The impact of Rainfall Sedimentation Scheme on the Meso-scale Cloud System

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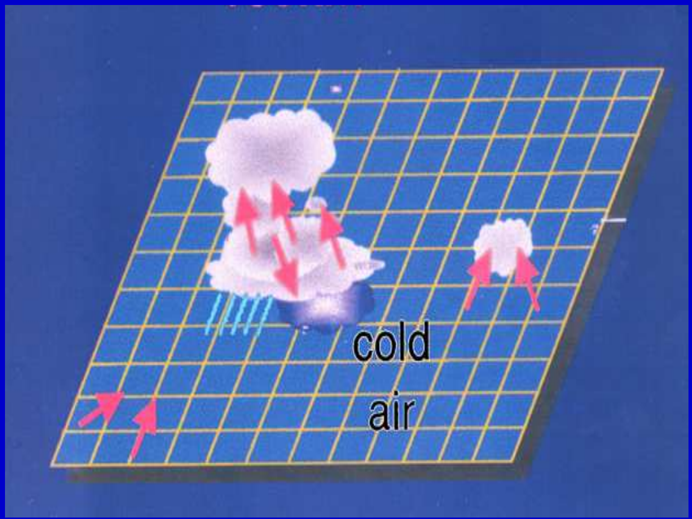
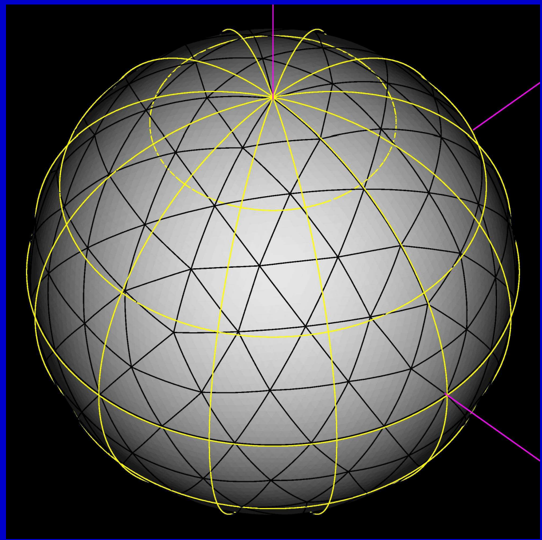




Outline

- **Motivation of this study**
  - Impact of rainfall sedimentation scheme on the cloud system
- **High order and efficient scheme for rain sedimentation**
  - Semi-Lagrangian Piecewise Parabolic Method
  - Some smoother and filtering
- **What impact does the sedimentation scheme on the cloud system?**
  - Numerical simulation of squall-line experiment
    - Precipitation property
    - Cold pool dynamics
- **Some discussion**
- **Summary**

Motivation

- Importance of vertical profile of rain in the CRM
  - Evaporation in the lower atmosphere
  - Generation of the cold pool
- Vertical profile of rain is mainly determined by
  - Physics :
    - Microphysics scheme itself
    - PBL scheme
  - Dynamics:
    - Vertical / horizontal advection
      - Relatively high order scheme
    - Rainfall sedimentation scheme
      - Relatively low order scheme for simplicity?

If rainfall sedimentation scheme is changed

from low order scheme to high order one,

what impact to meso-scale cloud system does it have?

Rainfall sedimentation scheme

- **Requirement of rainfall sedimentation scheme**
  - **Positive definite**
  - **Conservative**
  - **Good computational performance**
- **Euler scheme is not acceptable!**
  - **In the lower atmosphere, the mesh is dense, while the rainfall speed is high.**
    - **DT is restricted by severe CFL condition**

→ Semi-Lagrangian type scheme

e.g. Kato(1995) : box-Lagrangian scheme

all requirements are achieved!

But,….. accuracy is first order.

Typical Benchmark Test

- **Kato(1995)' test**
  - **Kessler type sedimentation**

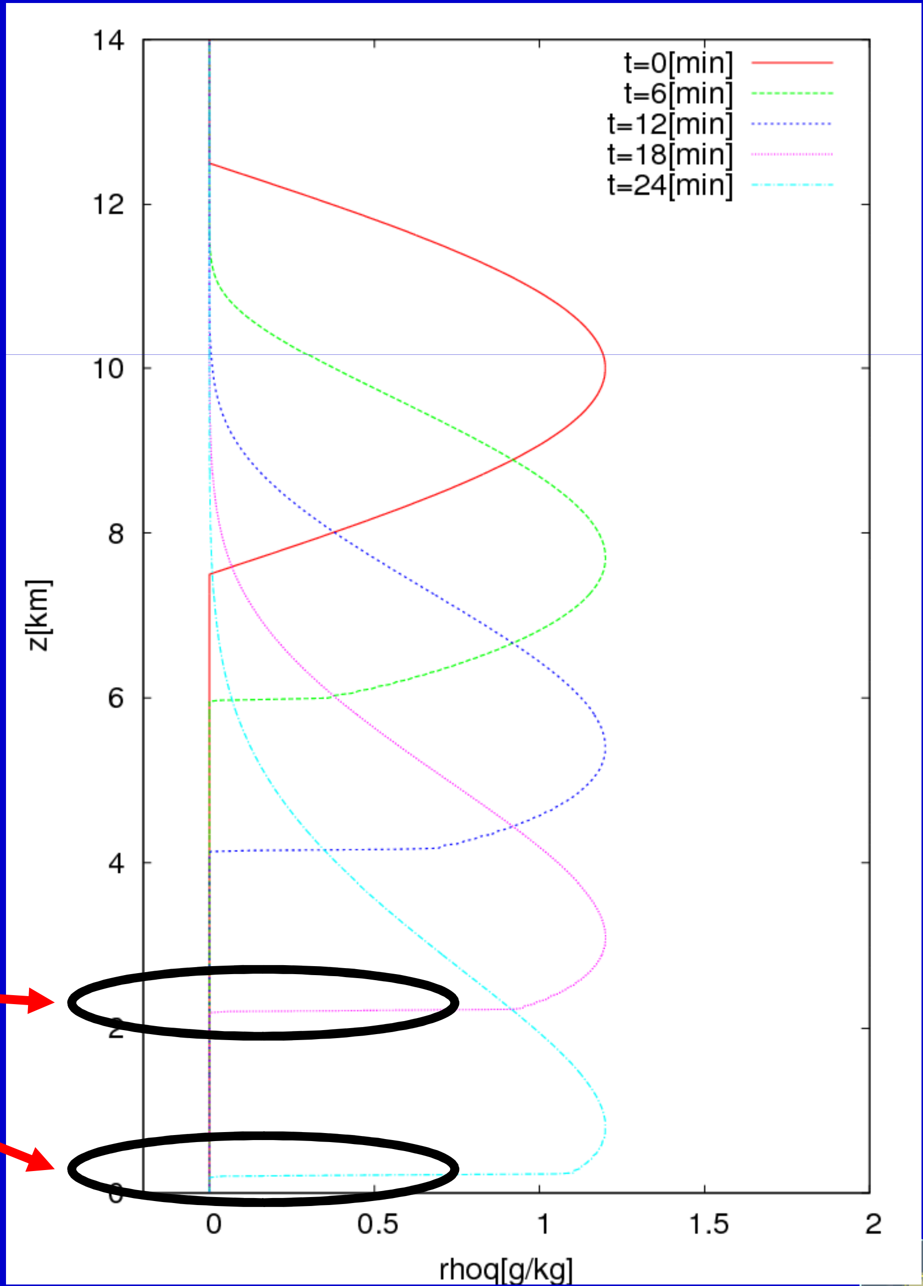
$$\frac{\partial f}{\partial t}+\frac{\partial}{\partial z}(wf)=0$$

$$w(z,t)=\kappa_1\left[f(z,t)\right]^{\kappa_2}$$

$$where \quad f=\rho q_r$$

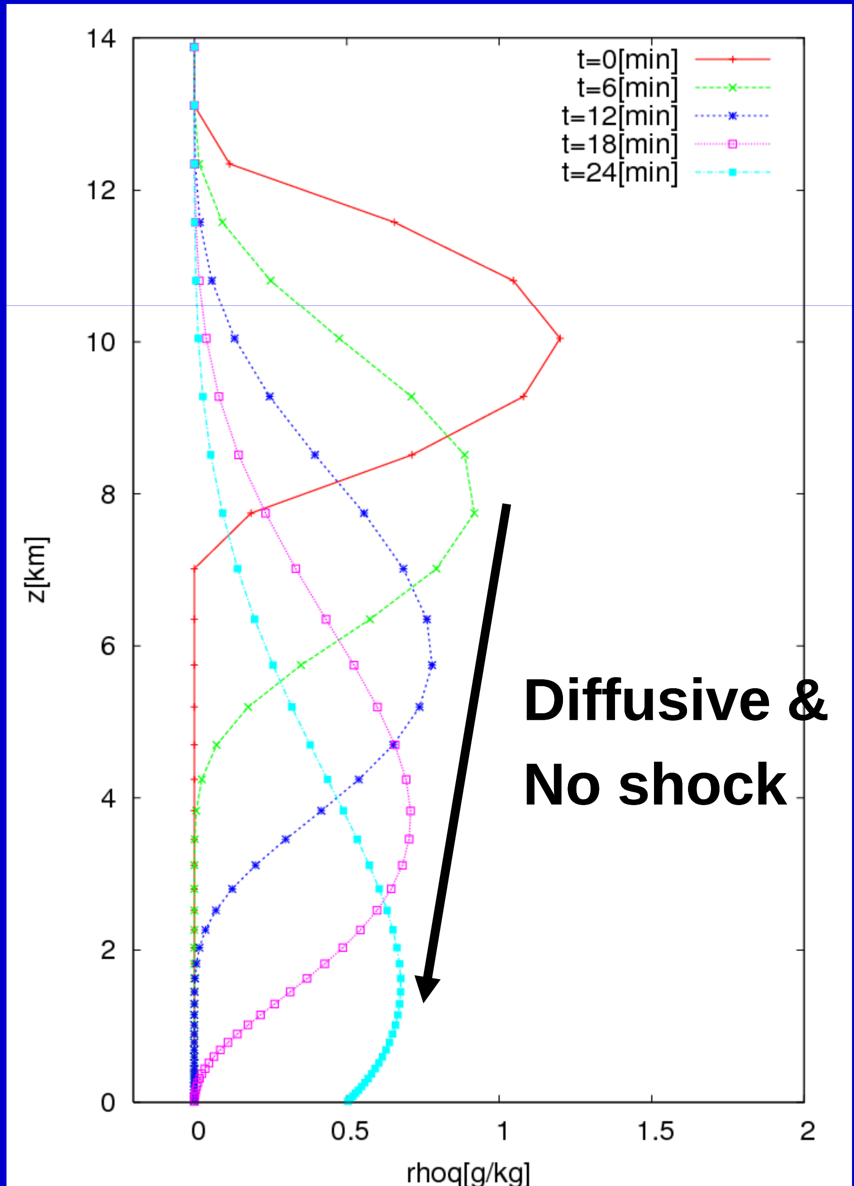
Highly nonlinear

- **Shock like distribution**

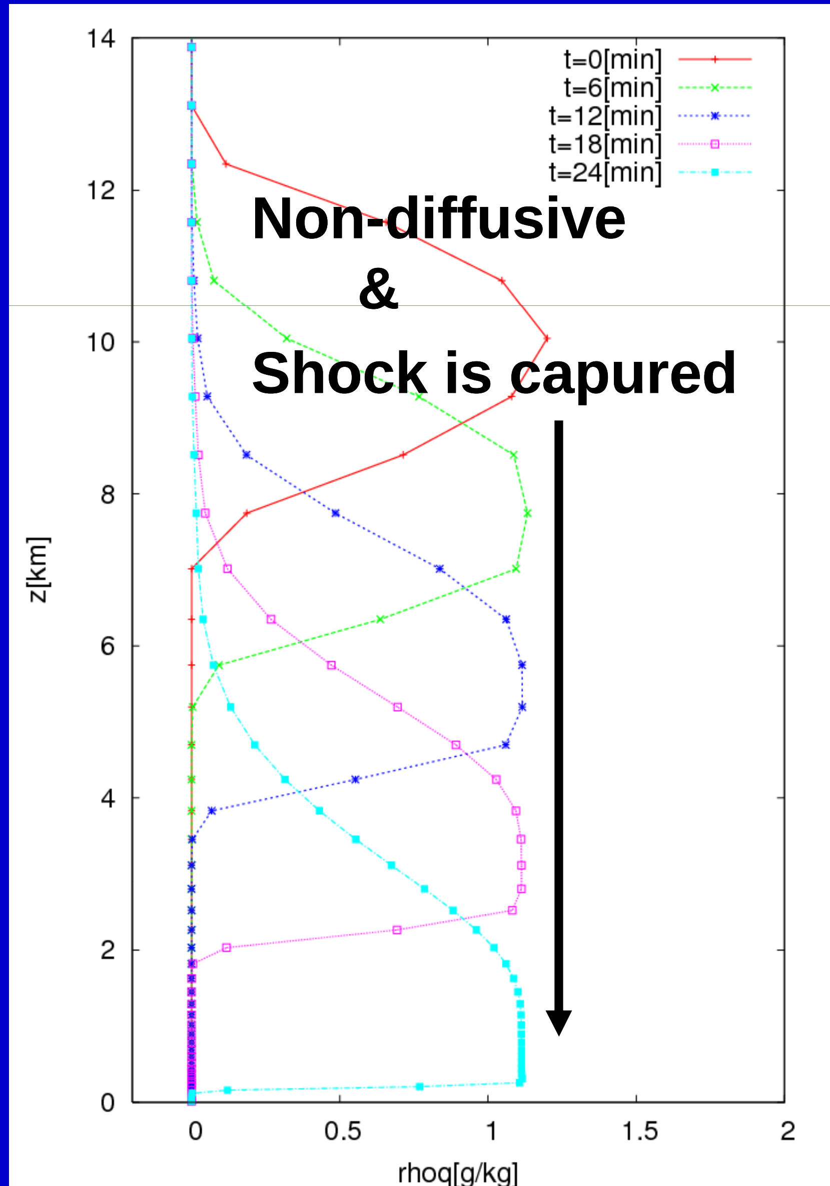


Result of dt=2[s]

CSL Upwind

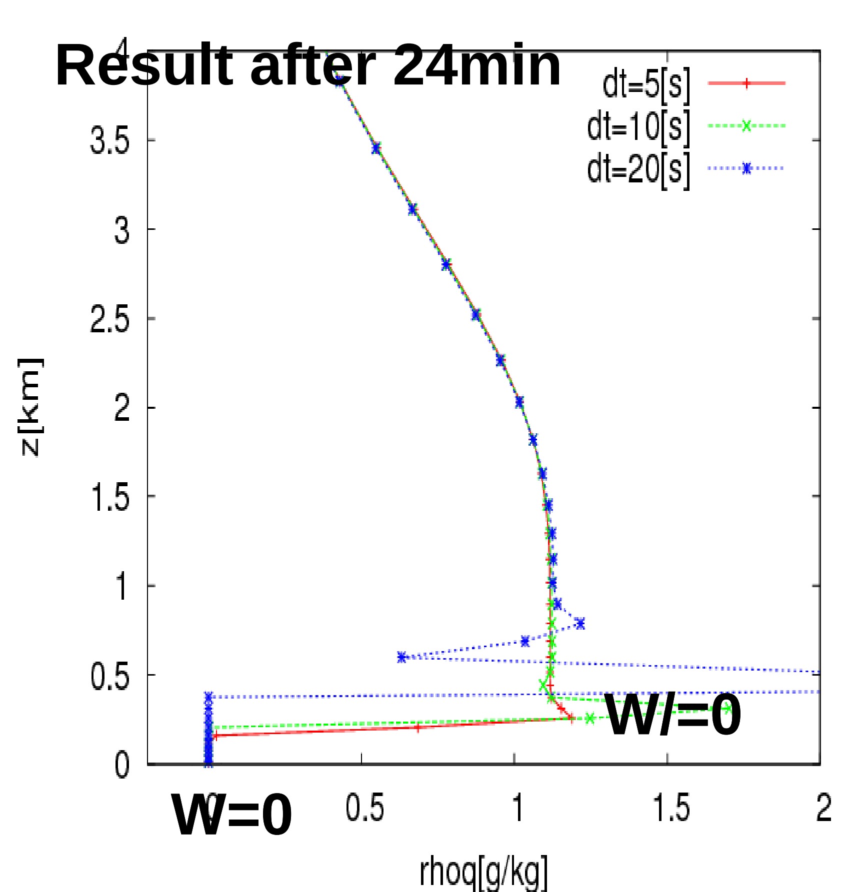


CSL PPM

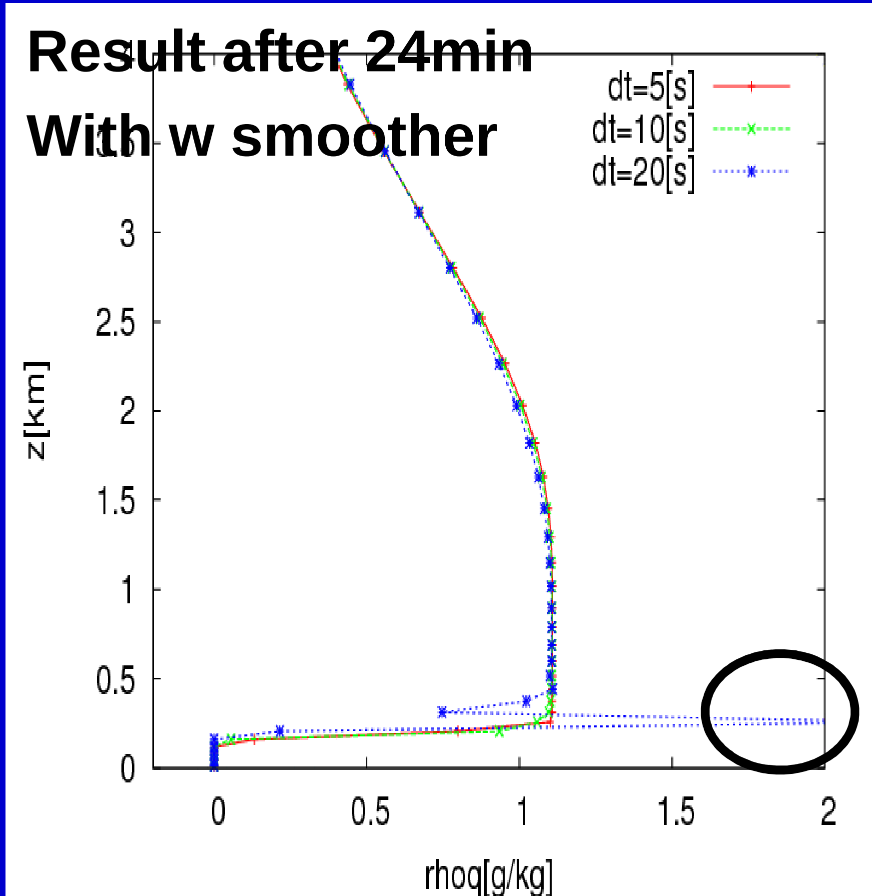


Dependency of profile against dt (PPM)

- **If dt increases, ……**
  - oscillation around the shock
  - cause : discontinuous velocity at the shock



- **To avoid the discontinuity of w,**
  - w smoother is applied. e.g. Xiao et al.(2003,MWR)
    - Profile is well improved.



Further improvement

Filtering technique

◆Similar to LES

$$\frac{\partial f}{\partial t} - \frac{\partial}{\partial z}\left[Kv \frac{\partial f}{\partial z} \right] = 0$$

$$Kv = C\left[\frac{f_{k+1} - f_k}{\Delta z_{k+1/2}} \cdot \frac{L_0}{f_0} \right]^2 \frac{(\Delta z_{k+1/2})^2}{\Delta t_0}$$

- Length scale : mean dz

$$L_0 = \Delta z_{mean}$$

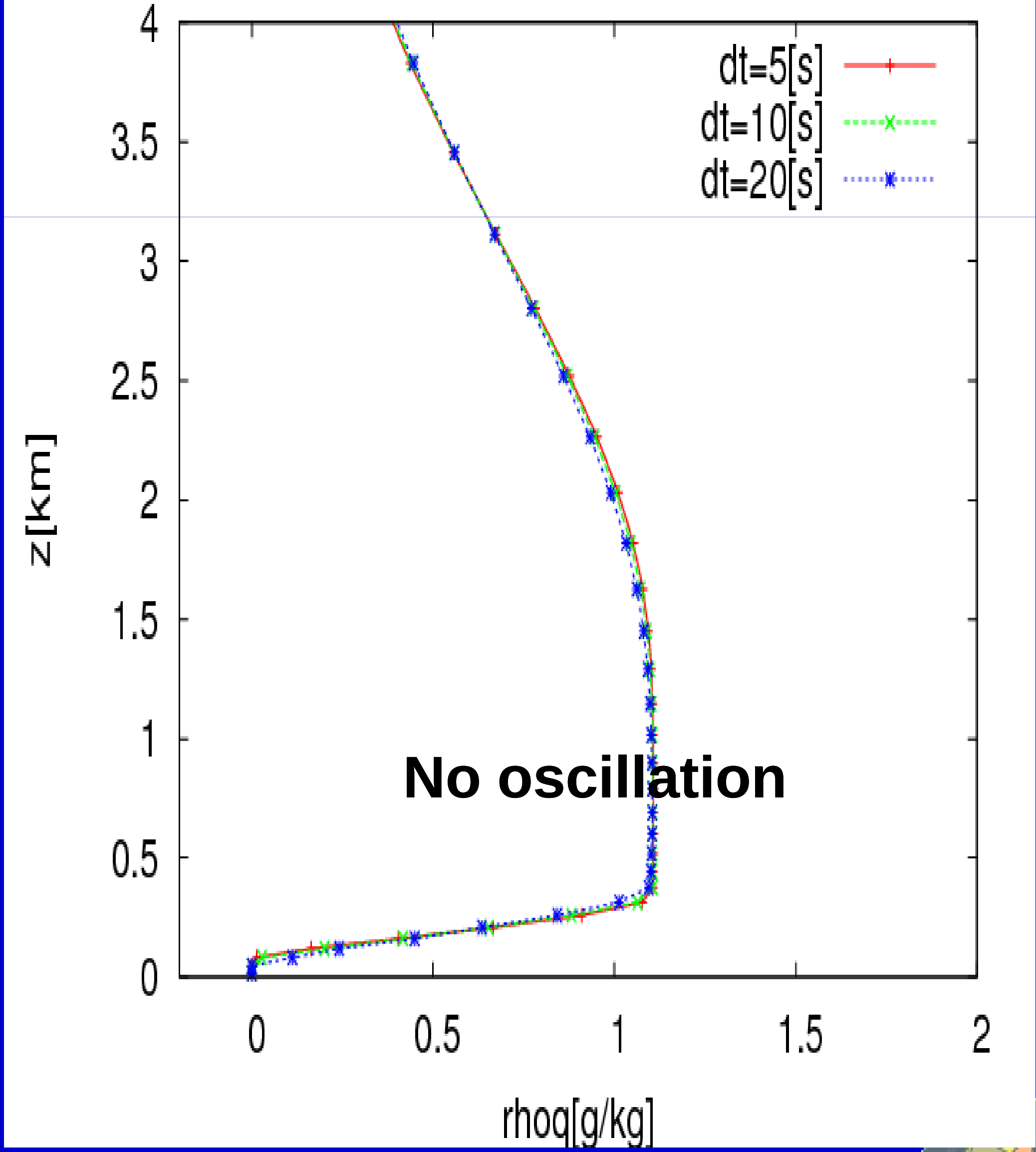
- Time scale : local time

$$\Delta t_0 = \frac{\Delta z_{k+1/2}}{V_0}$$

- Scale of f : column maxmum

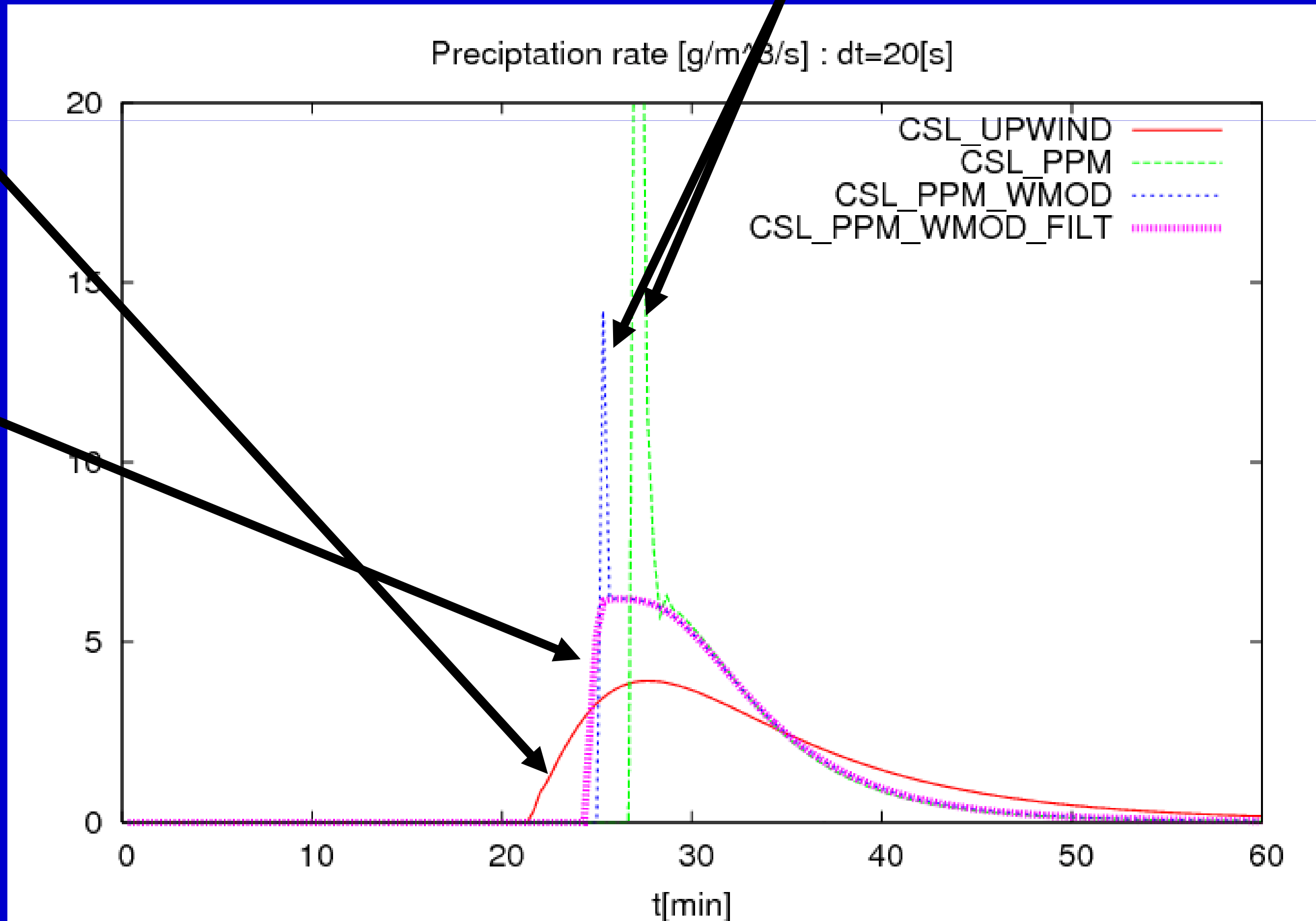
$$f_0 = \max(f_k)$$

Result from w smoother & filter

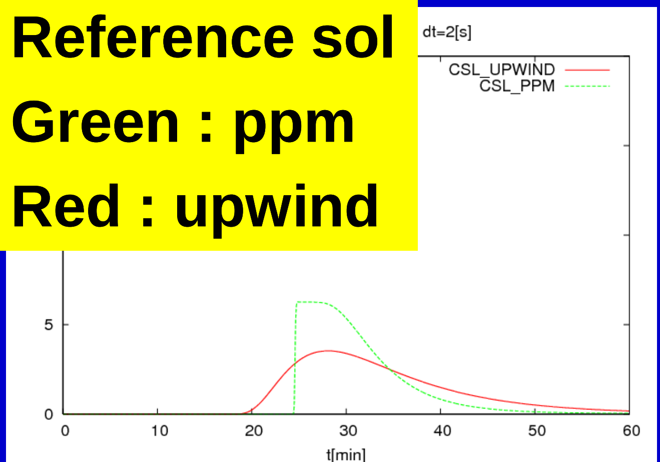


Precipitation rate at the surface with dt=20[s]

- **UPWIND**
  - Too diffusive
- **PPM & PPM only with w-smoother**
  - Spurious oscilation
- **PPM with w-smoother & filtering**
  - Same as refererence



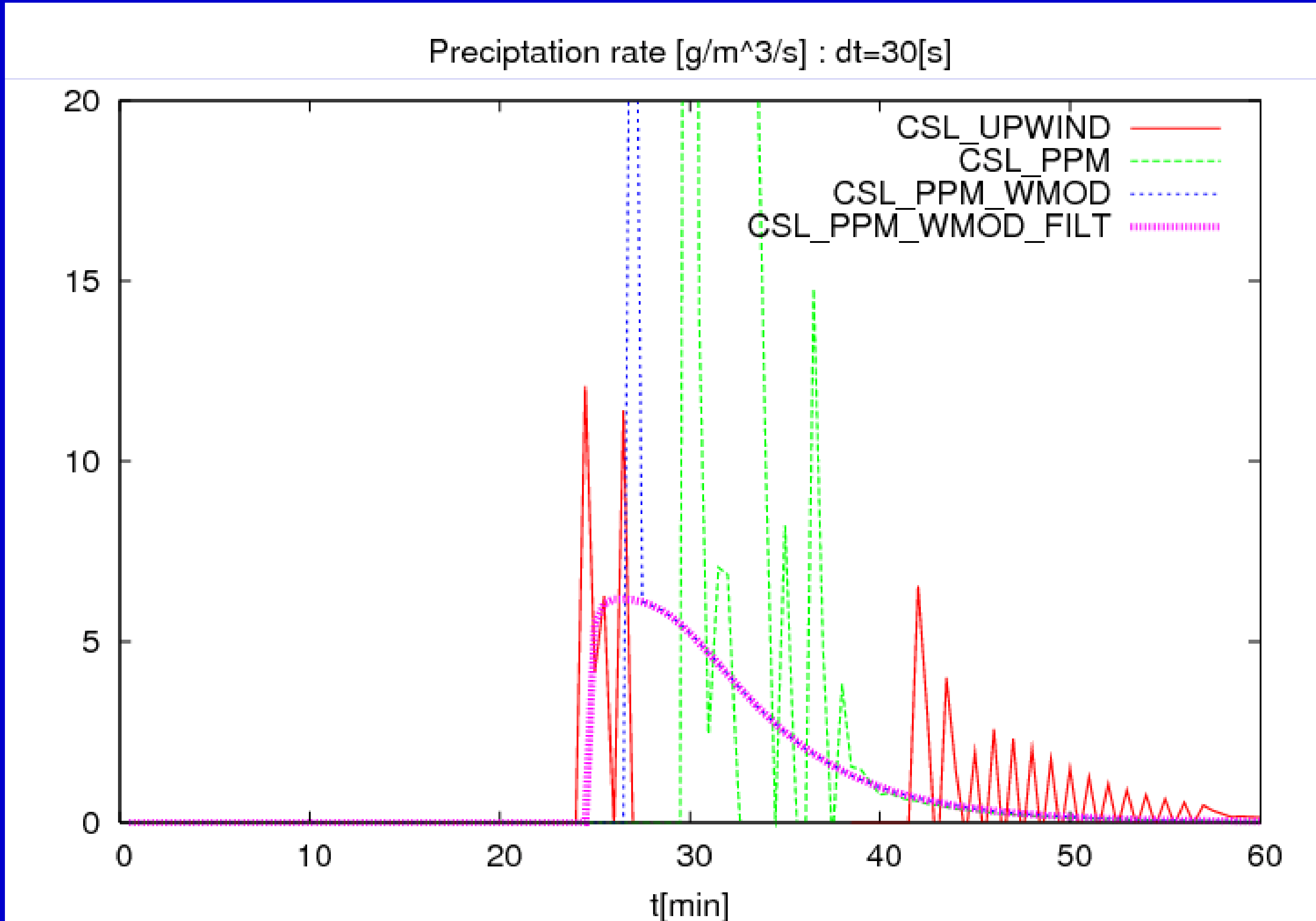
Reference sol
Green : ppm
Red : upwind



Test with dt=30[sec]

- **PPM with w-smoother and filtering :**
  - ◆ **robust result!**

  --- while the others schemes (even upwind) have no physical results.

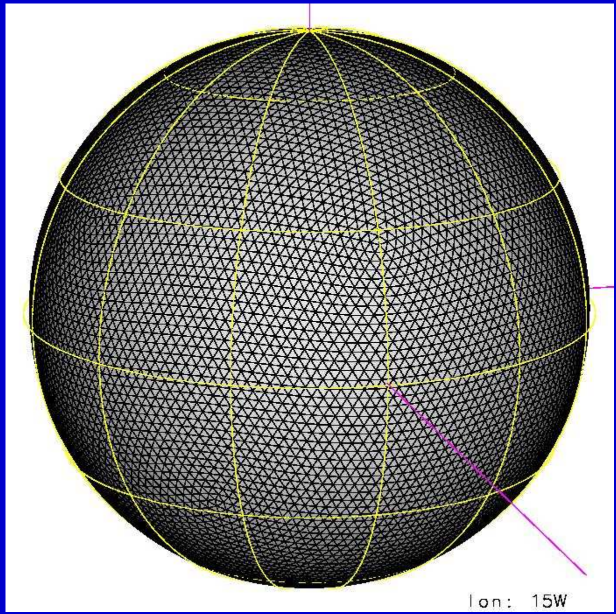


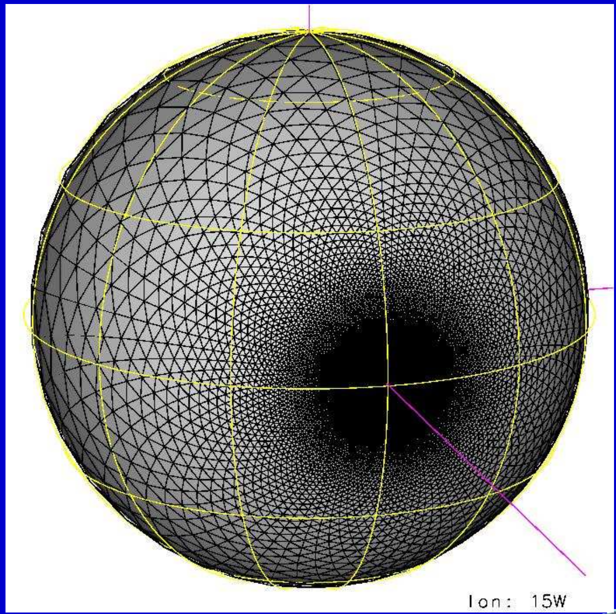
What impact to cloud system?

Squall line simulation:

- Based on GCSS WG4 Case1
- The mode used:
  - Stretched-NICAM
    - Schmidt transfromation
- Micophysics :
  - NSW6(Tomita 2008)
- No turbulence & radiation
- integration time : 8 hours
- time step : dt=20[s]

- Two experiments:
  - UPWIND
  - PPM with w-smoother & filtering

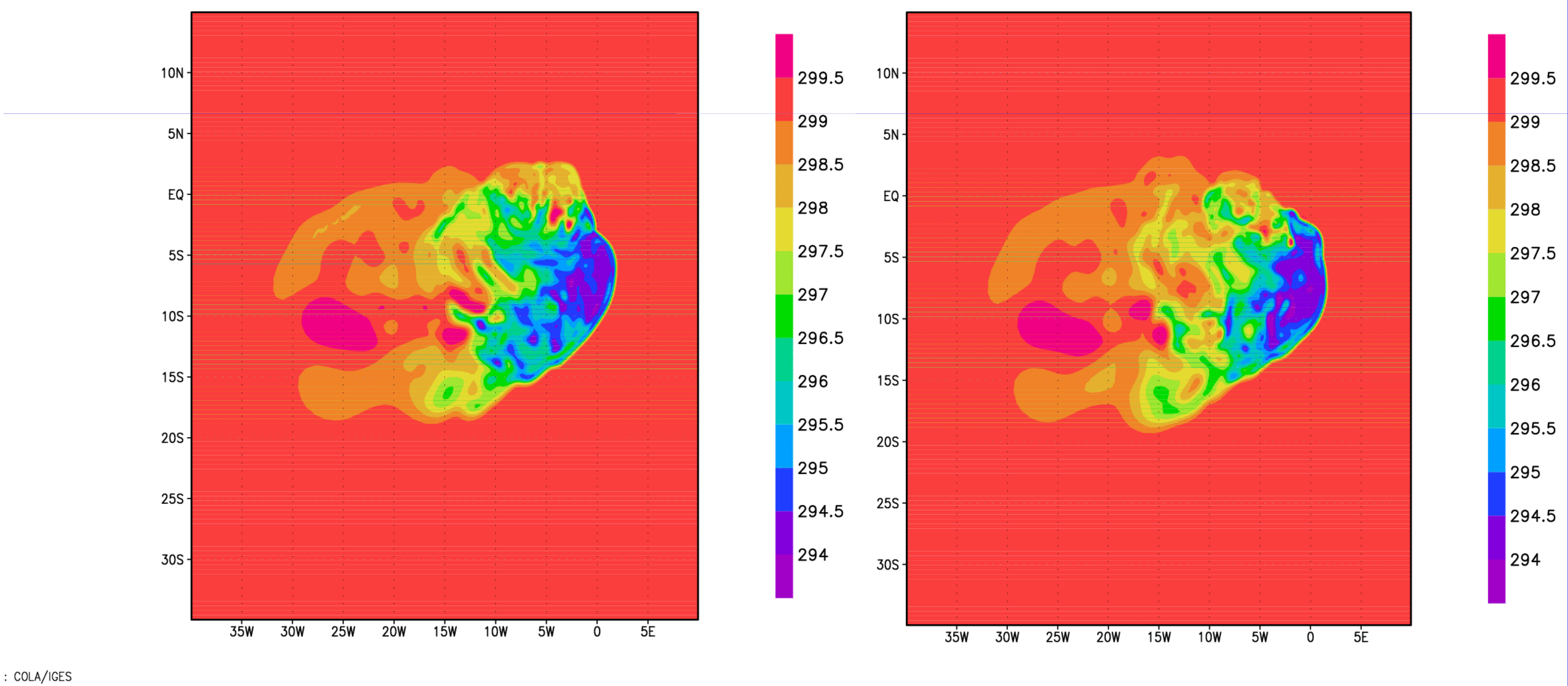




Cold pool at t=8[hour]

Temperature at z=100m

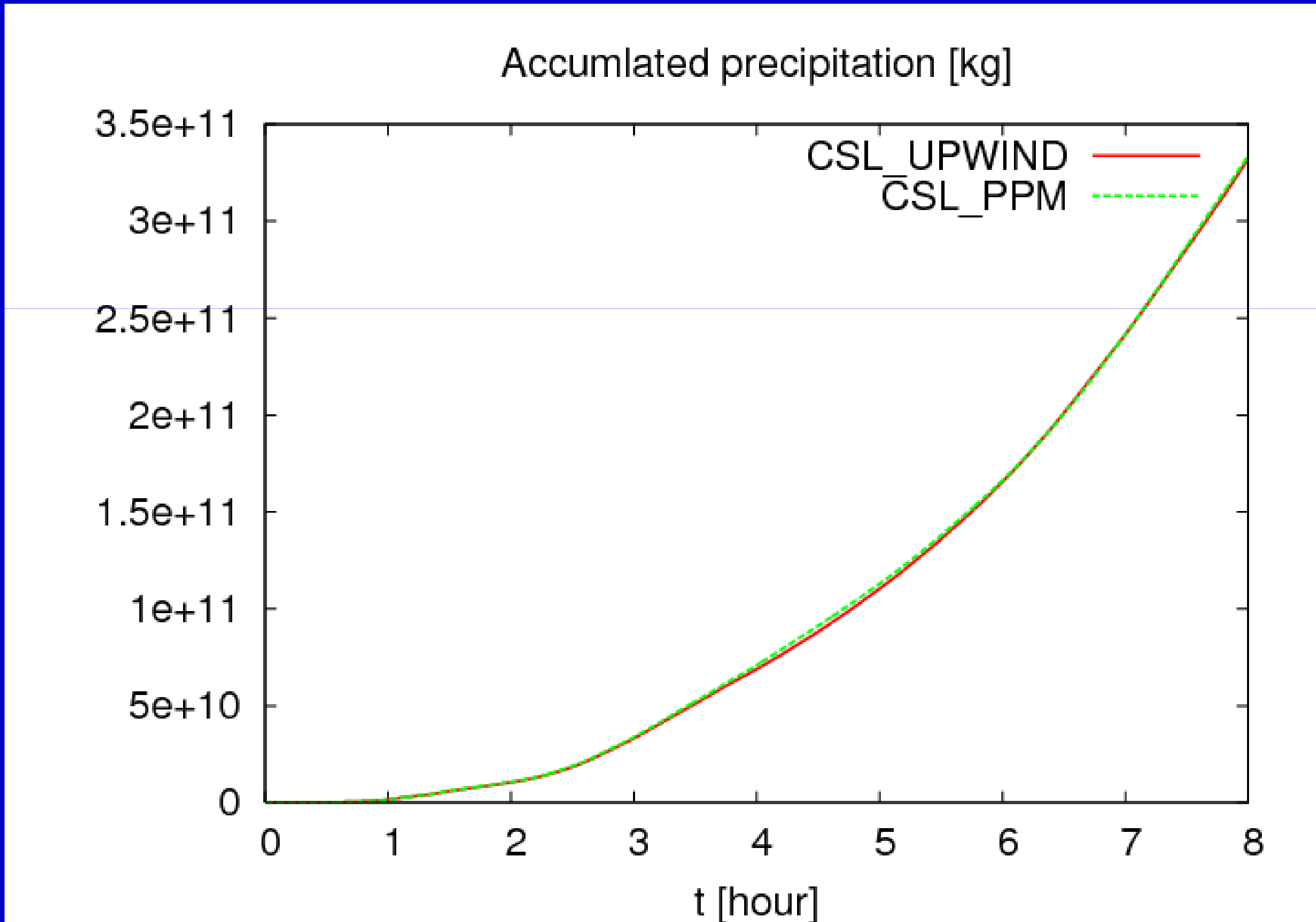
- **UPWIND**
- **PPM**



It seems that both of them are similar.

No difference!?

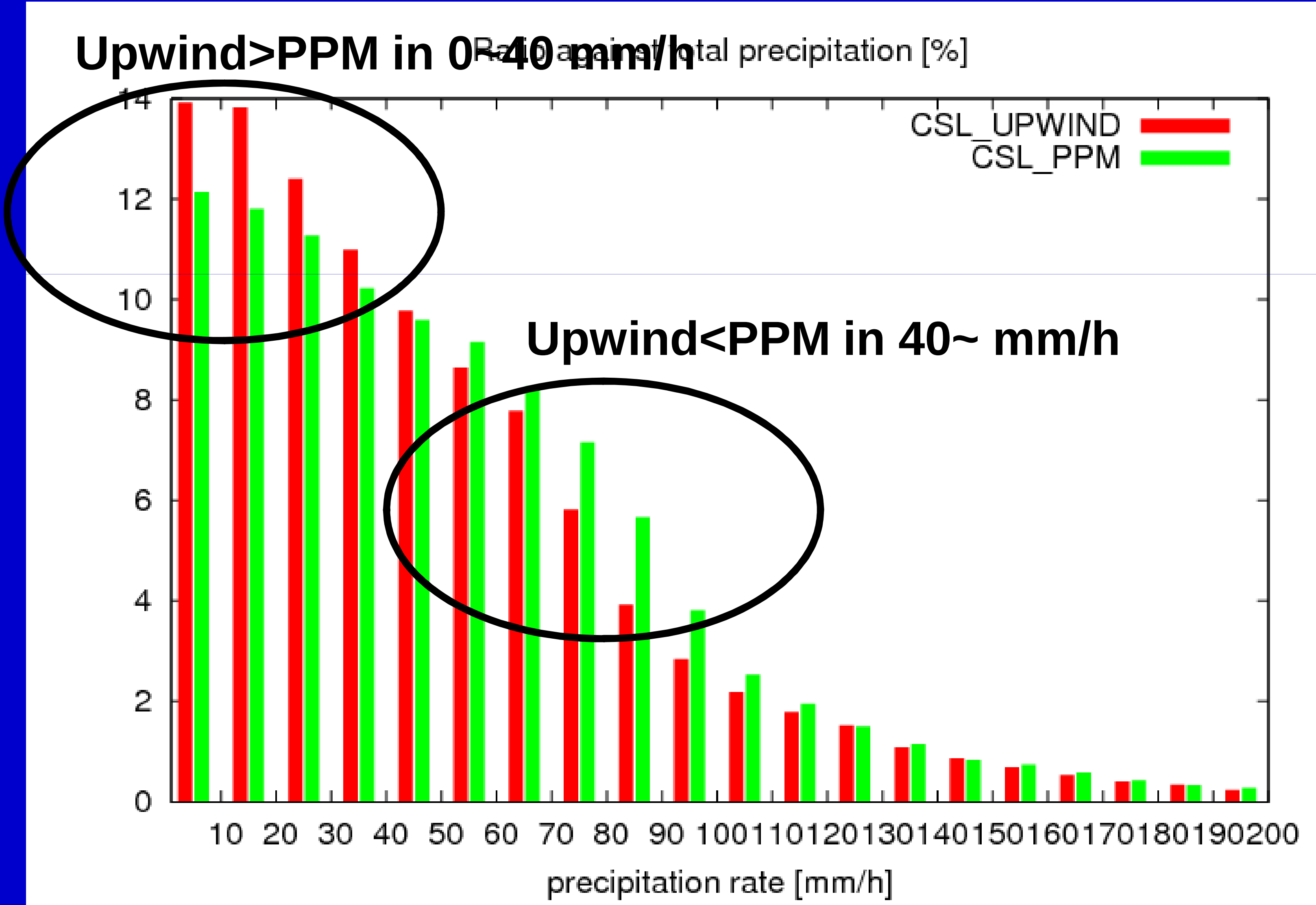
Accumulated precipitation during 8 hours



Almost no difference in the accumulated precipitation

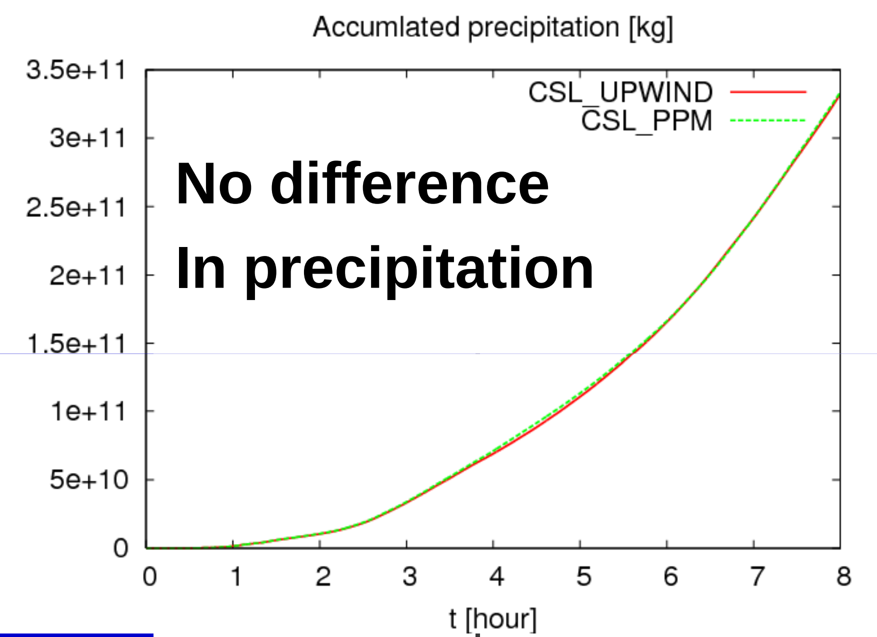
How about the precipitation intensity?

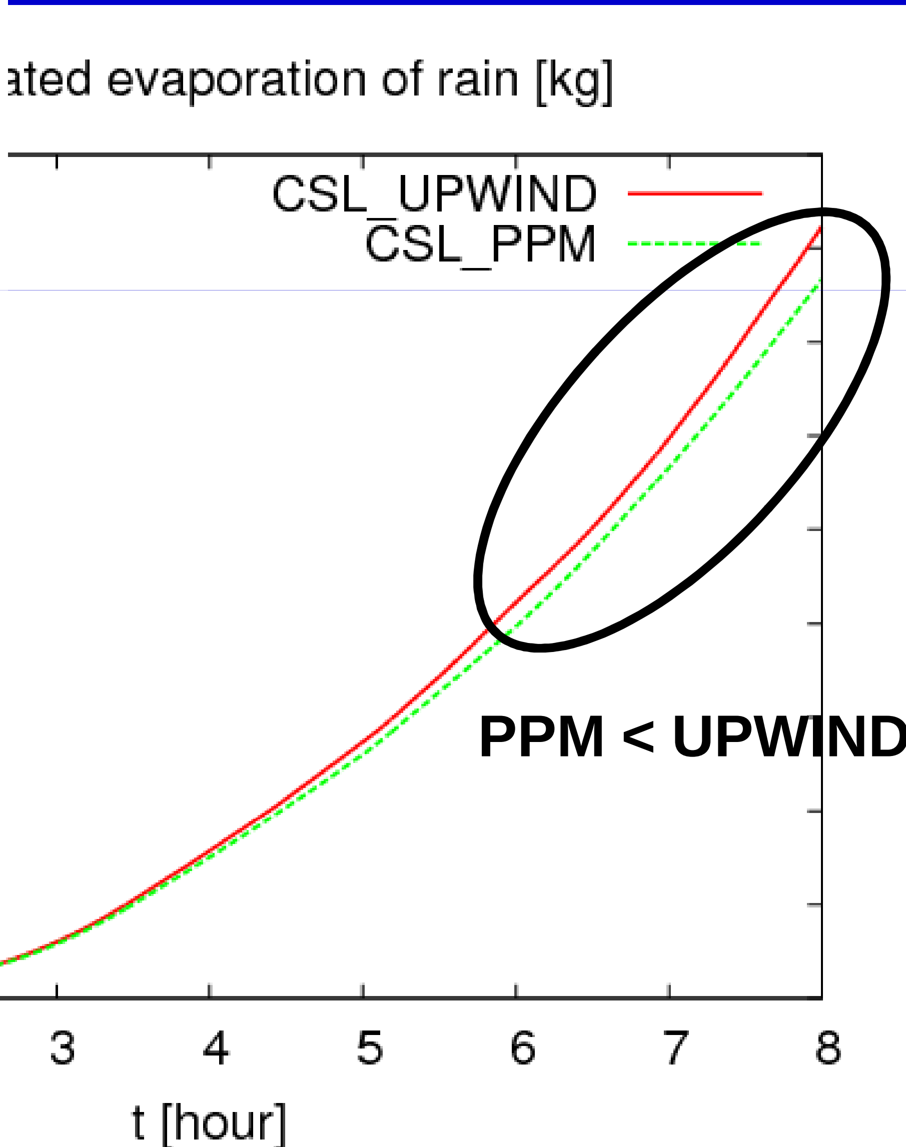
Ratio for total precipitation against precip. rate



Although the total precipitation does not so differ between two, PPM intends to lead the stronger precipitation.

Accumulated evaporation [kg]

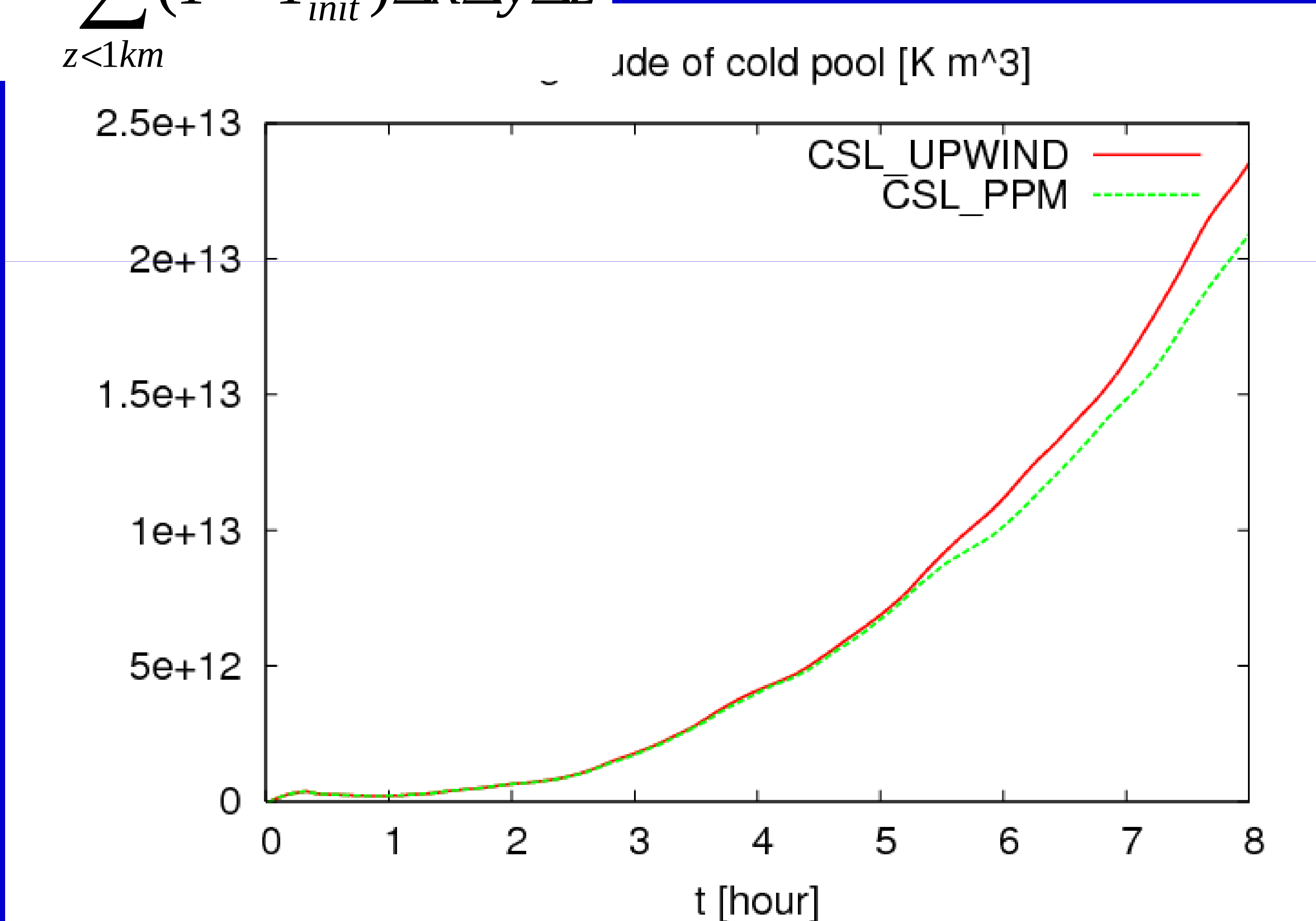




Upwind scheme intends to lead the larger evaporation.

Matunitude of cold pool

$$Mag = -\sum_{z<1km}(T - T_{init})\Delta x \Delta y \Delta z$$



The cold pool evolution in the PPM is slightly late for UPWIND
Mainly due to smaller evaporation in PPM.

Discussion

WHY DOES THE PPM SCHEME CAUSE SMALLER EVAPORATION?

- How does the evaporation rate change against rho*qr
  - From Marshall-Palmer distribution

$$\lambda = \left[\frac{\pi \rho_w N_0}{\rho q_r} \right]^{1/4} = \alpha (\rho q_r)^{1/4}$$

  - Terminal velocity

$$V_T = c \left(\frac{\rho_0}{\rho} \right)^{1/2} \frac{\Gamma(4+d)}{6} \frac{1}{\lambda^d} = \beta (\rho q_r)^{d/4}$$

  - evaporation rate

$$Pevp = F_1 \frac{1}{\lambda^2} + F_2 \frac{1}{\lambda^{(5+d)/2}} = F_1^* (\rho q_r)^{1/2} + F_2^* (\rho q_r)^{(5+d)/8}$$

Evaporation rate monotonically increases with rho*qr

PPM scheme causes to larger evaporation than UPWIND scheme?!

Contradiction???

Discussion(2)

The time during evaporation must be considered!

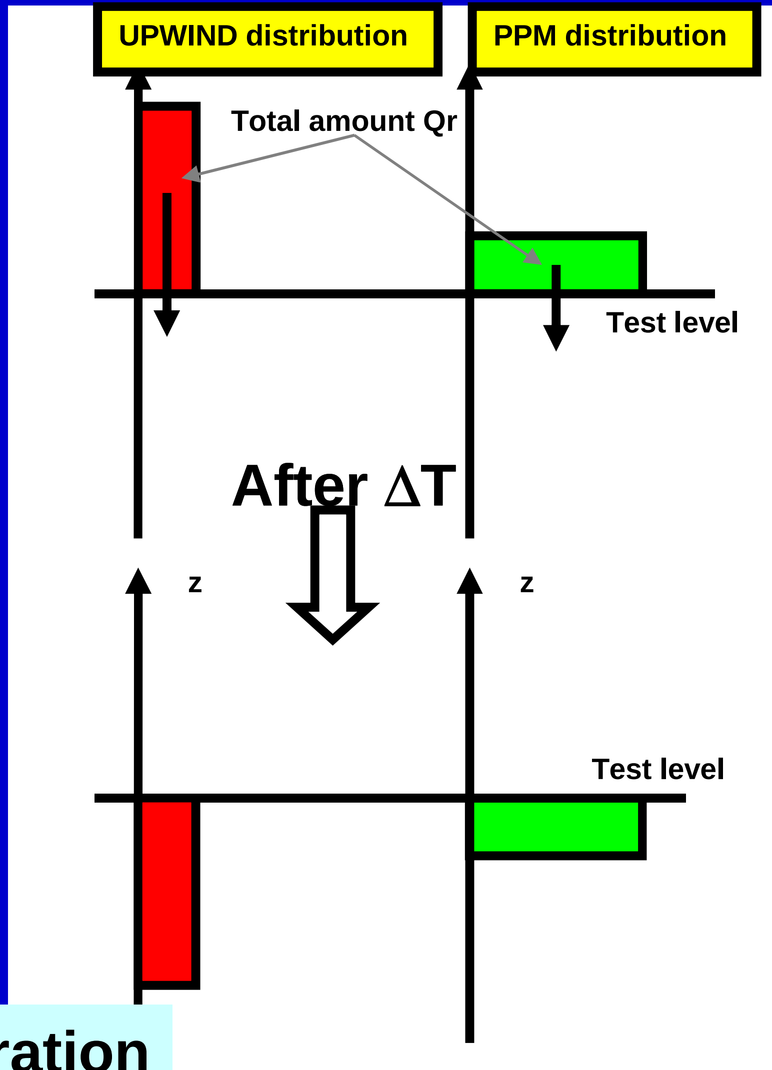
- **Ideal case**
  - **Total amount of rain : Qr**
    ρqr distribution : step
  - **Surrounding eviroment : fixed**
- **The time passing through an test level**

$$\Delta l = \frac{Q_r}{\rho q_r} \qquad \Delta T = \frac{\Delta l}{V_T} = \frac{Q_r}{\beta}(\rho q_r)^{-1-d/4}$$

- **Total evaporation rate during ΔT**

$$EVP_{total} = \Delta T \cdot Pevp = F_1^* \frac{Q_r}{\beta}(\rho q_r)^{(-2-d)/4} + F_2^* \frac{Q_r}{\beta}(\rho q_r)^{(-3-d)/8}$$

If the total amounts of rain are same,
Total evaporation decreases with ρqr



UPWIND scheme causes to larger evaporation than PPM scheme!

Summary

- Conservative remapping scheme based on PPM is applied to rainfall sedimentation scheme.
  - W smoother (Xiao et al.2003) is useful for large time step.
  - In addition, a numerical filter based on the gradient is very effective for numerical stability.
  - Comparing with SL-UPWIND scheme, the PPM based scheme has non-diffusive profile in the lower vertical levels.
- We have investigated the impact of rainfall sedimentation scheme on the cloud organized system (cold pool dynamics).
  - The precipitation rate:
    - PPM scheme intends to lead to the strong precipitation.
  - The cold pool intensity:
    - PPM scheme intends to delay the cold pool evolution due to slightly smaller evaporation amount than UPWIND scheme.

    → It suggests that the low order scheme has bias for precipitation rate and evolution of cloud system
- For precise prediction, the higher order scheme for rainfall sedimentation would be better.