# Kessler warm rain microphysics scheme

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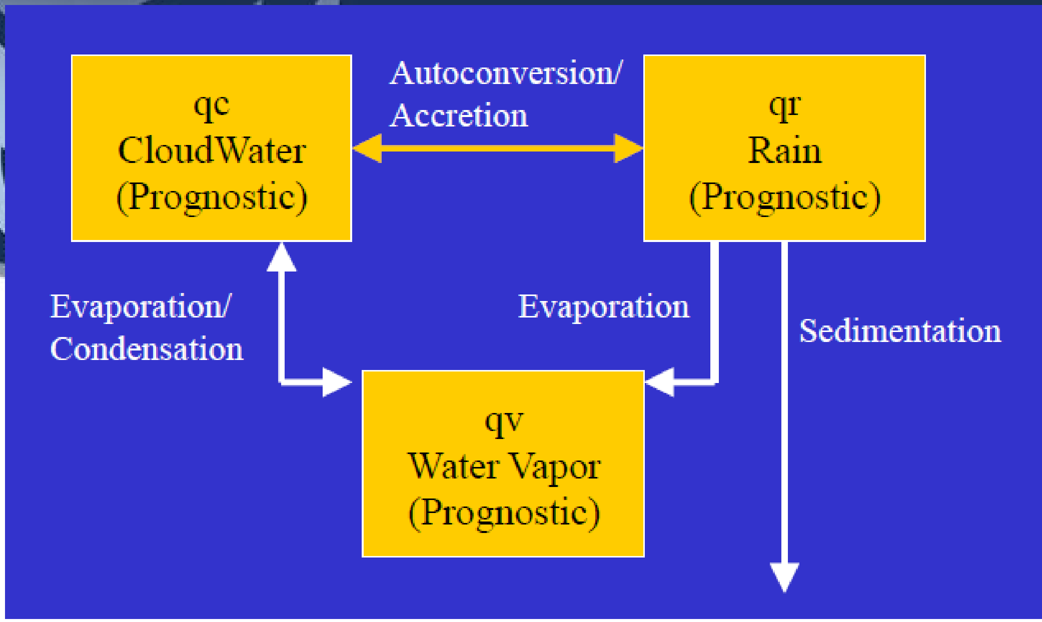
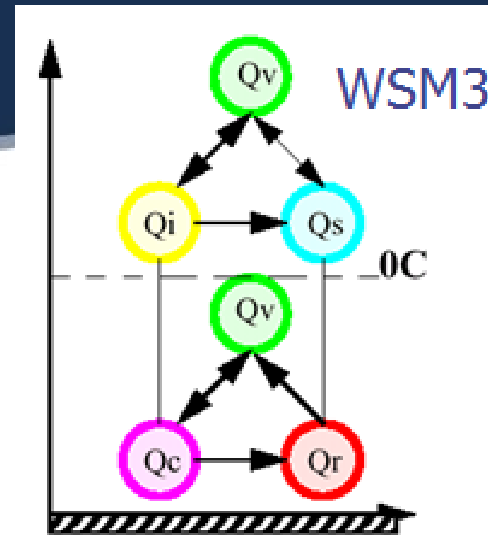
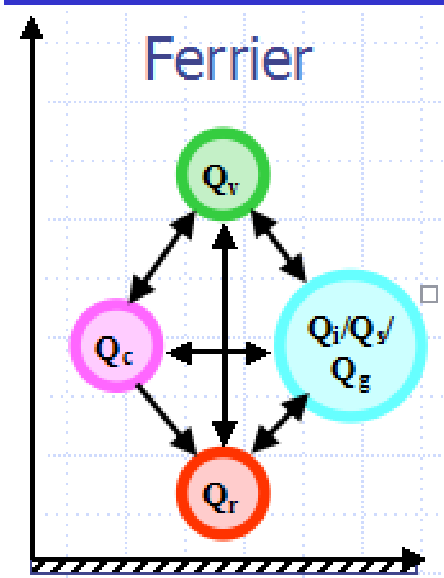
# INTRODUCTION

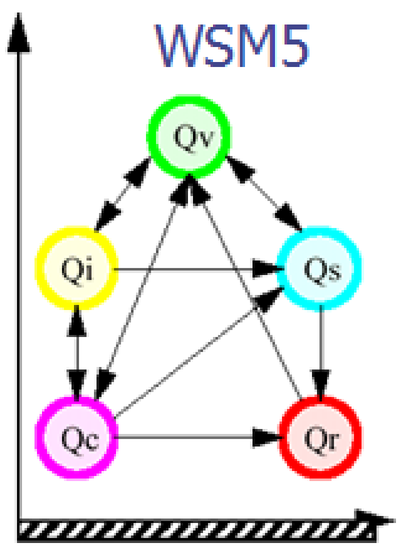
- One moment scheme,and many available bulk schemes have followed the approach of Kessler
- The purpose of the scheme is to increase understanding of the roles of cloud conversion, accretion, evaporation, and entrainment processes in shaping the distributions of water vapor, cloud, and precipitation associated with **tropical** circulations.
- Idealized microphysics process **without** the consideration of **ice phase** and **melting zone**

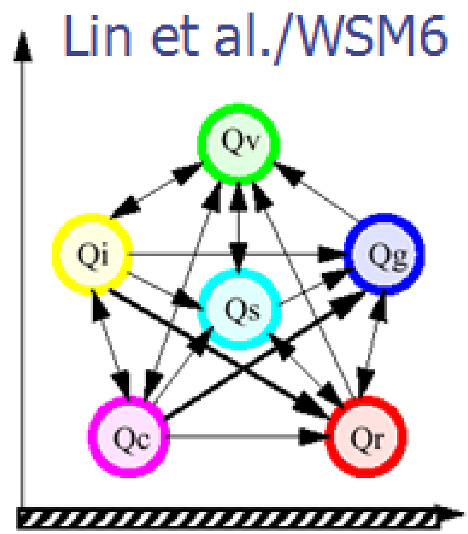
# INTRODUTION



# Prior studies

- simpilfied continuity equation

  N(V+w)=constant

  where N is the number density (number/m3) of precipitation particles uniform at each height, V is their terminal fall velocity and w is the updraft speed.

# Prior studies: cloud-free model

- included derivation of model profiles of **precipitation(M)**, that descended in a **saturated incompressible** atmosphere at constant fall speed V through updrafts
- Continuity equations for precipitation

$$\partial M / \partial t = -(w + V) \times \partial M / \partial z + w \times G$$

$$w = (4 \times w_{\max} / H) \times (z - z^2 / H)$$

$$dz / dt = V + w$$

G: condensation function.

# Prior studies: cloud-free model

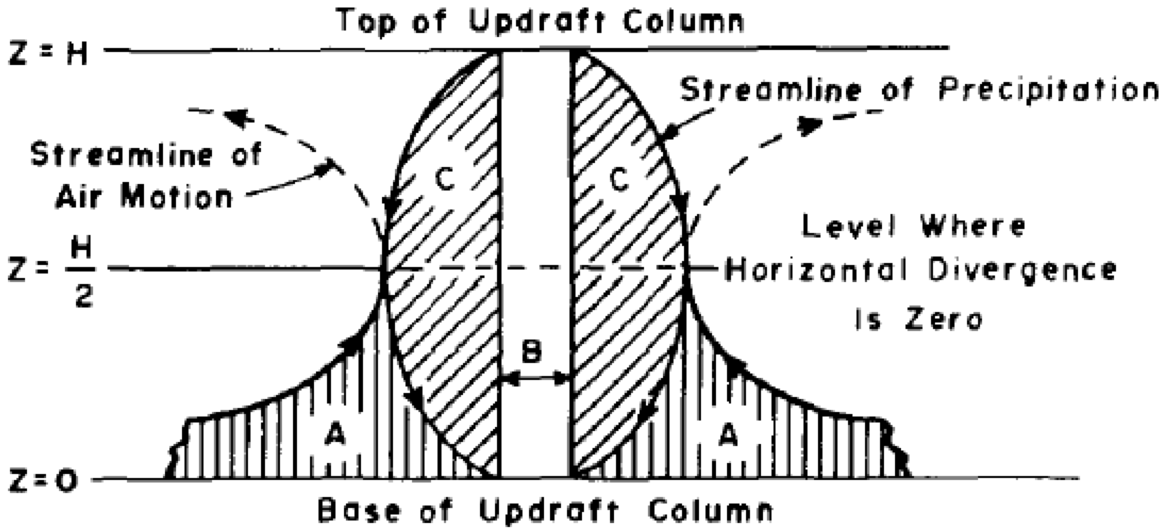



Fig. 2. Horizontal divergence at high altitudes accompanies rising air motion and spreads model precipitation packets horizontally as they descend at constant fall velocity relative to the air in *B* and *C*. At low altitudes the packets contract in the horizontally convergent wind field. Precipitation at the ground can therefore be greater than the condensation that occurs vertically overhead. When cloud is collected by precipitation at a particular altitude, but not below, the region contributing moisture can be further increased as indicated by the vertically shaded area *A* (from Kessler, 1969).

# CONCEPTUAL FRAMEWORK FOR KESSLAR SCHEME

- separate liquid into cloud water and rain
- two continuity equations derived from the continuity eqn. for air are required for cloud(m) and precipitation(M)

$$\frac{\partial m}{\partial t} = -u\frac{\partial m}{\partial x} - v\frac{\partial m}{\partial y} - w\frac{\partial m}{\partial z} + wG + mw\frac{\partial \ln \rho}{\partial z} - AC - CC + EP$$

$$\frac{\partial M}{\partial t} = -u\frac{\partial M}{\partial x} - v\frac{\partial M}{\partial y} - (V + w)\frac{\partial M}{\partial z} - M\frac{\partial V}{\partial z} + Mw\frac{\partial \ln \rho}{\partial z} + AC + CC - EP$$

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G: generation (condensation) function

V: terminal fall velocity

w: updraft speed.

microphysical processes:

AC: autoconversion of cloud

CC: collection (accretion) of cloud by precipitation

EP: evaporation of precipitation.

# Autoconversion process

$$Autoconversion = k_1 * (m - a)$$

$k_1$ would be zero up to a threshold u and thereafter adopt an assigned value.

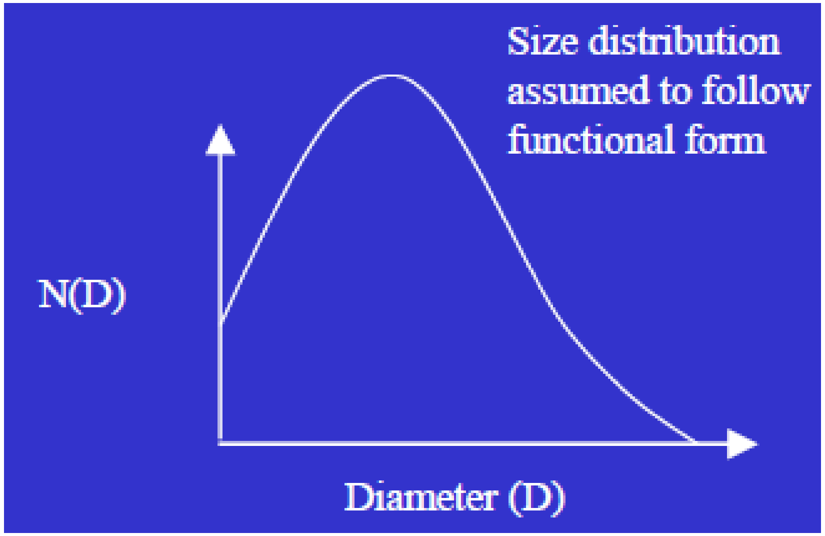
# Accretion process

- follow the Marshall and Palmer (1948) dirtribution of precipitation

$$N = N_0 \exp(-\lambda D)$$

- N:the number density of particles in unit size range of the distribution
- D: diameter
- λ: can be obtained from

the predicted mixing ratio



# Accretion process

- single precipitation particle of diameter $D_i$ and falling at velocity $V_i$

$$\delta M_i / \delta t = -\pi D_i^2 E_i V_i m / 4$$

$$dM / dt_{accretion} = 6.96 \times 10^{-4} E N_0^{1/8} m M^{7/8} (g m^{-3} s^{-1})$$

E:capture efficiency of collecting cloud particles

dM/dt applied with M>0 only when m>0

# Evaporation of rain

$$dM/dt_{evaporation} = 1.93\times10^{-6} N_0^{7/20} m M^{13/20} (gm^{-3}s^{-1})$$

- applied with M > 0 only when m < 0
- (<0 for saturation)

# Study results of comprehensive models

- high-speed updraft

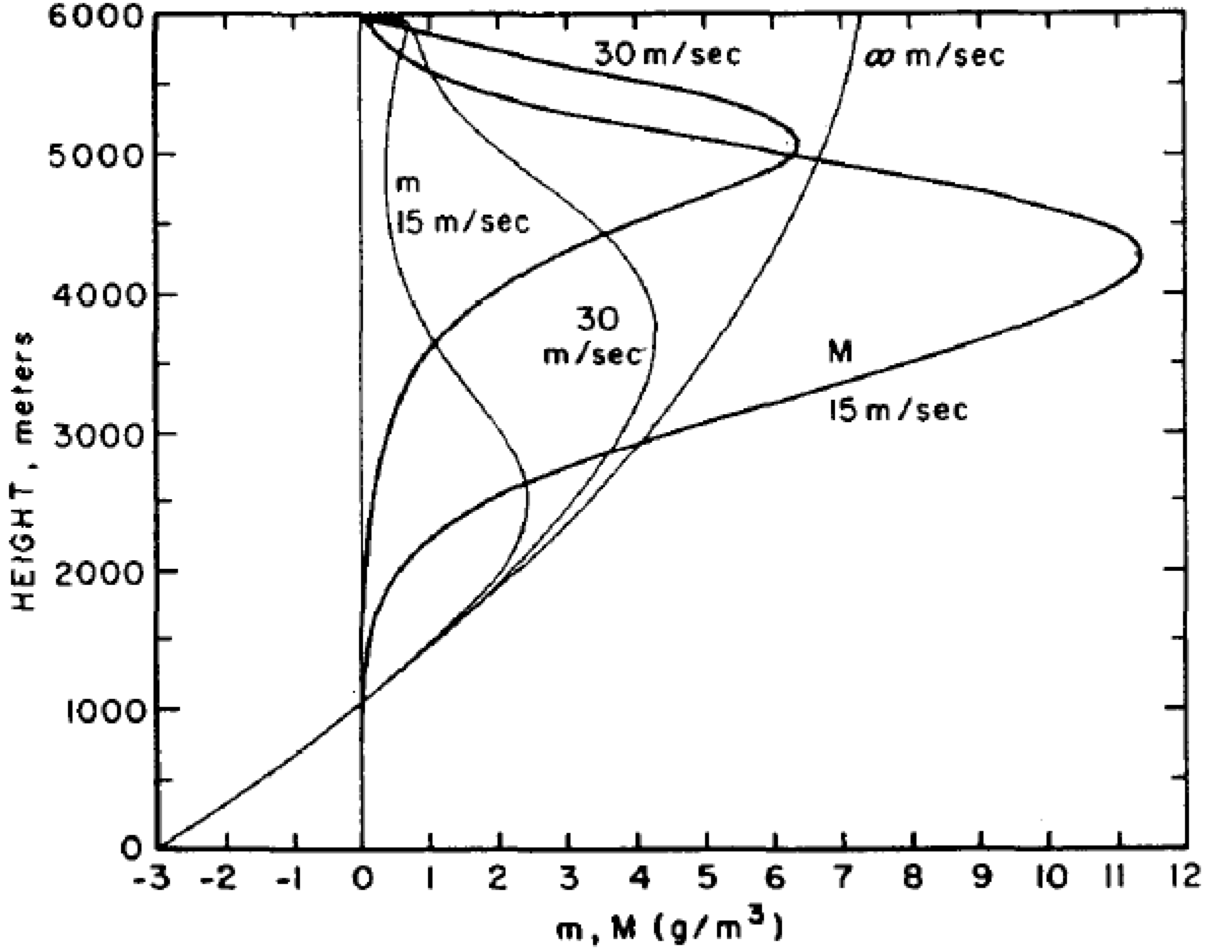



Fig. 3. Model steady-state profiles of coexisting cloud (light lines) and precipitation in summer updraft columns. for two speeds of strong updrafts. The precipitation maxima occur above those of cloud and both maxima are at higher altitudes when updrafts are stronger (From Kessler, 1969).

# FURTHER STUDIES

- subsequent studies extended the Kessler approach to include ice
  (e.g., Koenig and Murray 1976; Lin et al. 1983; Rutledge and Hobbs 1984; Lord et al. 1984; Dudhia1989)

- **Ice microphysical processes**
  Diffusionalgrowth/sublimation
  Aggregation (autoconversion, accretion)
  Collection of rain and cloud water (riming)
  Melting
  Freezing
  Ice particle initiation (nucleation)
  Sedimentation

# Comparasion between Kessler and other bulk microphysics schemes

- F. Cossu and K. Hocke (2014)

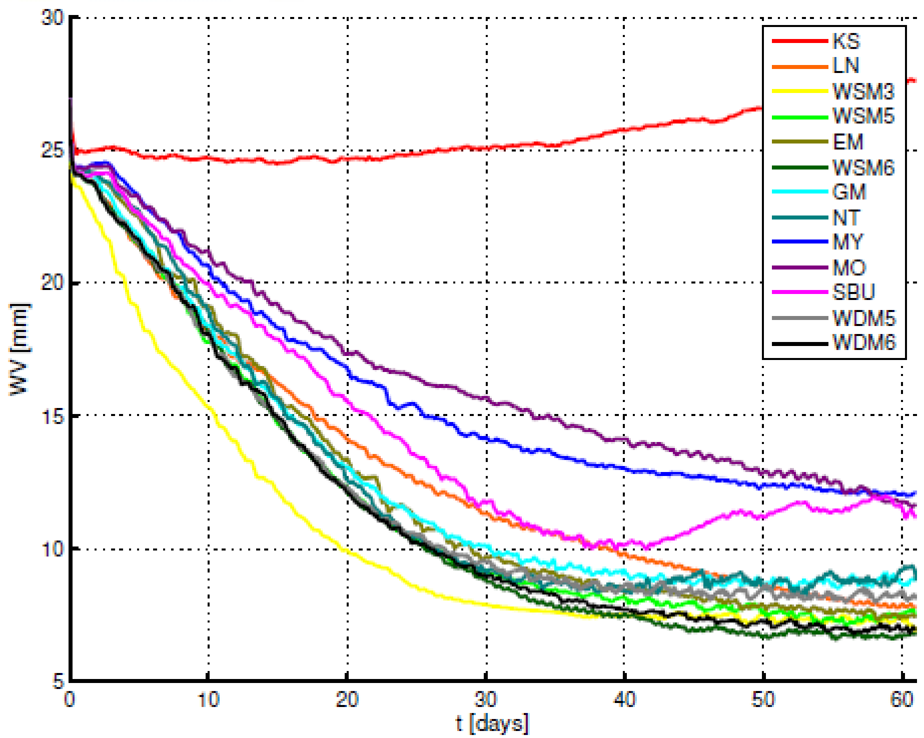



**Fig. 4.** Comparison of water vapour mean column density for the 13 microphysical schemes. Water vapour is depleted through its conversion into hydrometeors (Fig. 5) and accumulation at the surface under the form of precipitation (Fig. 6).

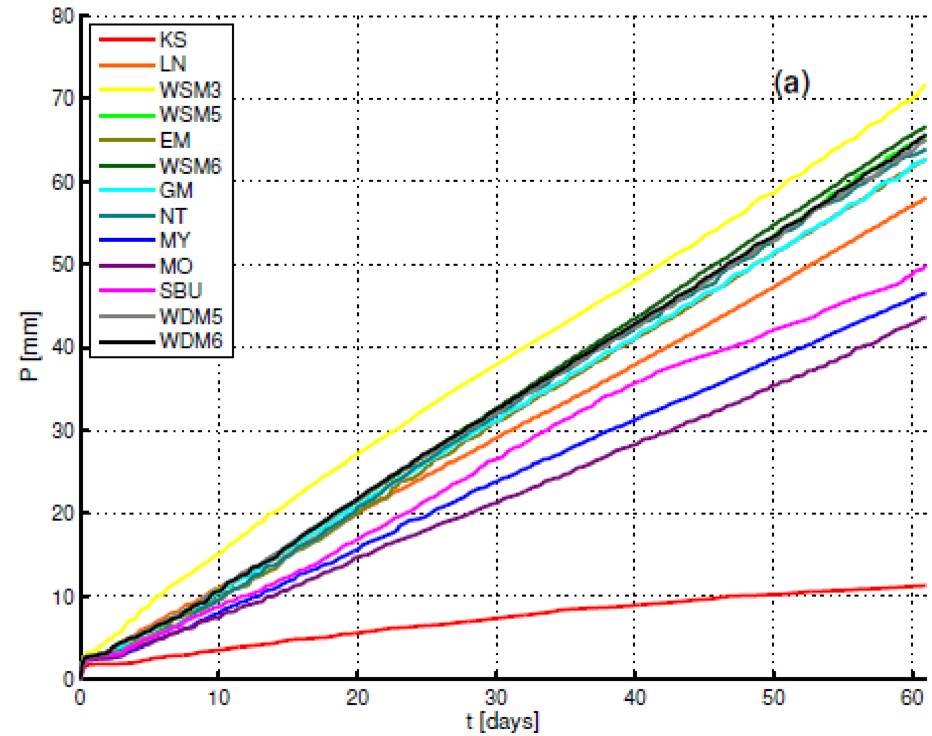



**Fig. 6.** Comparison of mean accumulated precipitation

KS in the plots stands for Kessler scheme

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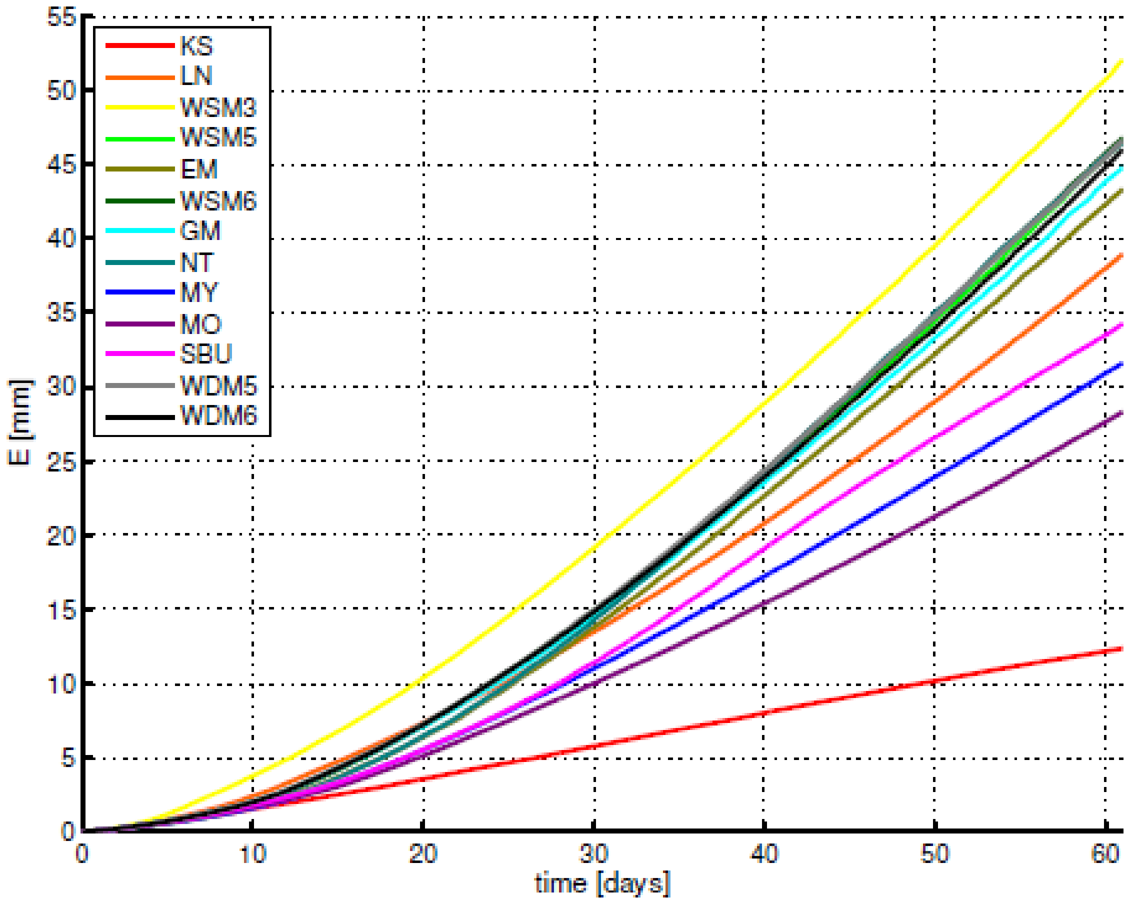


**Fig. 7.** Comparison of mean accumulated evaporation for the 13 microphysical schemes. The lines seem to follow an exponential increase rather than the linear increase of the lines in Fig. 6a.

# LIMITATION

- Kessler scheme has been used widely in cloud modeling studies due to its simplicity
- many important microphysics processes haven't been considered in the scheme
- the equation represented the processes between cloud, vapor and rain are also much simpilfied compared with other scheme

- may show unrealistic precipitation profiles

in some studies, Kessler scheme produced much heavier precipitation

# CONCLUSIONS

- Warm rain – no ice,only contains cloud water, rain and water vapor

  seperate the water substance in to cloud and precipitation, and use different continuity equations
- One moment scheme and followed Marhsall-Palmer distribution for rain

# REFERENCES

Kessler, E., 1969: On the distribution and continuity of water substance in atmospheric circulation,Meteor. Monogr., 32, Amer. Meteor. Soc., 84 pp.

Kessler, E., 1995: On the continuity and distribution of water substance in atmospheric circulations. Atmos. Res., 38, 109–145

Cossu,F., and  Hocke K. 2014: Influence  of microphysical schemes on atmospheric water in the Weather Research and Forecasting model. Geosci. Model Dev., 7, 147–160

Morrison, H. 2010:An overview of cloud and precipitation microphysics and its parameterization in models

# QUESTIONS?