla \bar{q} + \bar{w} \frac{\partial \bar{q}}{\partial z} = -\frac{1}{\bar{\rho}} \frac{\partial}{\partial z} [M_u q_u + M_d q_d - (M_u + M_d) \bar{q}] - (c_u - e_d - \tilde{e}_l - \tilde{e}_p) - \frac{1}{\bar{\rho}} \frac{\partial}{\partial z} (\bar{\rho} \overline{w'q'})_{\mathrm{tu}}, \quad (6)$$

Convection vs. Advection

- Contributions from convection processes in large-scale budget equations allow for:
  - total energy conserved
  - reduction in numerical errors
  - better interaction between cloud layer and sub-cloud layer
  - realistic thermal forcing is maintained as model resolution is increased approaching the explicit condensation scheme
- Vertical profiles of convective drying and heating sensitive to finite differencing methods

Updraft Assumptions

- Steady state
- Updraft mass flux linked to sub-cloud layer moisture convergence
- Entrainment of mass plumes by:
  - turbulent exchange of mass through cloud edges
  - organized inflow at cloud base associated with large-scale convergence
  - detrainment exchanged through turbulent and organized outflow at the cloud top
- Sub-cloud layer heat and moisture fluxes decrease linearly towards ground

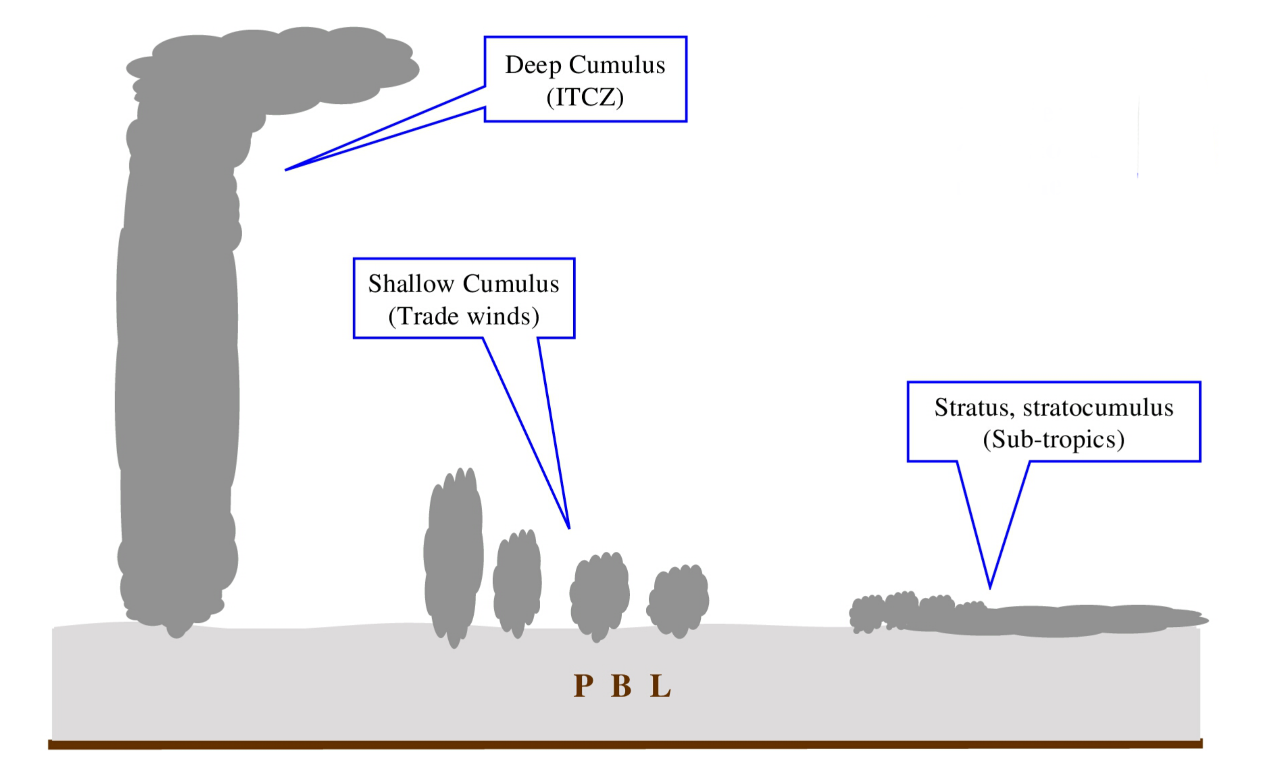
Downdraft Assumptions

- Downdraft mass flux is directly proportional to the updraft mass flux
- Entrainment and Detrainment are executed in same way as in updrafts
- Mass flux is independent of height and effectively detrains in the sub-cloud layer
- Level of free sinking air at highest model level

Types of Convection Parameterizations

- Highly simplified microphysics scheme
  - conversion of cloud condensate to precipitation is directly proportional to amount of cloud condensate
- Tendencies are computed with T, q, u, v, and convective precipitation
- Three types of convection specified
  - Penetrative convection
  - Shallow convection
  - Mid-level convection

Convective Parameterization



Penetrative Convection

- Occurs in disturbed situations
- Moisture content is maintained in presence of large-scale transports, turbulent transports, and convective transports
- Cloud base height established by condensation level for surface air
- Entrainment and detrainment properties

Shallow Convection

- Occurs in undisturbed flow in absence of large-scale convergent flow
- Moisture supply predominantly from surface evaporation
- Controlled by sub-cloud layer convergence
- Very small cumuli ignored
- Detrainment occurs just below and above the trade wind inversion
- Also accounts for overshooting tops

Mid-Level Convection

- One of the biggest new additions at the time
- Occur at levels above the boundary layer
- Usually formed by lifting of low-level air dynamically to the level of free convection
- Moisture supply predominantly from low-level large scale convergence
- Low level temperature inversions usually exist which inhibits the convection from starting freely at the surface
- Makes the model more realistic

Results

- Strengths
  - better simulate the hydrological cycle
  - shallow and deep convection both accounted for
  - accounts for elevated convection
  - produces realistic fields of convective heating over time
  - does not initiate strong adjustment process
- Limitations
  - errors in mass field could result in false grid-scale convection
  - different types of finite differencing methods could reduce quality
  - if environmental air is convectively and unstably stratified the numerical model becomes unstable

Performance

- Convective heating in midlatitudes is stronger because of mid-level convective parameterization
- More heating present in tropics in comparison to previous models
- Change in modeling of Hadley Circulation
- Momentum transport reduces wind errors in rotational flow but had little to no effect on the divergent flow

Conclusions

- Determined the 1-D bulk model was sufficient
- The moisture budget hypothesis provides a realistic framework for cloud mass flux
- Produces more realistic results due to incorporation of mid-level cumulus parameterizations, cumulus downdrafts, and cumulus momentum transports.
- Have to use caution when using finite differencing schemes to resolve the model as to not cause the model to become unstable.

Questions

Works Cited

Mironov, Dmitrii V. "Parameterisation of Cumulus Convection." COSMO-CLM Training Course, 7 Feb. 2011. Web. 01 Oct. 2014. <http://www.clm-community.eu/dokumente/upload/d2cfe_Training11_Convection_Mironov.pdf>.

Tiedtke, M. "A Comprehensive Mass Flux Scheme for Cumulus Parameterization in Large-Scale Models." Monthly Weather Review 117.8 (1989): 1779-800. Web.

Warner, Thomas T. Numerical Weather and Climate Prediction. Cambridge: Cambridge UP, 2011. Print.