WSM5 微物理方案於CWB-GFS的評估

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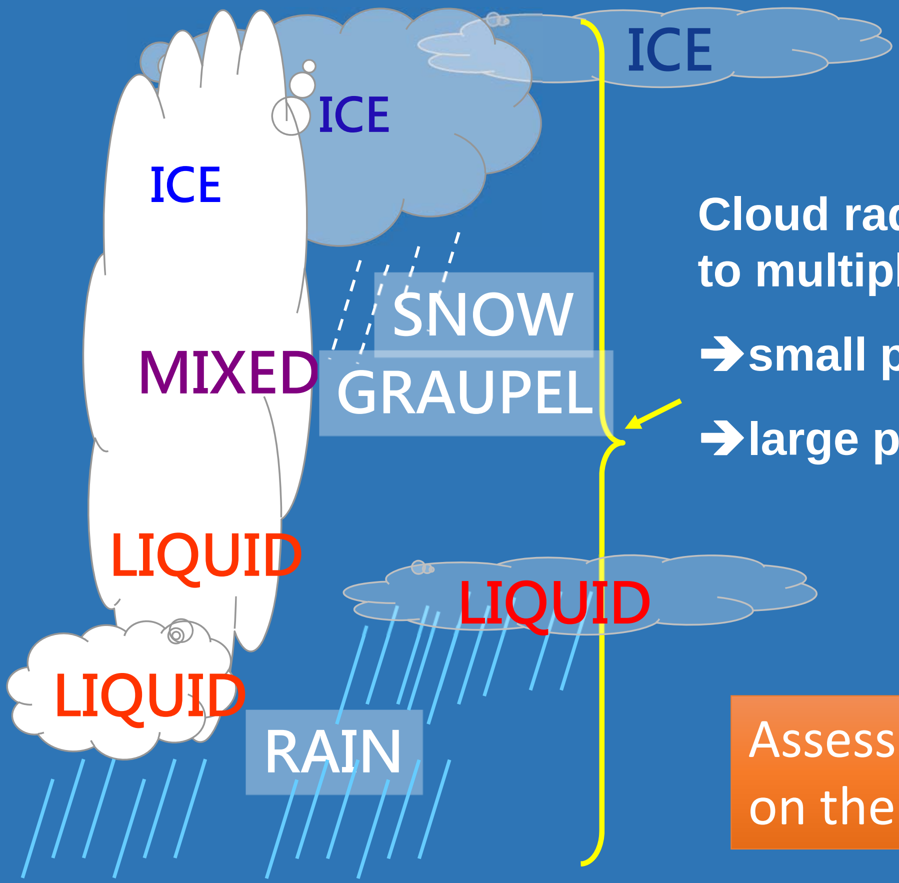
中央氣象局

- **Motivation**
- **Description of the schemes**
- **Result**

motivation



Cloud radiation effect are sensitive to multiple particle types:

➔small particle: cloud ice, liquid

➔large particle: rain, snow, graupel

Assessment of the WSM5 MPS on the cloud radiation process

From Jui-Lin Li

CWB-GFS網格尺度降水方案

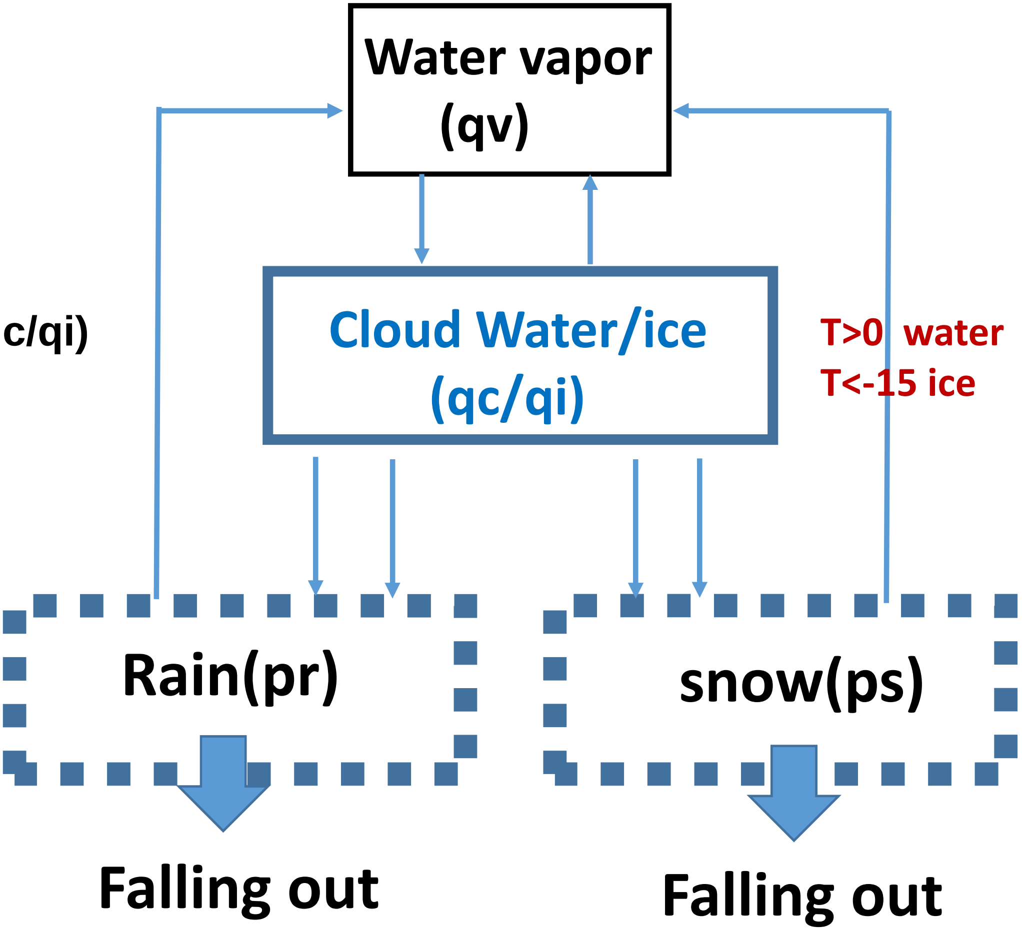
Explicit prognostic cloud scheme (Zhao and Carr, 1997, ZC97)

Major features

1. **Cloud water and cloud ice are prognostically calculated with one predictive variable(qc/qi)**

2. **Precipitation diagnosed from cloud mixing ratio(qc/qi) and falling to next level immediately.**

- 大氣中產生雲滴或是雲冰, 由溫度決定。
- 大氣中不會有雨滴或雪的停留。



Water vapor (qv)

Cloud Water/ice (qc/qi)

T>0 water

T<-15 ice

Rain(pr)

snow(ps)

Falling out

Falling out

Wsm5 微物理方案 (Hong et al 2004)

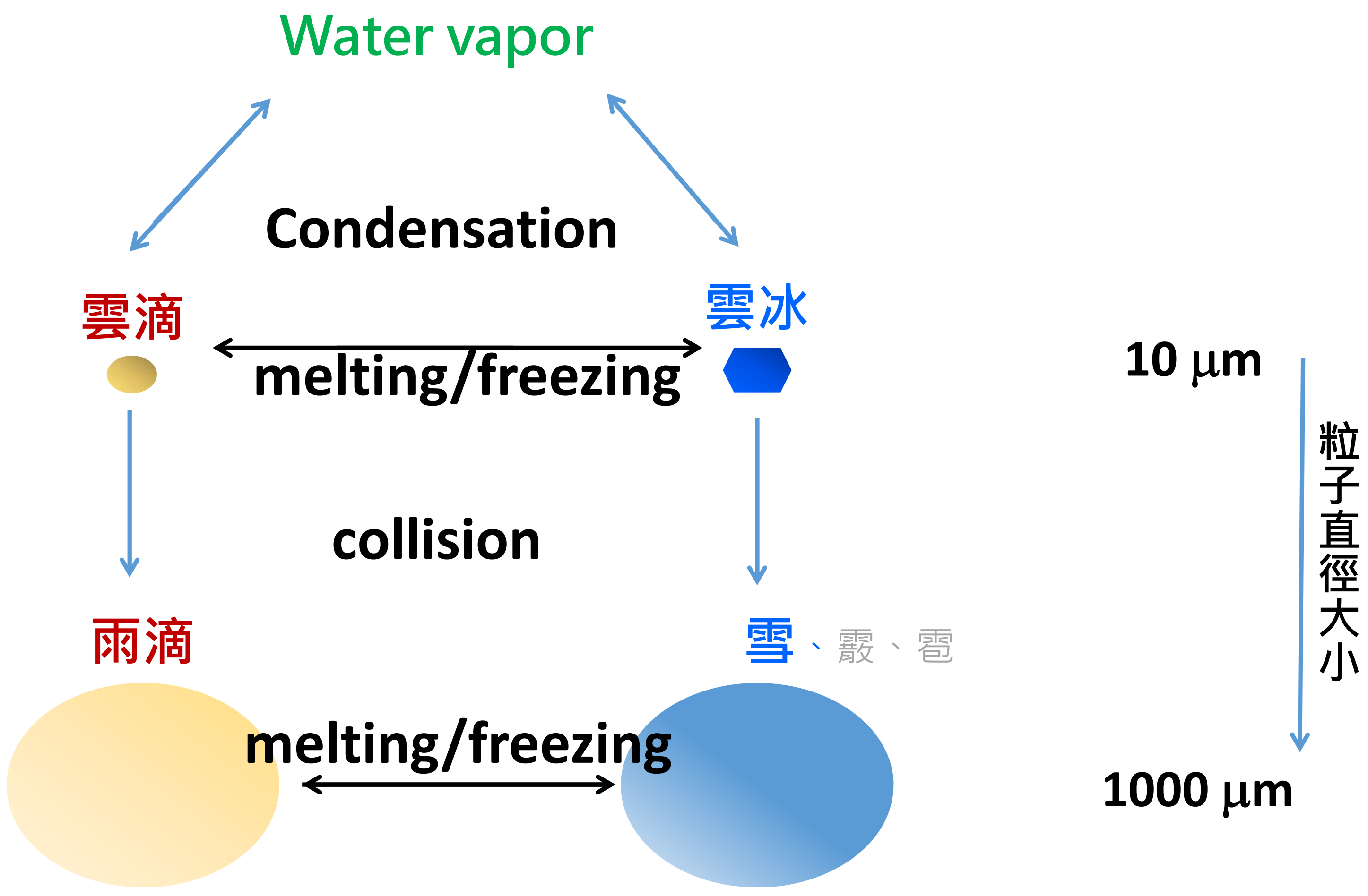
- 總體水物參數法(Bulk method)

  假設水物粒子的粒徑-個數濃度分佈，為一連續函數

  - 單矩量(single moment)

    預報量--水物粒子的質量混和比

WSM5 考慮的雲與降水粒子



Water vapor

Condensation

雲滴

雲冰

melting/freezing

collision

雨滴

雪、霰、雹

melting/freezing

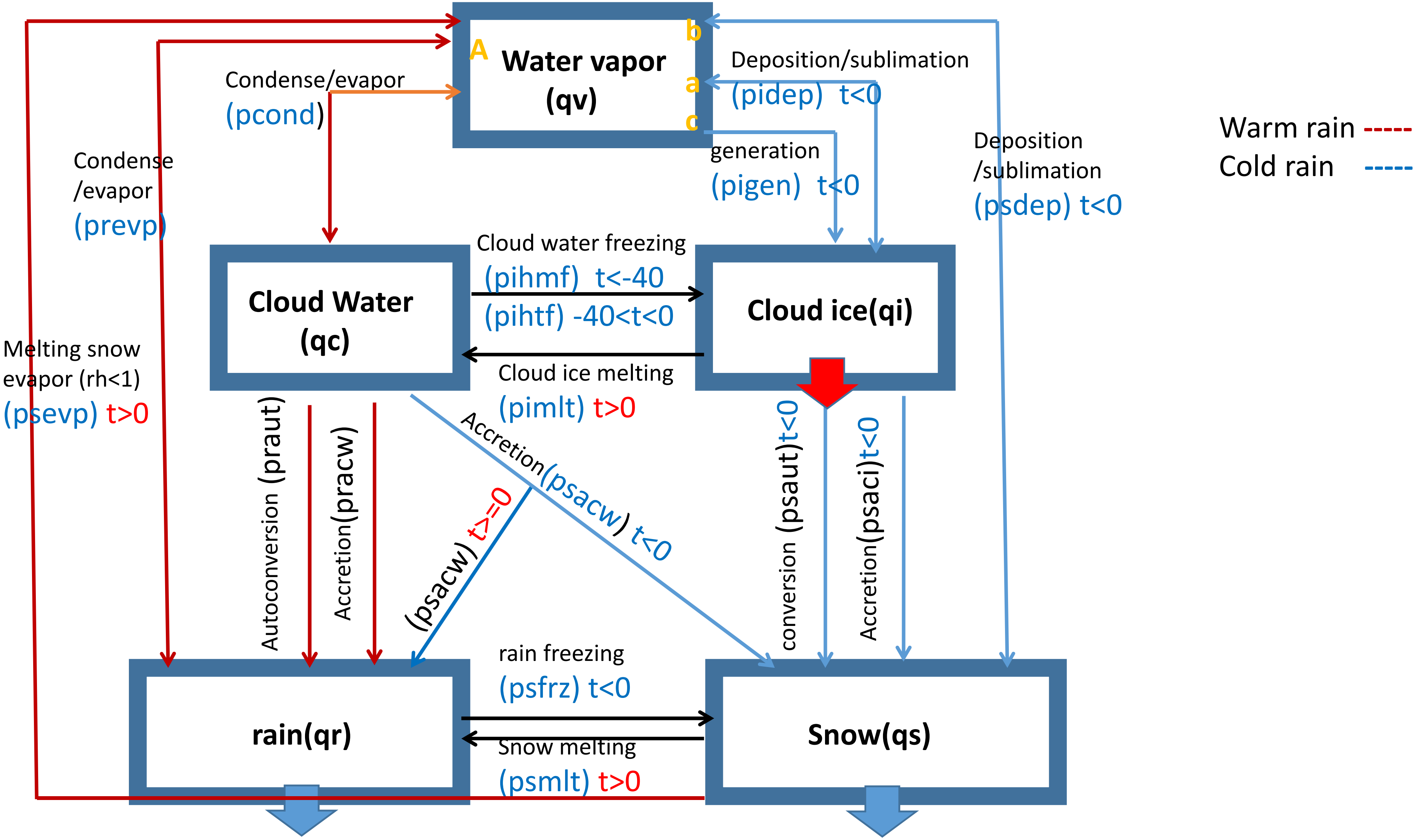
10 μm

粒子直徑大小

1000 μm

WSM5 microphysical process diagram

(ref to Lin et al 1983)



Warm rain -----

Cold rain -----

Water vapor (qv)

A

b

a

c

Condense/evapor (pcond)

Condense /evapor (prevp)

Melting snow evapor (rh<1) (psevp) t>0

Deposition/sublimation (pidep) t<0

generation (pigen) t<0

Deposition /sublimation (psdep) t<0

Cloud Water (qc)

Cloud ice(qi)

Cloud water freezing (pihmf) t<-40 (pihtf) -40<t<0

Cloud ice melting (pimlt) t>0

Autoconversion (praut)

Accretion(pracw)

(psacw) t>=0

Accretion(psacw) t<0

conversion (psaut)t<0

Accretion(psaci)t<0

rain(qr)

Snow(qs)

rain freezing (psfrz) t<0

Snow melting (psmlt) t>0

CWBGFS 模式簡介

Model : CWB-GFS T511L60

- **Horizontal : ~ 25 km , vertical : 60 layers**

- **Physics :**

Radiation	RRTMG scheme
Cumulus	New Simplified Arakawa-Schubert (Pan and Wu , 1994)
Large Scale Precipitation	Predict could water scheme (Zhao and Carr 1997)
Shallow Convection	Li and Young (1993)
PBL	First-order nonlocal scheme (Troen and Mahrt 1986)
Surface Flux	Similarity theory (Businger 1971)
Land Model	Noah Land model(4-layer)
Gravity Wave Drag	Palmer et al. (1986)

- Experiment design

  - ops : CWB GFS with ZC97 scheme
  - wsm5 : CWB GFS with wsm5 scheme

  Case study
  - Initial 00 UTC 01 Jan, 2013

  Full cycle run
  - 6-hr cyclic frequency
  - 01-14 Jan, 2013
  - Evaluation for 5-day prediction at 00/12 UTC run

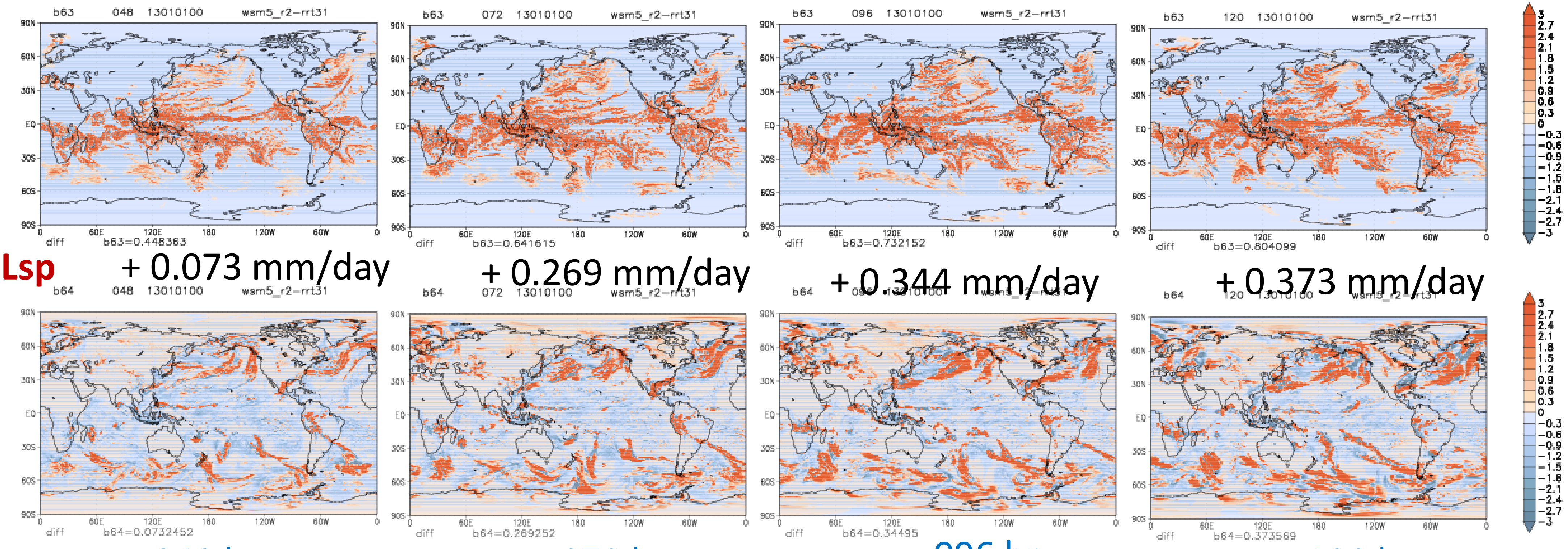
- Verification truth

  Era-Interim(0.75°x0.75°)

- **問題:** 降水增加，且差值隨預報時間變大

Precipitation difference(wsm5-ops)

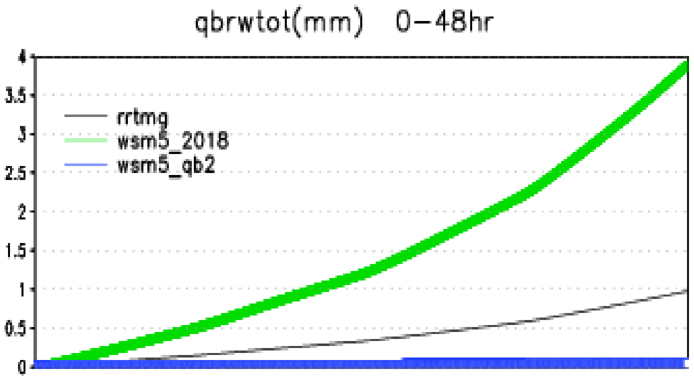
Cup + 0.448 mm/day + 0.641 mm/day + 0.732 mm/day + 0.804 mm/day



Lsp + 0.073 mm/day + 0.269 mm/day + 0.344 mm/day + 0.373 mm/day

048 hr 072 hr 096 hr 120 hr

Q borrow 累積量



Ops ----------
Wsm5 ---------
Wsm5_qb -----

Q(Ops) : qv+qi/qc

Q(Wsm5) : qv+qi+qc+qs+qr

修改 Negative q 處理策略(qb)

ops: 1. 向下層借
2. 最底層若有負值則無條件轉為正值

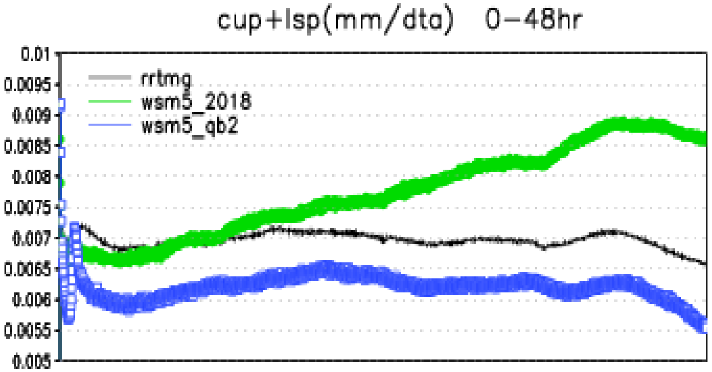
總水量不保守!!

修改: 1. 負值轉正，並將借量累計(qb)
2. 將正值點總和累加(qp)
3. 將正值點等比例降低，以維持總量保守。
(q*(qp-qb)/qp)

Impact of
Negative q adjust policy

- 降水率維持平穩
- 水物粒子混和比降低

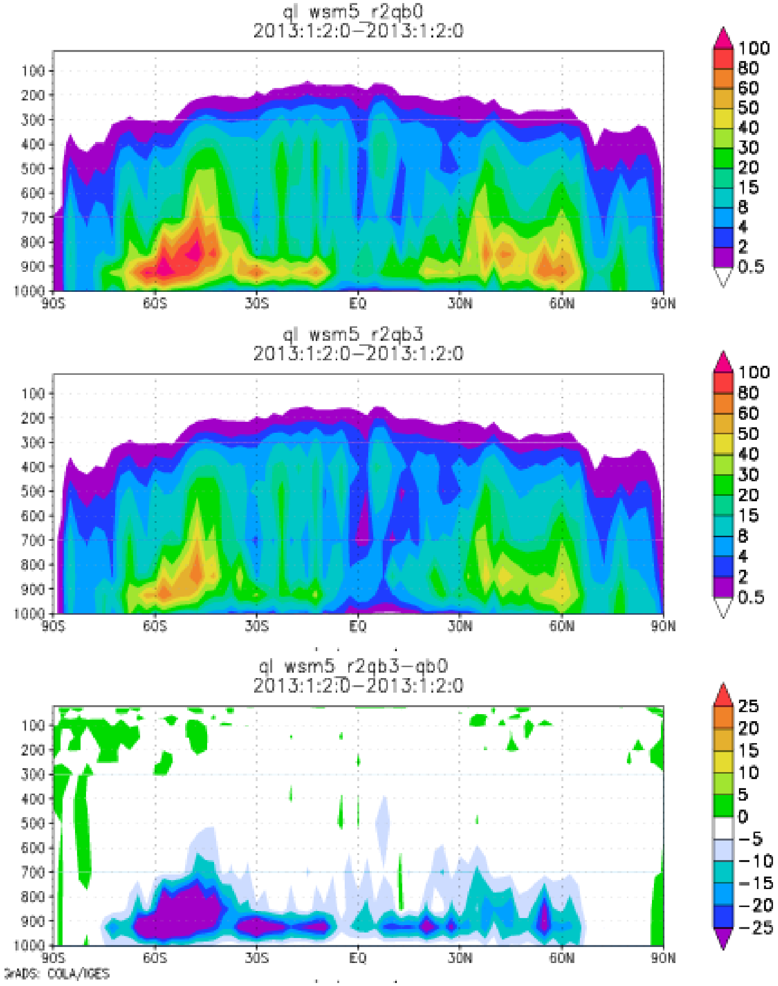
Precip(mm/dta)



WSM5

WSM5_qb

Total ql (24h fcst)
zonal mean , y-z profile



WSM5
(qc+qi+qr+qs)

WSM5_qb
(qc+qi+qr+qs)

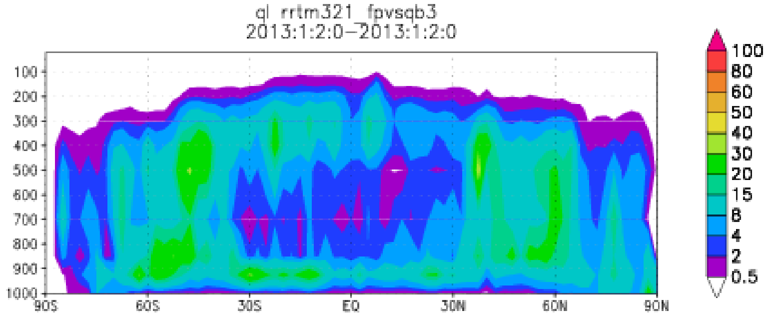
WSM5_qb
- wsm5

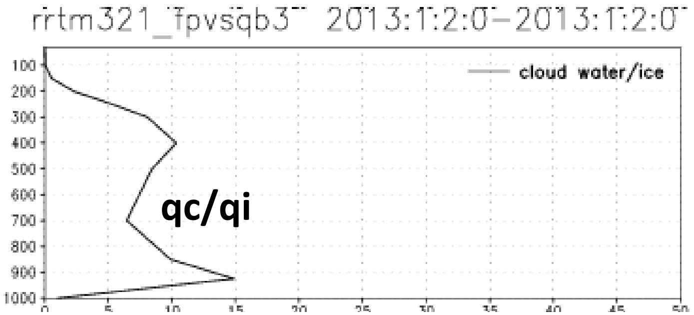
Total ql (mg/kg) 24h fcst

zonal mean , y-z profile

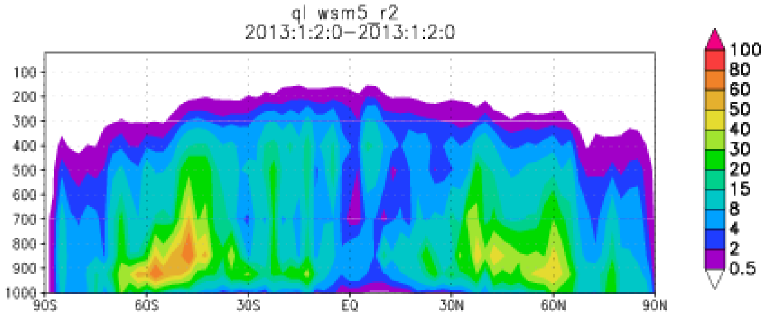
global mean , z profile

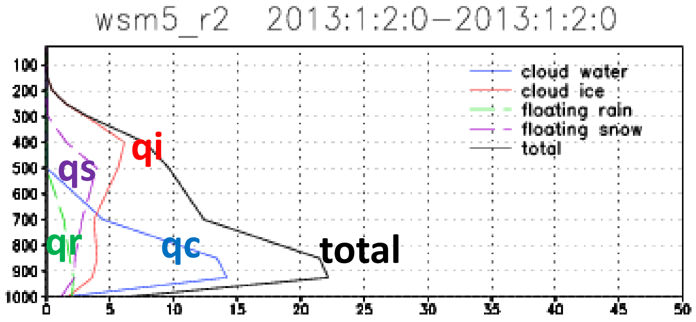
ops
(qc/qi)



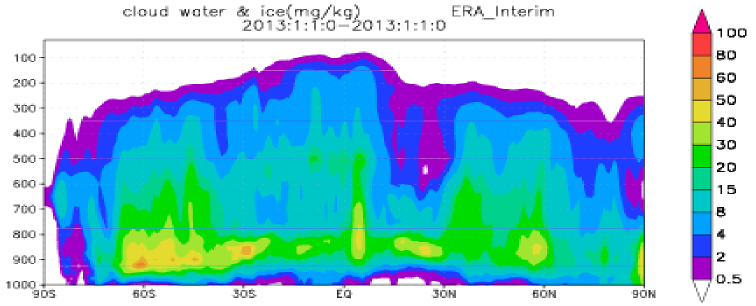


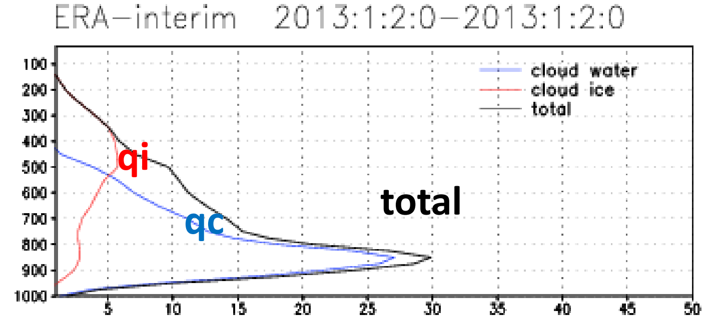
WSM5_qb
(qc+qi+qr+qs)



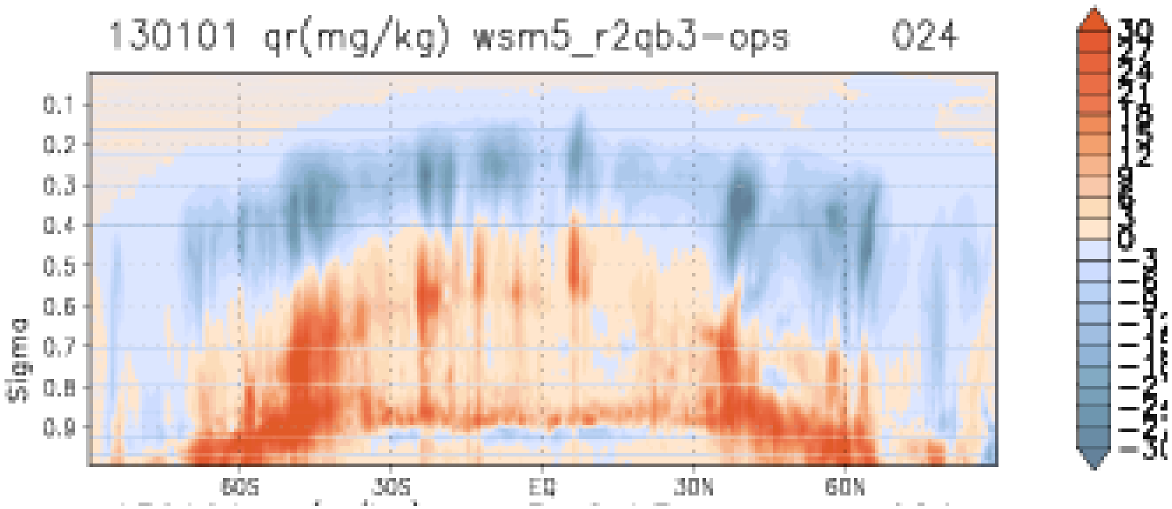


ERA_interim
(qc+qi)





Total ql(mg/kg) **Wsm5 - ops**



Wsm5 impact on ql

ql=qc+qi+qs+qr

- **ql** 高層減少， 中低層增加

Wsm5 impact on cloud

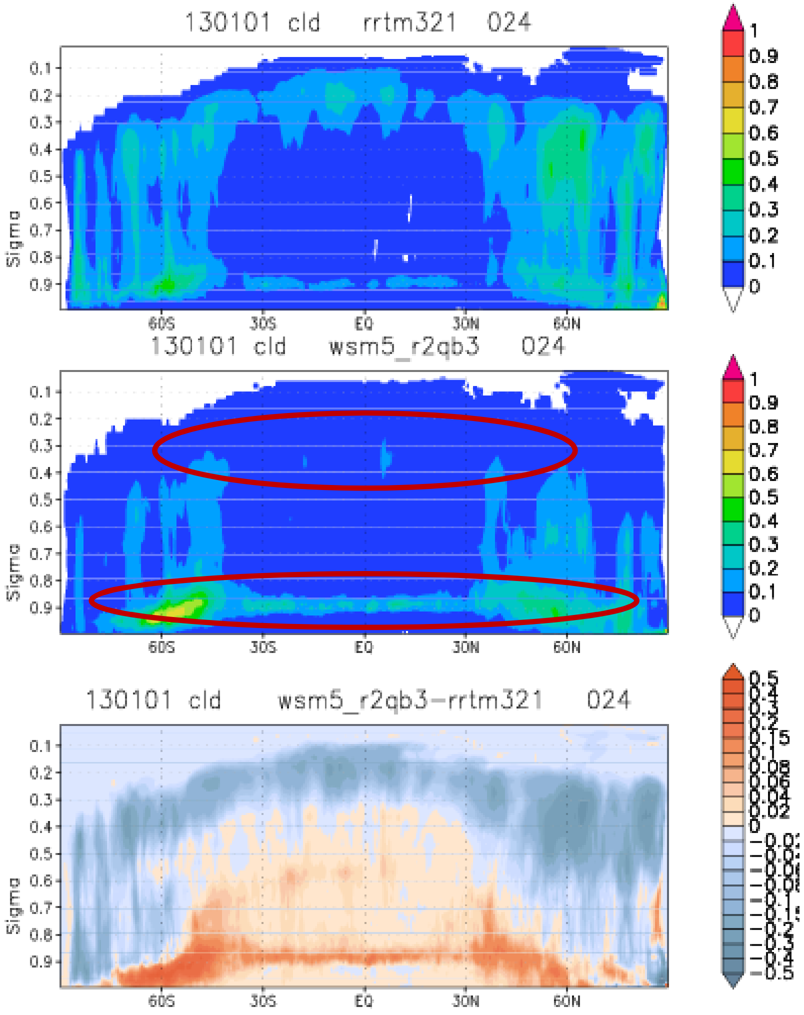
- 高層雲量減少
- 低層雲量增加

Cloud fraction

ops

Wsm5_qb

Wsm5_qb-ops



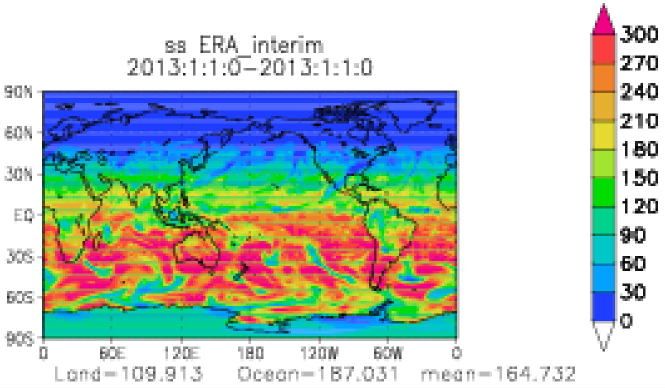
Cloud fraction

$$c = rh^{1/4}\left(1 - exp\left(\frac{-100ql}{\left((1-rh)qs\right)^{0.49}}\right)\right)$$

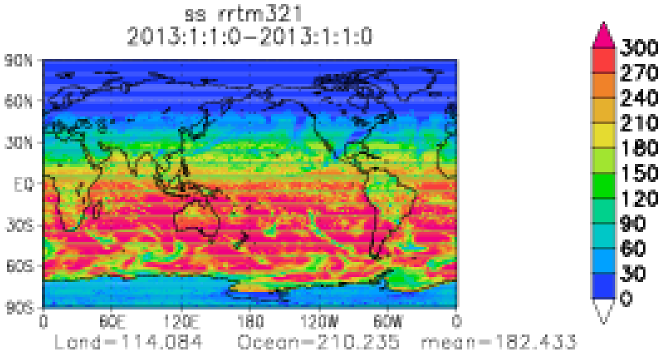
$ql=qi+qc+rs+qr$ (Xu and Randall 1996)

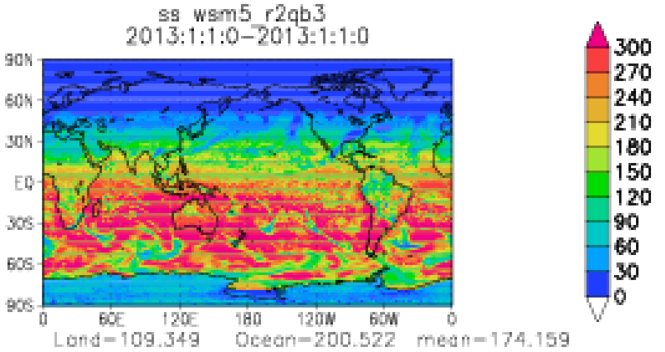
Surface net solar rad (W/m2)
2013/1/1 day 1 fcst

Era_interim
164.7 W/m2



ops
182.4 W/m2

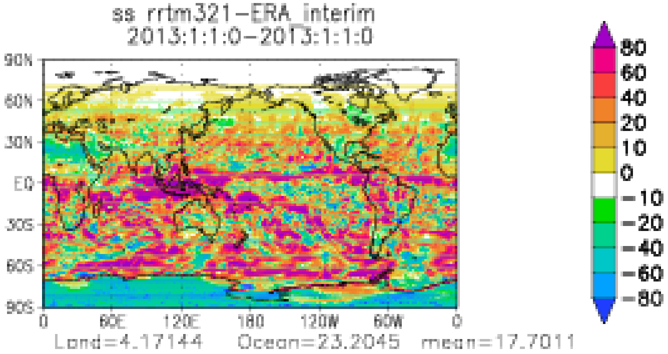


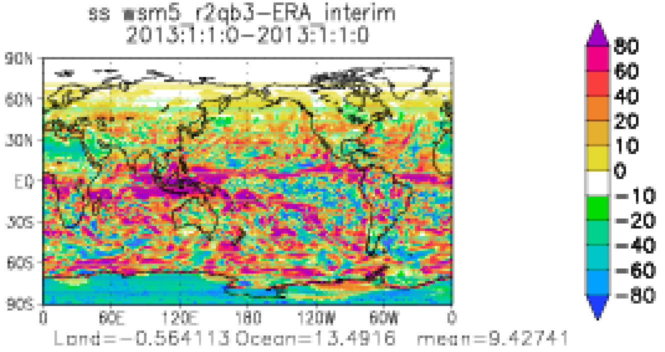


Wsm5_qb
174.1 W/m2

ops-Era
+17.7 W/m2

>> SS過大



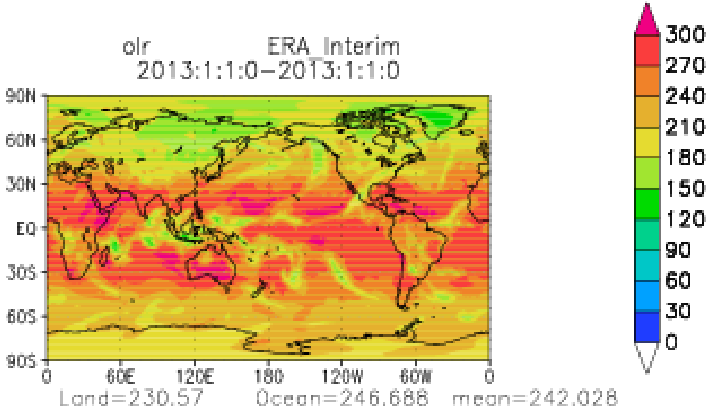


Wsm5_qb-Era
+9.4 W/m2
伴隨低層雲量增加,
SS 顯著減少

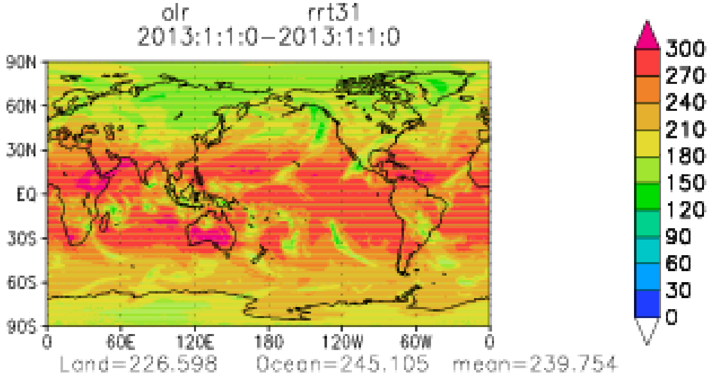
>> 較趨近ERA

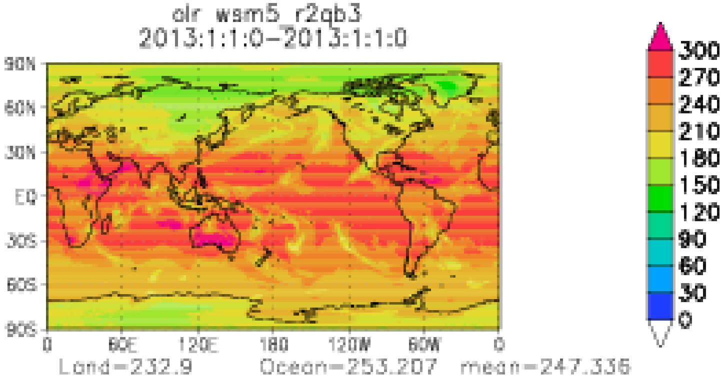
Outgoing Longwave Rad(W/m2)
2013/1/1 day 1 fcst

Era_interim
242.0 W/m2



ops
239.7 W/m2

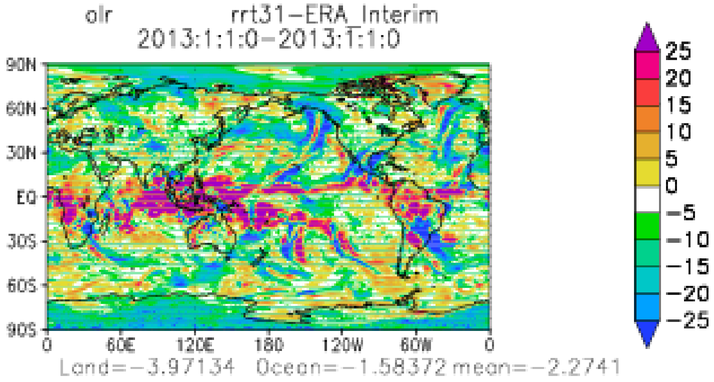


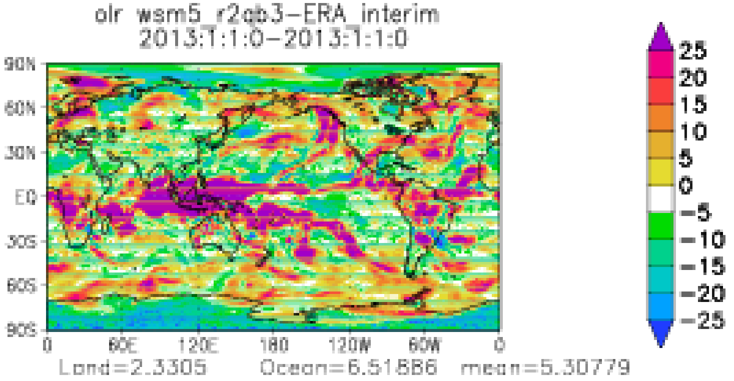


Wsm5_qb
247.3 W/m2

ops-Era
-2.27 W/m2

>> OLR 偏少





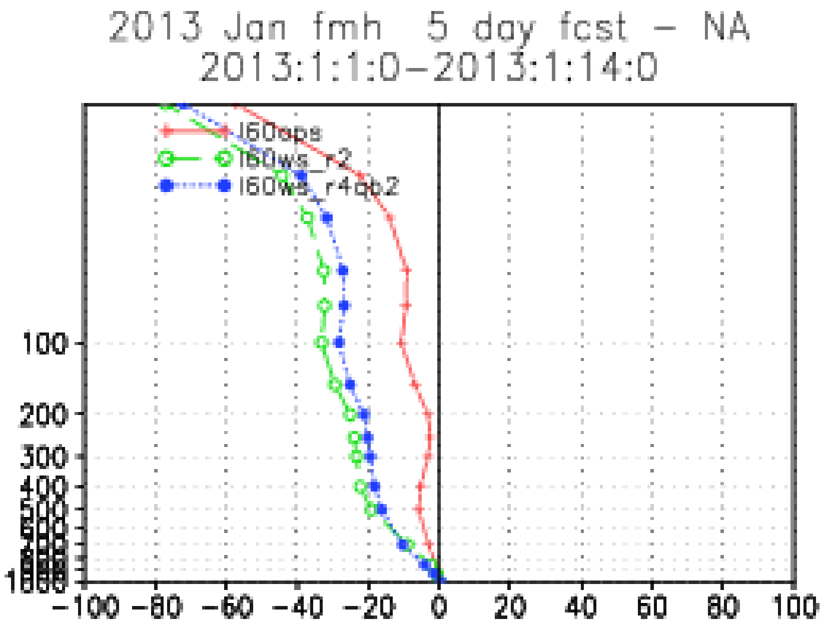
Wsm5_qb-Era
+5.3 W/m2
伴隨高層雲量減少
Olr大幅增加

>>有增加過多趨勢

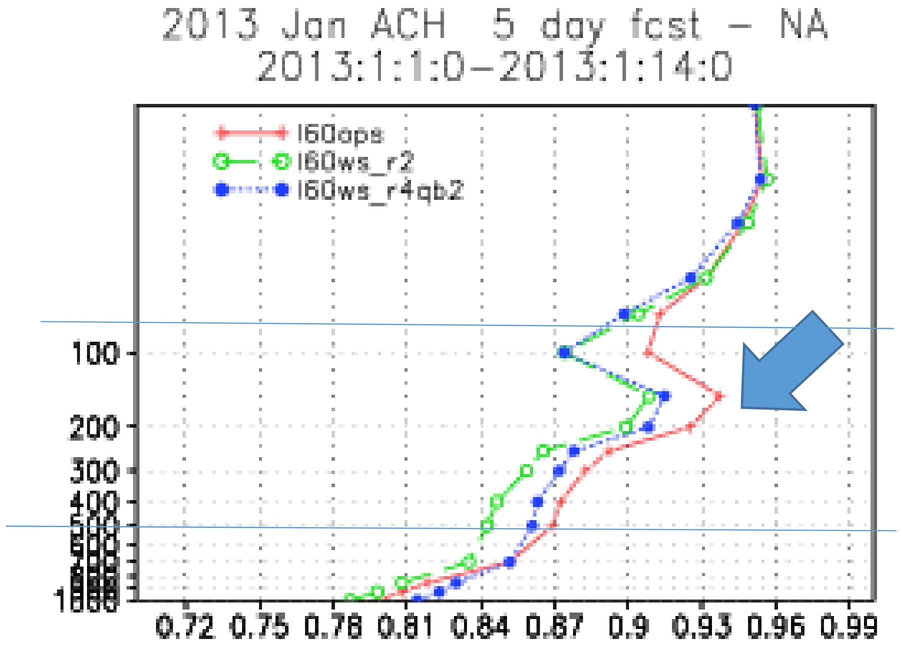
ops -------
wsm5 -------
wsm5_qb -------

T511L60
2013/01/01-14
day 5 FCST NA(20N-80N)

FMH 負偏差增加

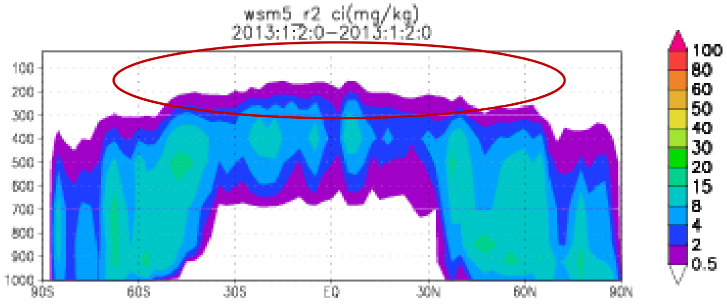


ACH 顯著降低

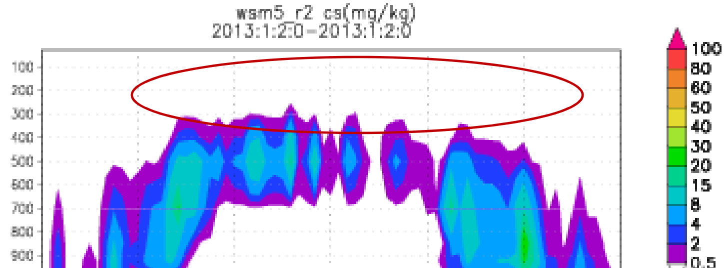


WSM5_qb
130101 24hr FCST

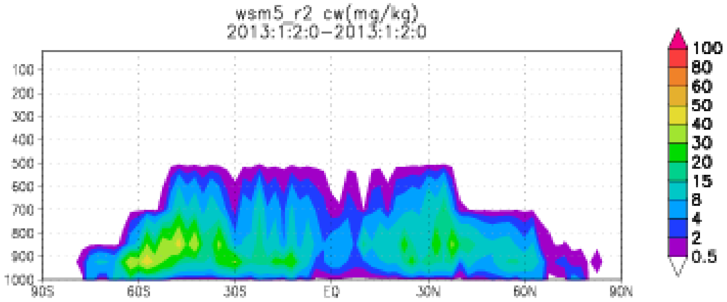
Qi(mg/kg)
Cloud ice



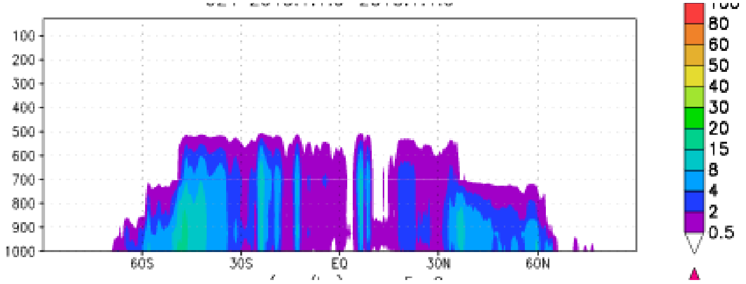
Qs(mg/kg)
snow

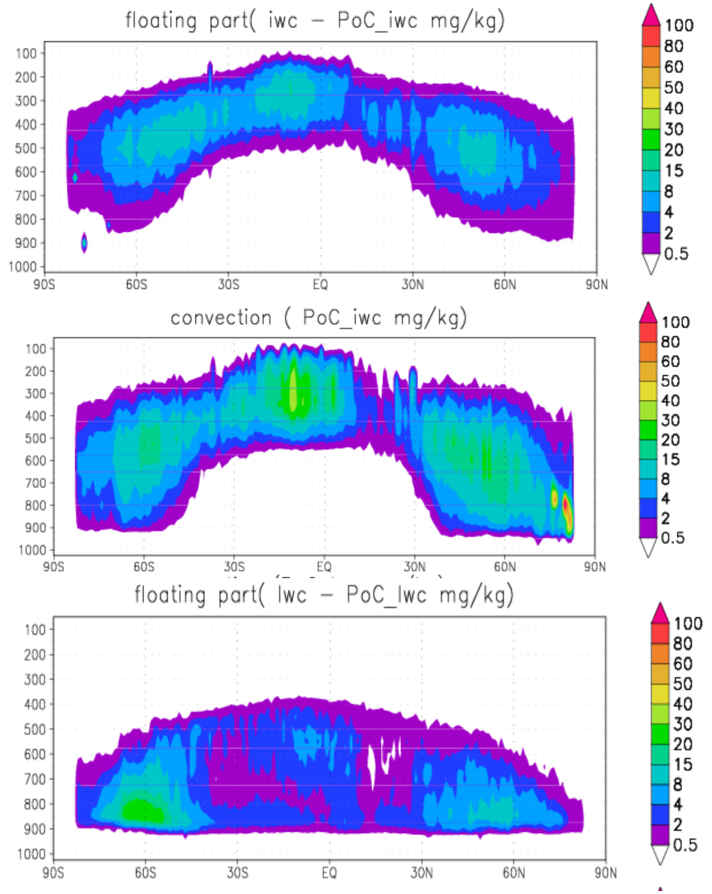


Qc(mg/kg)
Cloud water



Qr(mg/kg)
rain





CLDSAT DATA(Jan. 2013)

- 大氣中高層水物粒子偏少

調整測試:

- 高雲過少

➢ 減小雲冰的終端速度(增加雲冰於高層的停留)
Vice =0.01 m/s （wsm5_qbvi01)

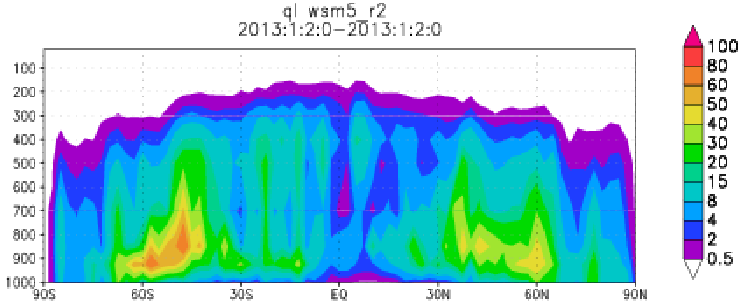
$V_t(ice)=3.29(\rho q_i)^{0.16}$ Original Wsm5 雲冰終端速度

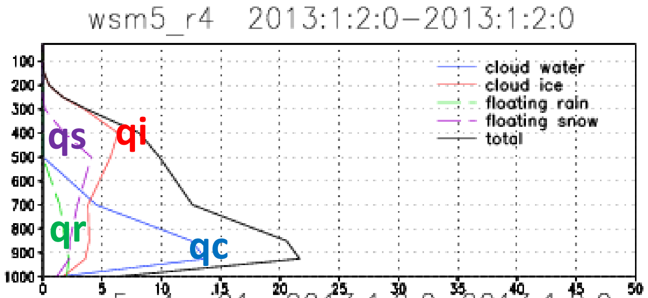
Wsm5_qbvi01 impact
On ql (mg/kg)

Total ql zonal mean , y-z profile

Total ql global mean , z profile

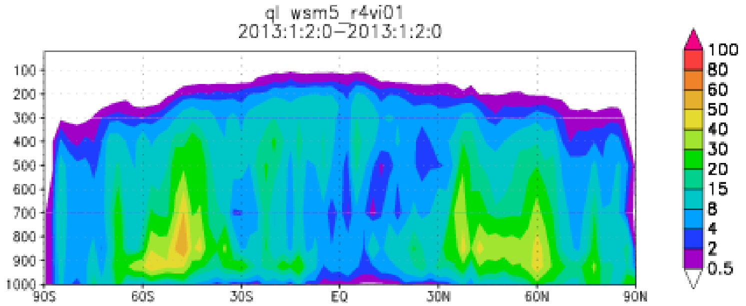
Wsm5_qb
qi+qc+qs+qr

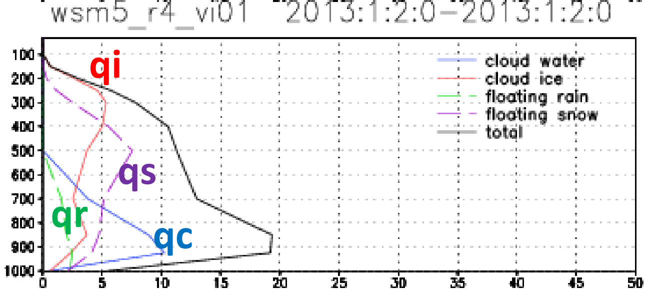




Wsm5_qb

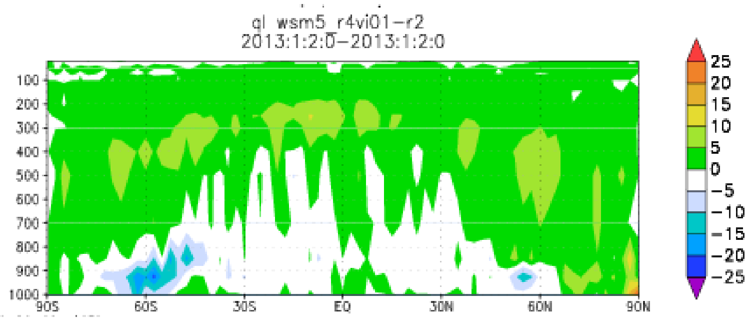
Wsm5_qbvi01
qi+qc+qs+qr





Wsm5_qbvi01

Diff
Wsm5_qbvi01
-wsm5_qb

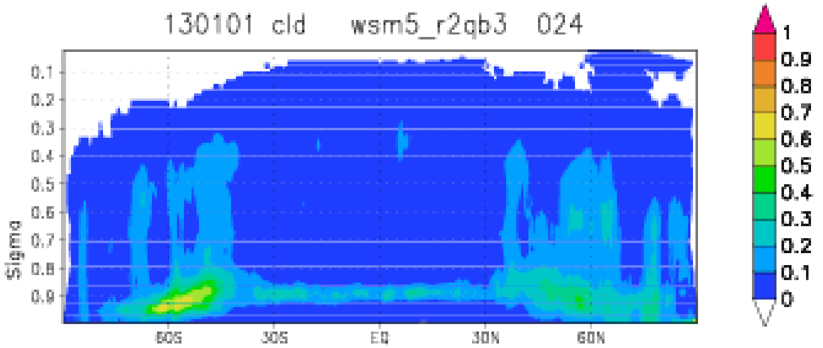


- qi(cloud ice) 分佈往更高層延伸
- qs(snow) 量值增加

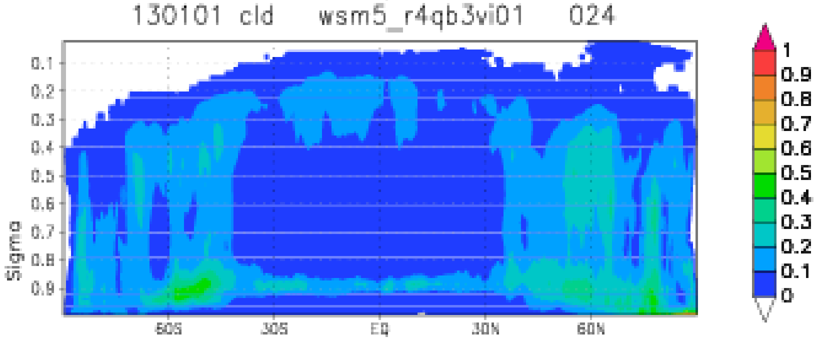
Wsm5_qbvi01 impact On cloud fraction

Cloud fraction

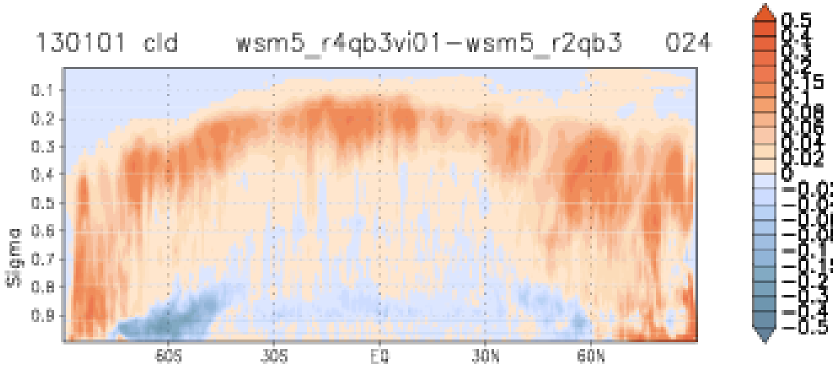
Wsm5_qb



Wsm5_qbvi01



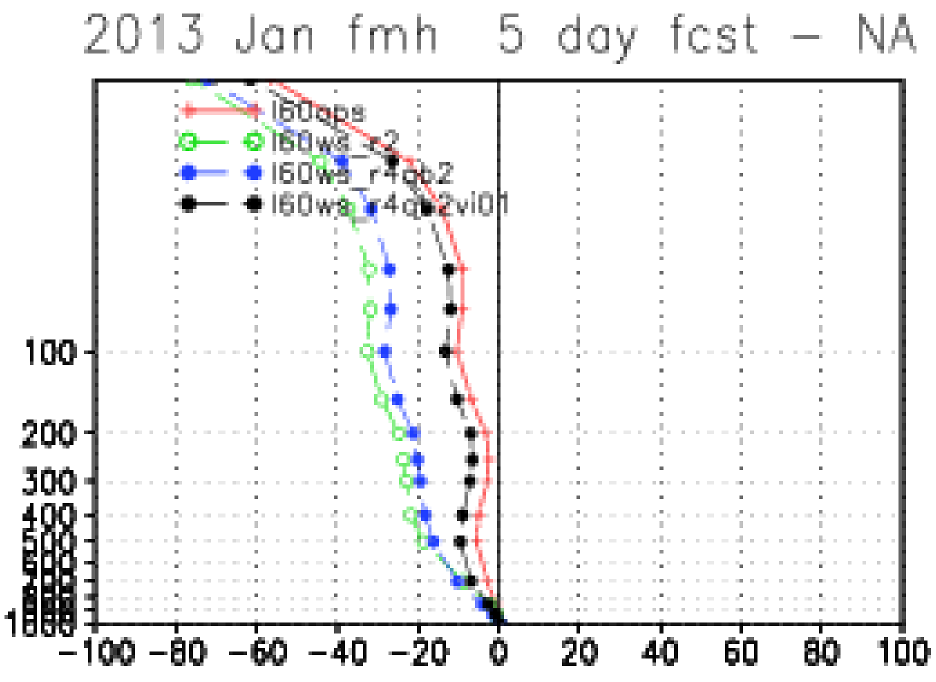
Diff
Wsm5_qbvi01
-wsm5_qb



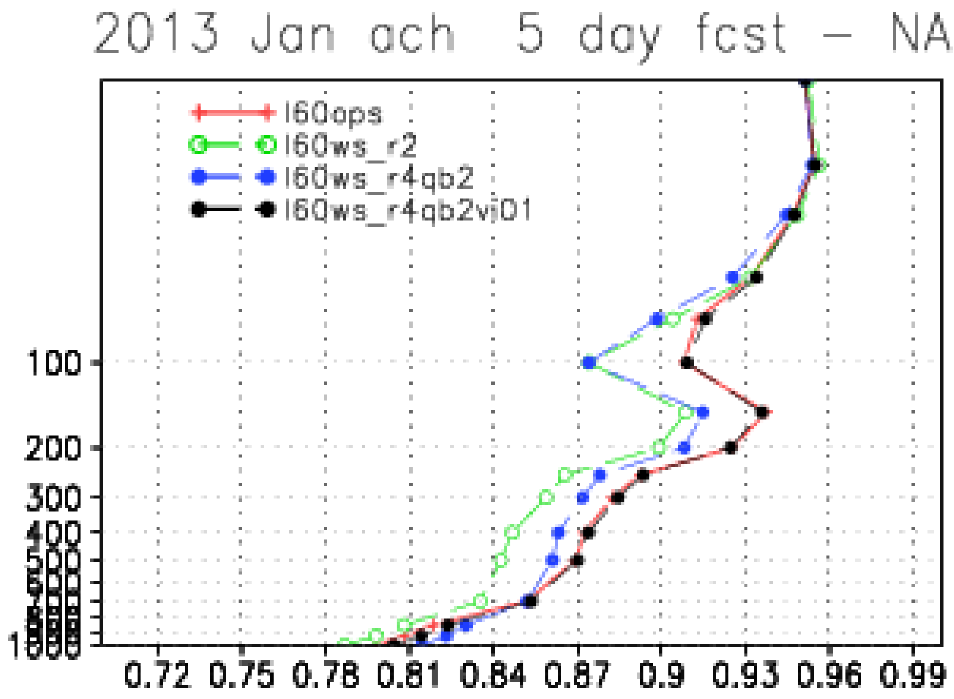
ops -------
wsm5 -------
wsm5_qb -------
wsm5_qbvi01 -------

T511L60
2013/01/01-14
day 5 FCST NA(20N-80N)

FMH



ACH



待解決問題:

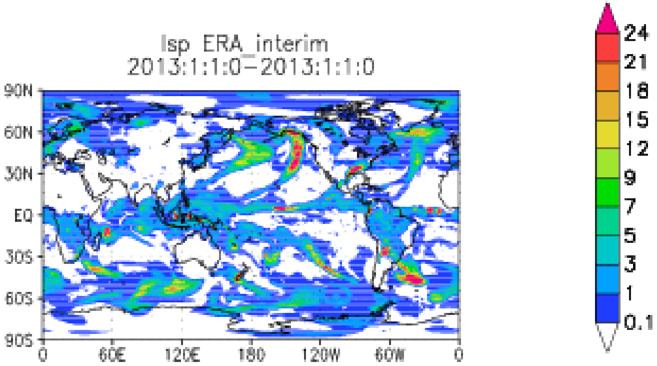
- 網格尺度降水偏少

➢ wsm5設定的凝結條件，
是要求格點平均濕度達飽和。

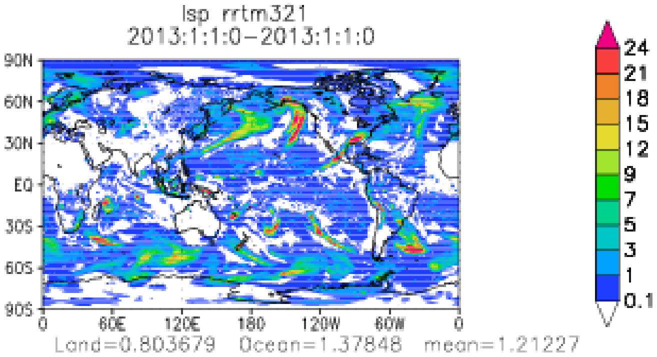
此條件對較粗網格(25km)模式是否適合?

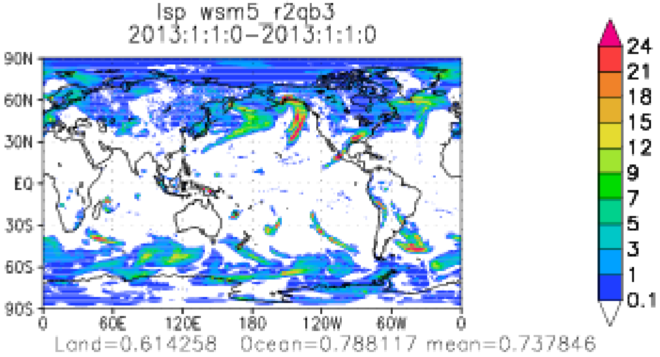
Grid-scale precipitation (mm/day)
2013/1/1 day 1 fcst

Era_interim
1.287 mm/day



ops
1.212 mm/day

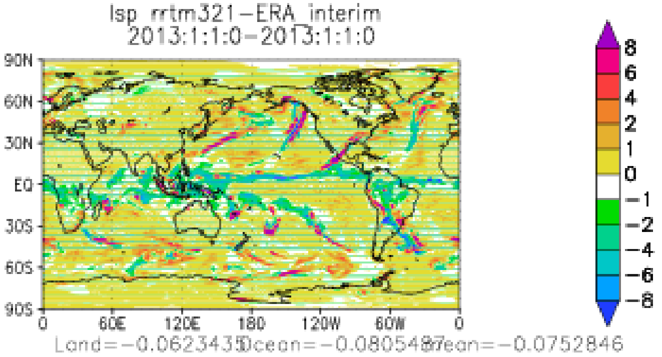


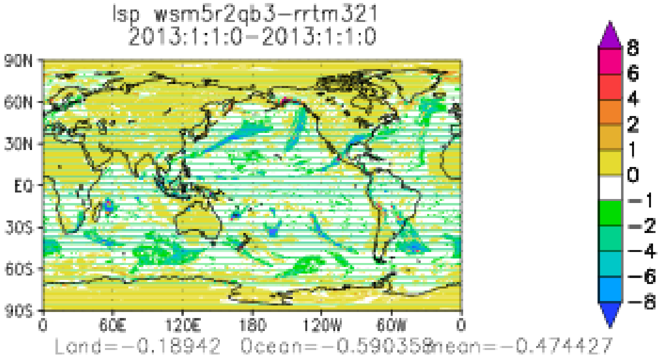


Cwb_wsm5
0.737 mm/day

Ops-era
-0.07 mm/day

網格降水偏少





Wsm5_qb-ops
-0.47 mm/day

洋面網格降水減少
偏少誤差增加

WSM5 評估與建議

- ■ 水物粒子分布(雲)有較為合理的基本垂直結構

多項微物理過程可提供較大調整彈性，

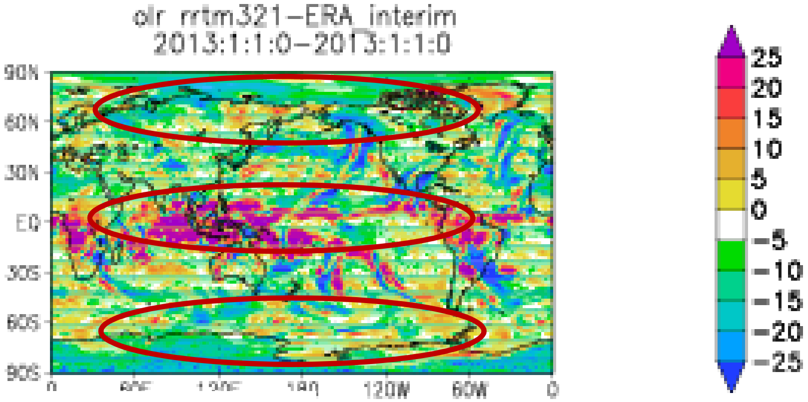
得到最佳輻射通量（olr,ss ）

但是

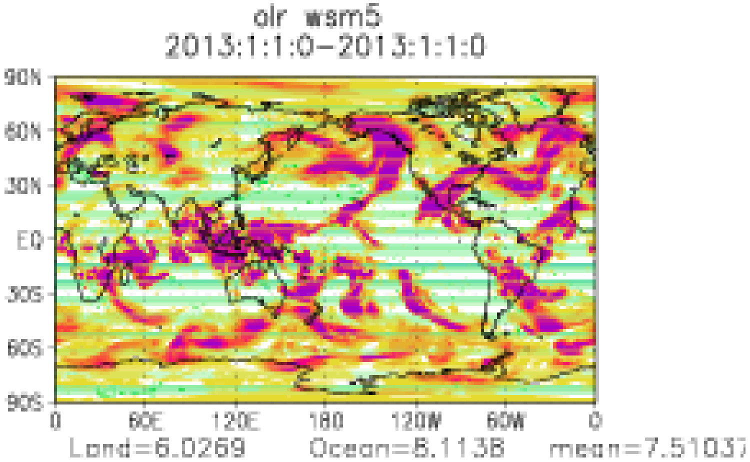
- 模式必需水量保守
- 解析度必須提高，解決網格尺度降水效率偏低問題
- 時間耗費為原3/2，須有足夠電腦資源

The end -

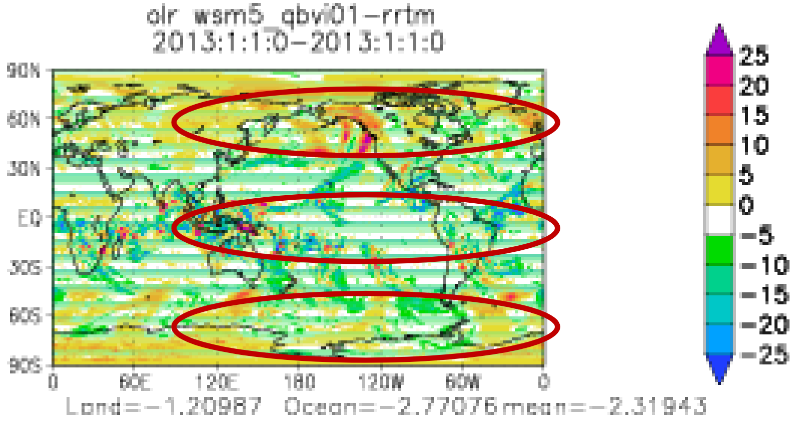
Wsm5_qbvi01 impact on Outgoing Longwave Rad(W/m2)
2013/1/1 day 1 fcst



Ops-Era



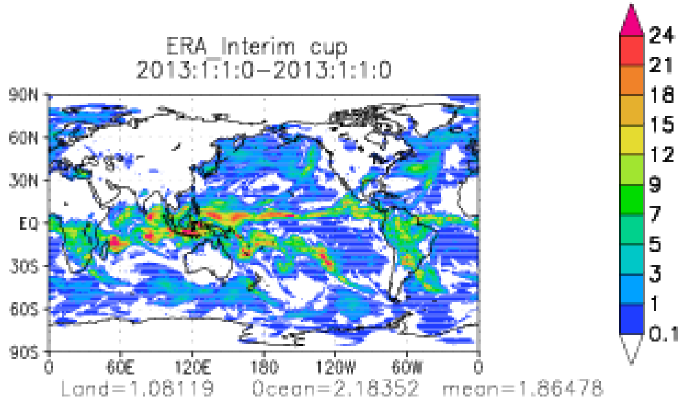
Wsm5-Ops



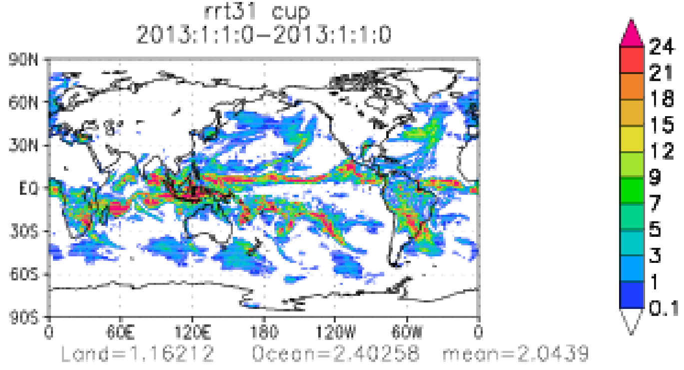
Wsm5_vi01-Era

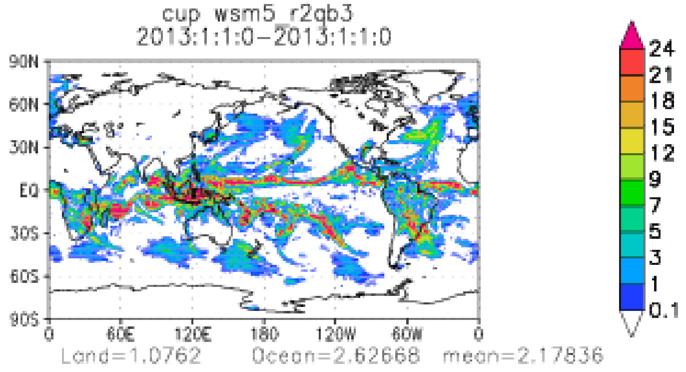
Cumulus precipitation (mm/day)
2013/1/1 day 1 fcst

Era_interim
1.864 mm/day



ops
2.043 mm/day

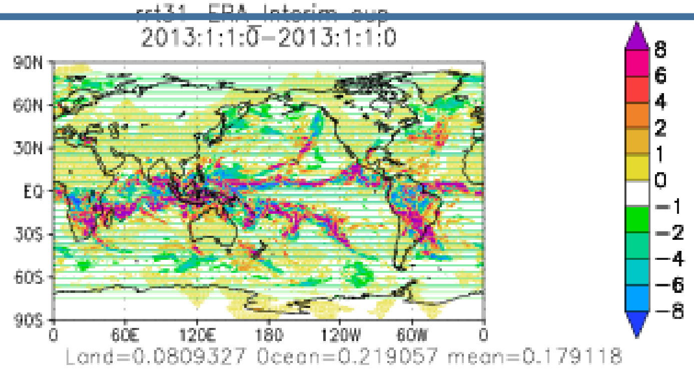


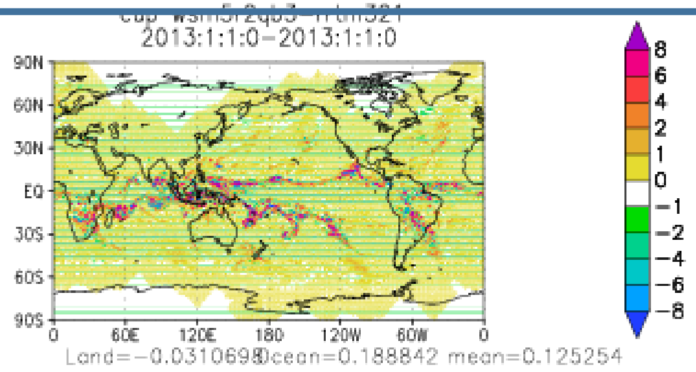


Wsm5_qb
2.178 mm/day

Ops-era
0.17 mm/day

對流降水偏多





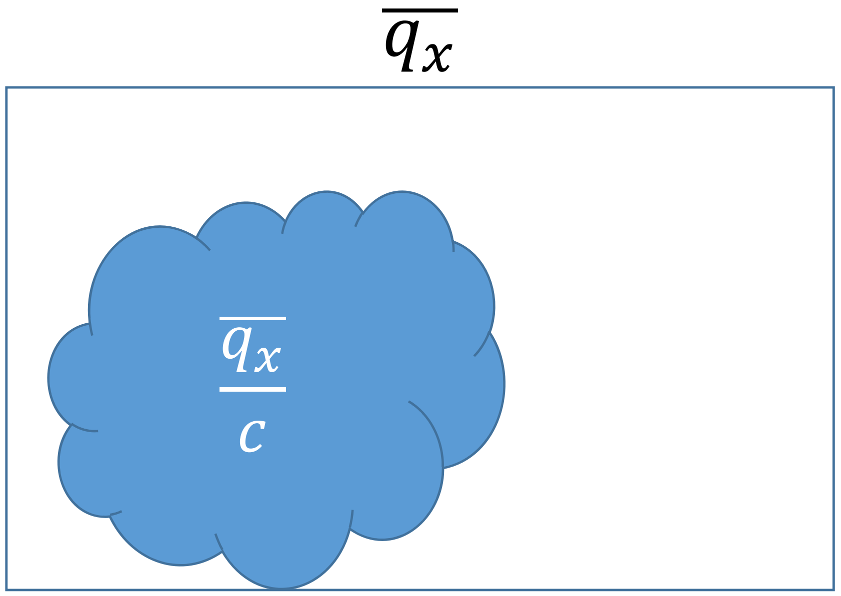
Wsm5_qb-ops
0.13 mm/day

對流降水普遍增加
偏多誤差增加

方法 1

$$\frac{d\overline{q_x}}{dt} = f\left(\frac{\overline{q_x}}{c}\right) \times c$$

$\overline{q_x}$: grid mean mixing ratio
C : cloud fraction
$\frac{\overline{q_x}}{c}$: in cloud mixing ratio



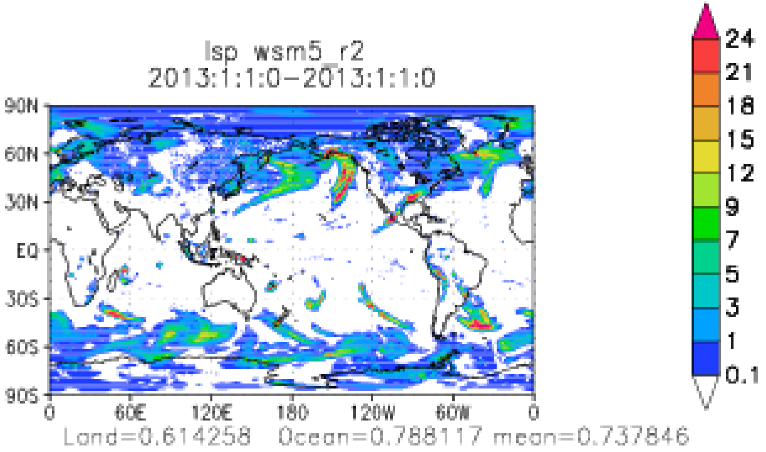
方法 2

$$\overline{q_s}_{modify} = \text{rh\_cri} \times \bar{q}_s$$

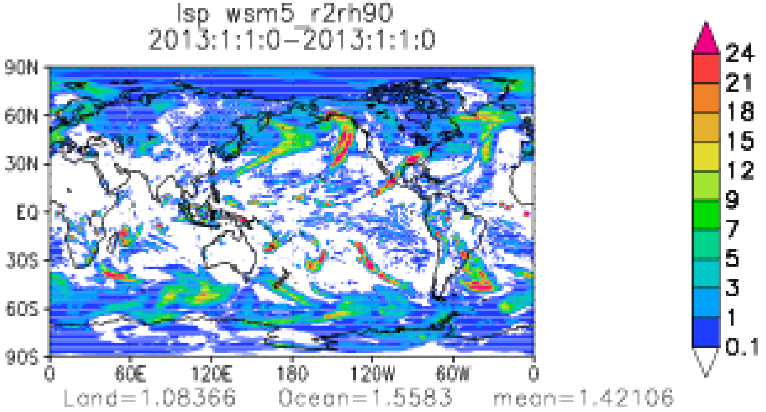
$\bar{q}_s$: saturated mixing ratio
0< rhcri <1

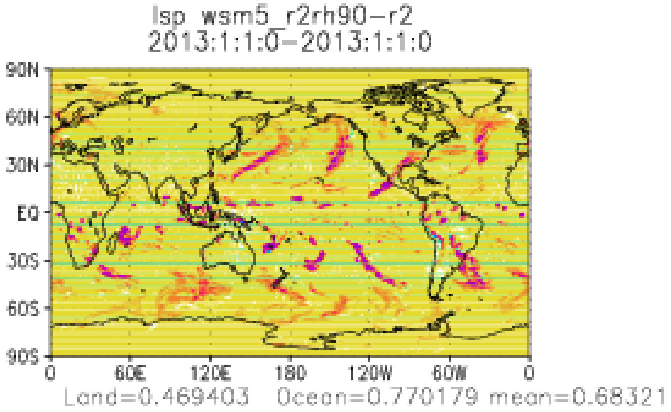
Rh=0.9 impact on lsp

Wsm5
0.74 mm/day



Wsm5_rh90
1.42 mm/day



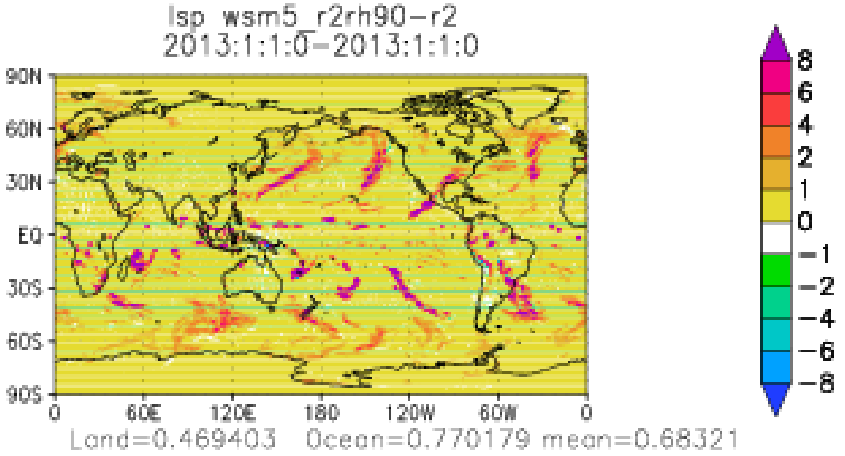


Diff = 0.68 mm/day
rh90-wsm5

Grid scale precip is increasing!!

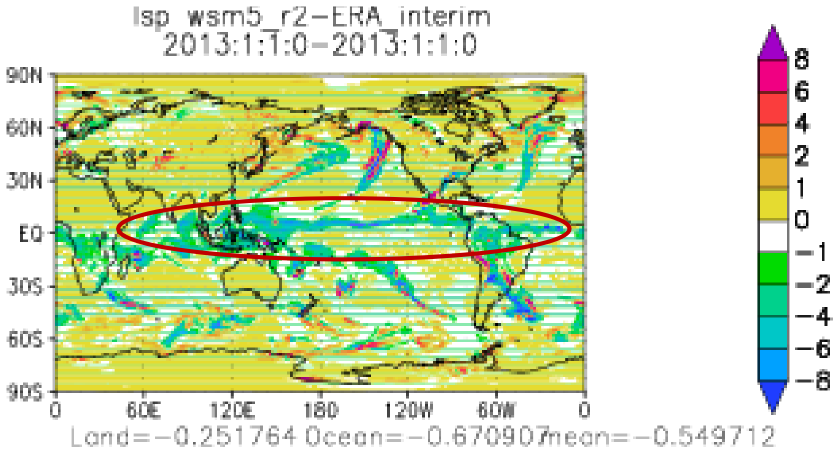
Rh=0.9 impact on lsp

Wsm5_rh90-wsm5



Lsp 全面增加

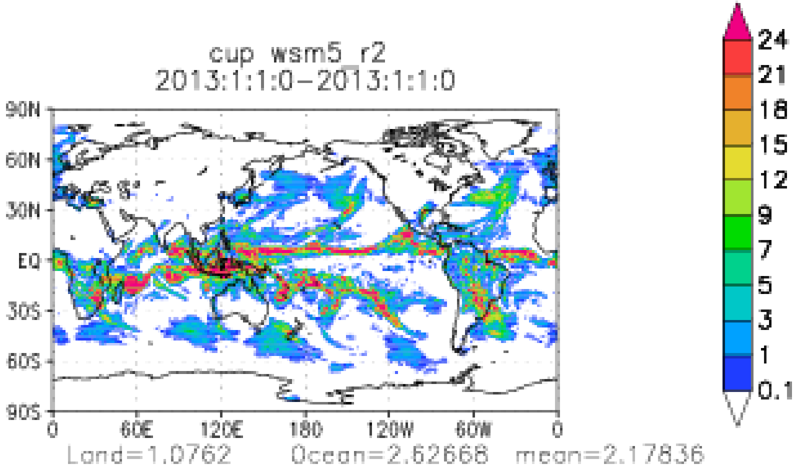
Wsm5-ERA_interim



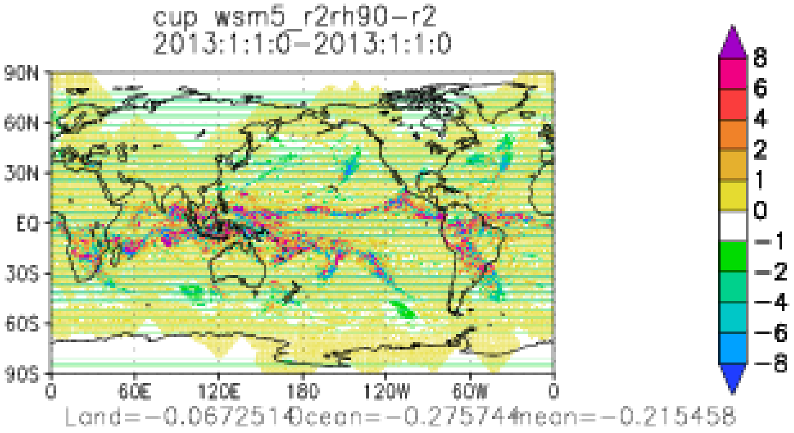
Lsp 主要偏少區域在熱帶

Rh=0.9 impact on cup

Wsm5
2.17 mm/day

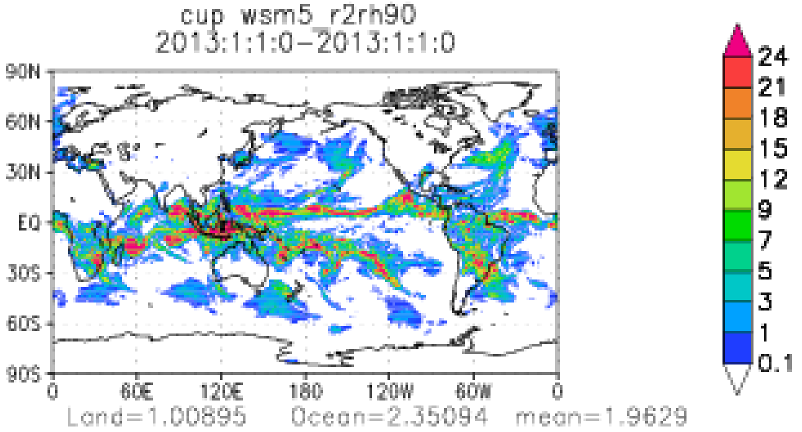

cup wsm5_r2
2013:1:1:0–2013:1:1:0

Land=1.0762 Ocean=2.62668 mean=2.17836


cup wsm5_r2rh90–r2
2013:1:1:0–2013:1:1:0

Land=–0.0672514 Ocean=–0.275744 mean=–0.215458

Wsm5_rh90
1.96 mm/day


cup wsm5_r2rh90
2013:1:1:0–2013:1:1:0

Land=1.00895 Ocean=2.35094 mean=1.9629

Diff = -0.215 mm/day
rh90-wsm5

Convective precip is decreasing!!

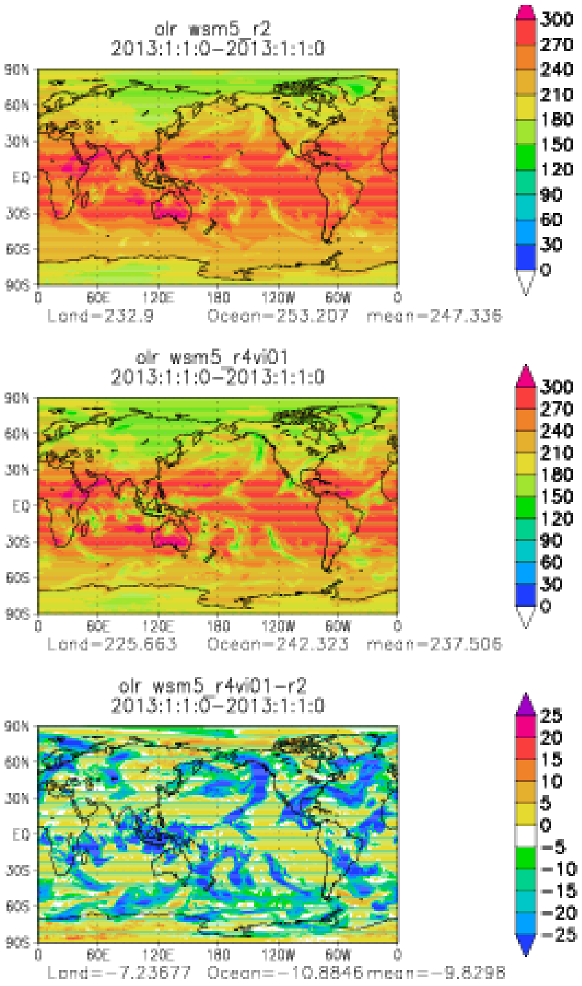
Wsm5_r4vi01 impact
On OLR & cfr

Wsm5_r2
247.3 W/m2

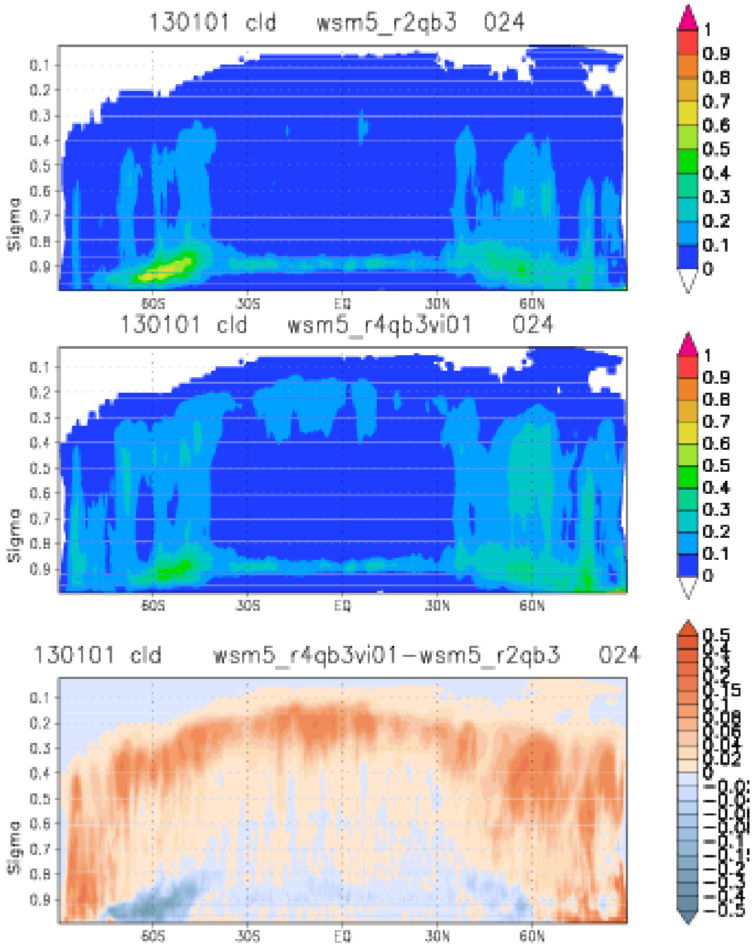
Wsm5_r4vi01
237.5 W/m2

Wsm5_r4vi01
-r2

OLR (w/m2)



Cloud fraction



Goddard bulk microphysical scheme (from WRF)

- **Bulk-method, Single moment scheme**
- **考慮的水物粒子 qc,qr,qi,qs,qg,qh(2ICE, cloud ice & snow)**

粒徑分布函數亦是**M-P**分布，但參數設定不同

沒有考慮**cloud ice**的沉降

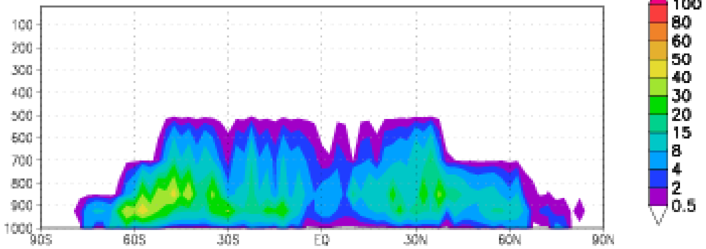
20130101 024
Yz profile

Wsm5

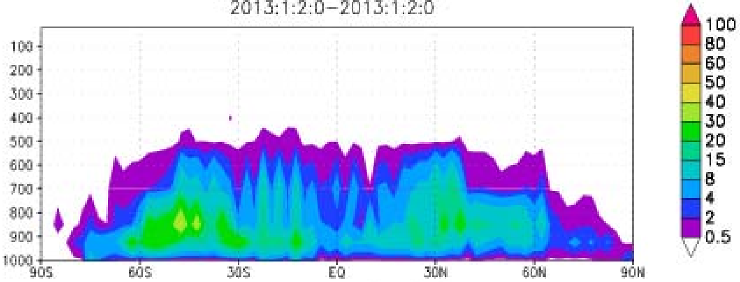
Goddard

qc
Cloud water

wsm5_r2 cw(mg/kg)
2013:1:2:0–2013:1:2:0

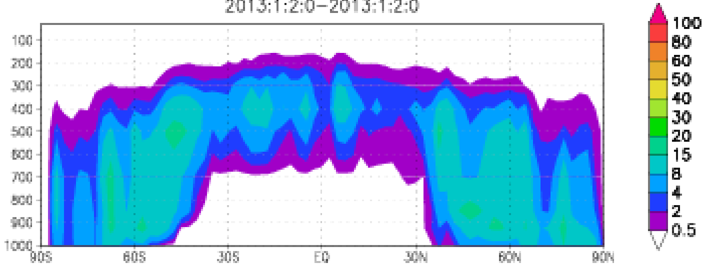


goddard_qb3 cw(mg/kg)
2013:1:2:0–2013:1:2:0

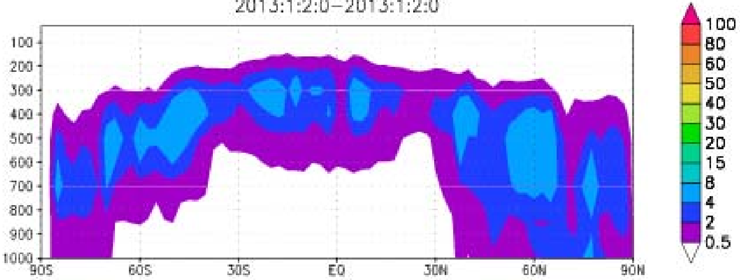


qi
Cloud ice

wsm5_r2 ci(mg/kg)
2013:1:2:0–2013:1:2:0



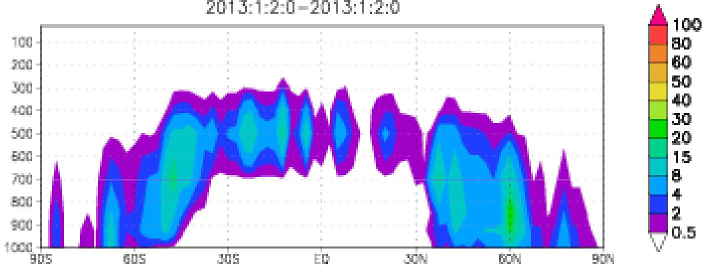
goddard_qb3 ci(mg/kg)
2013:1:2:0–2013:1:2:0



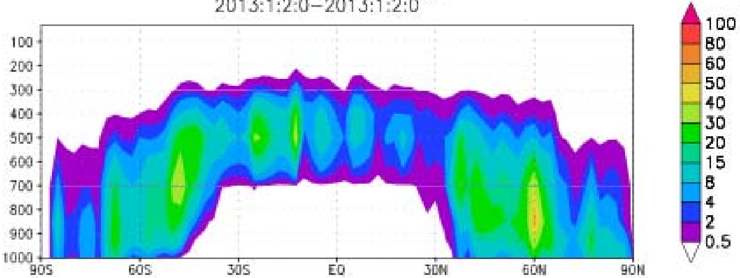
Cloud Ice 較少

qs
snow

wsm5_r2 cs(mg/kg)
2013:1:2:0–2013:1:2:0



goddard_qb3 cs(mg/kg)
2013:1:2:0–2013:1:2:0



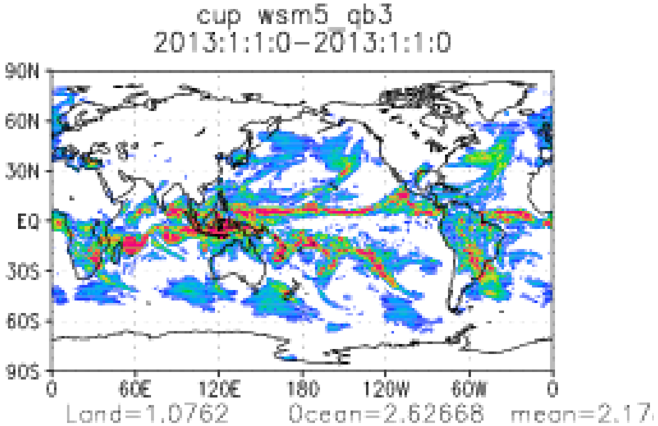
Snow 較多

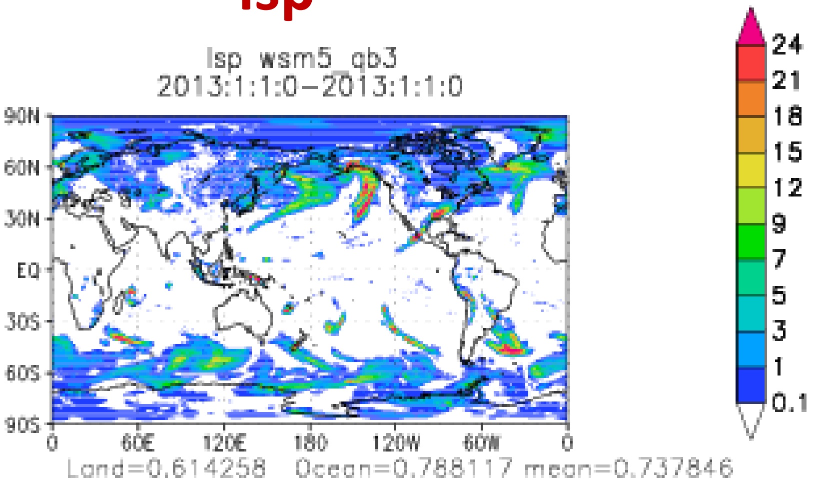
Goddard scheme impact

cup

lsp

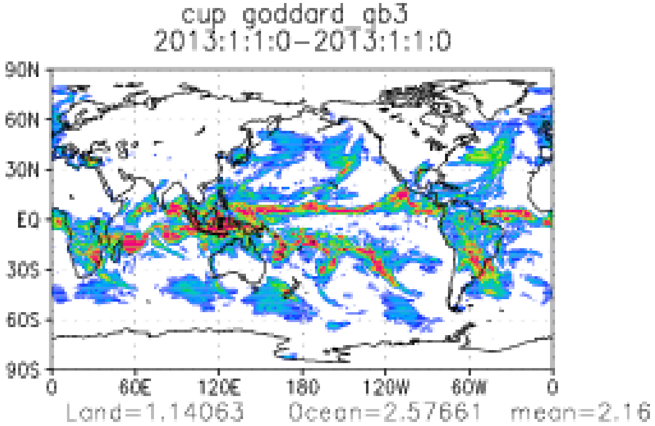
Wsm5
2.17 mm/day

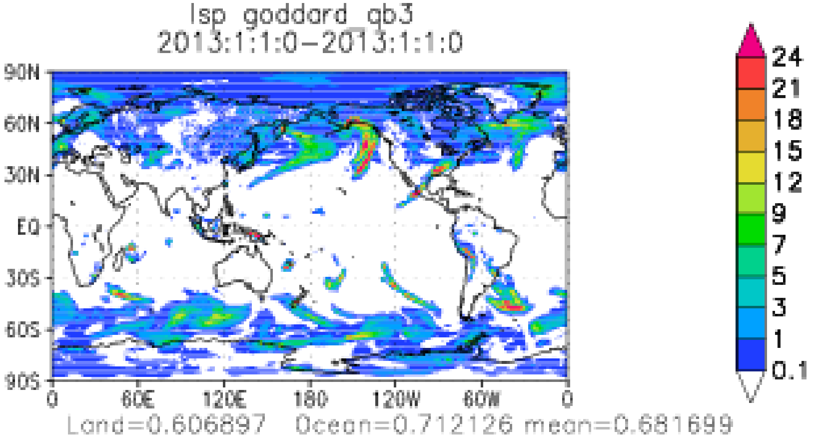




Wsm5
0.73 mm/day

Goddard
2.16 mm/day





Goddard
0.68 mm/day

Wsm5 (ref to Lin et al. 1983 ,Rutledge and Hobbs 1983)

Modification (Hong et al 2004)

高層雲冰過多問題 $N_{io} = 10^{-2}\exp(0.6(T_0 - T))$ (Fletcher 1962)

- **冰核(nuclei)粒子濃度與冰晶(crystal)粒子濃度分開估算**

  - 假設**冰核**濃度為**溫度**的函數 $ice\ nuclei\quad N_{io} = 10^{3}\exp(0.1(T_0 - T))$
  - 假設**雲冰**濃度是雲冰**質量混合比**的函數

- **加入雲冰的沉降作用** $V_t(ice)=3.29(\rho q_i)^{0.16}$

Cloud-radiation effect

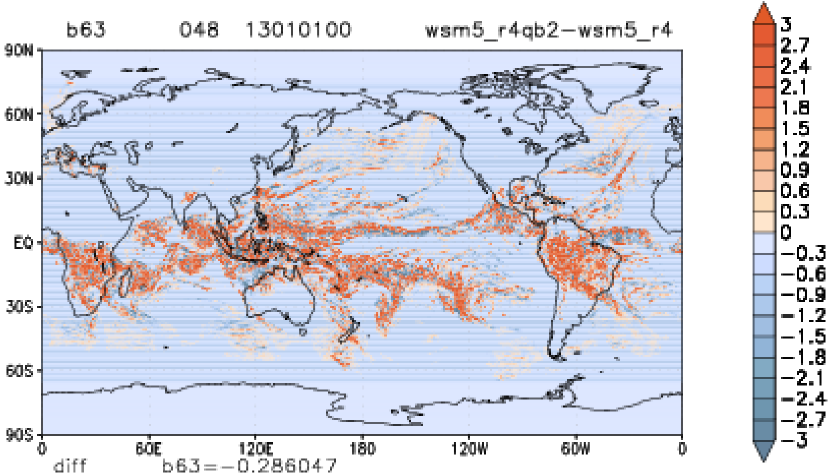
optical depth(ql path, effective radius)

$$\tau = f\left(\frac{particle\ path = \int_{ps}^{ptop} ql(p)dp}{effective\ radius(rq)}\right)$$

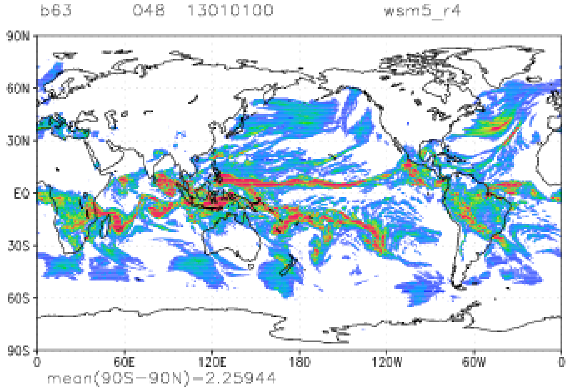
	r2	**r4**
Cloud water	qc_rad=f(qc+qi+qs+qr, T) rqc=f(T)	qc, rqc =f(qc) from wsm5
Cloud ice	qi_rad=f(qc+qi+qs+qr, T) rqi=f(T)	qi, rqi =f(qi) from wsm5
Rain drop	x	qr, rqr =1000um
snow	x	qs ,rqs =f(qs) from wsm5

postq ajust impact on precipitation

Cup diff(r4qb2-r4)= **-0.286 mm/day**

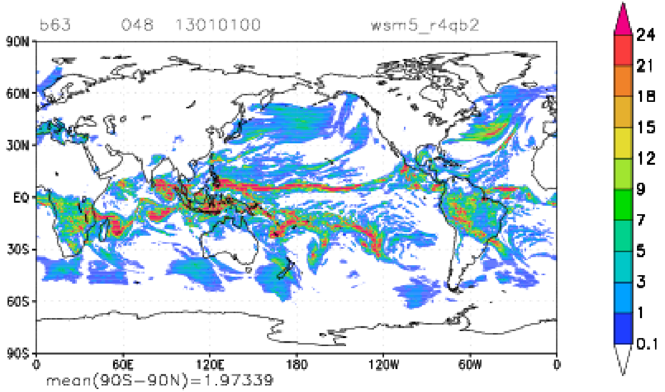


Wsm5_r4



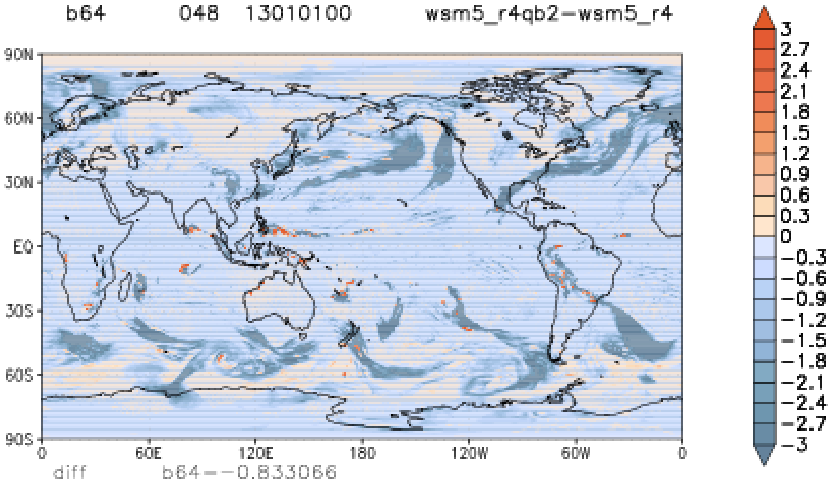
2.259 mm/day

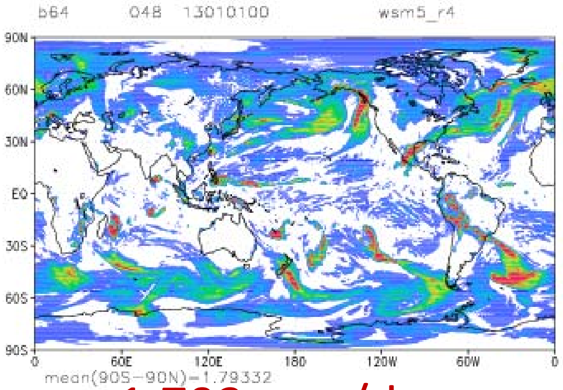
Wsm5_r4qb2



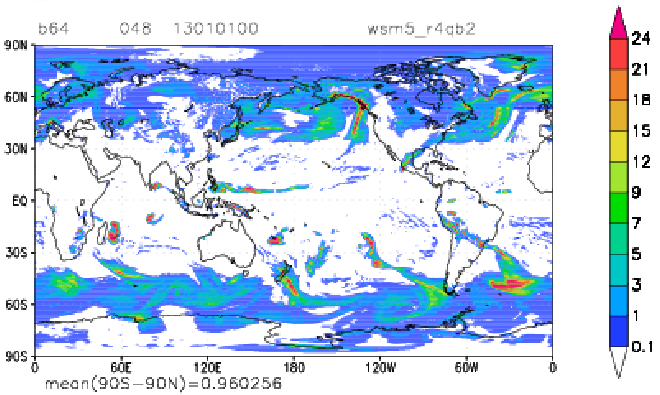
1.973 mm/day

lsp diff(r4qb2-r4)= **-0.833 mm/day**





1.793 mm/day



0.960 mm/day

飽和調整策略

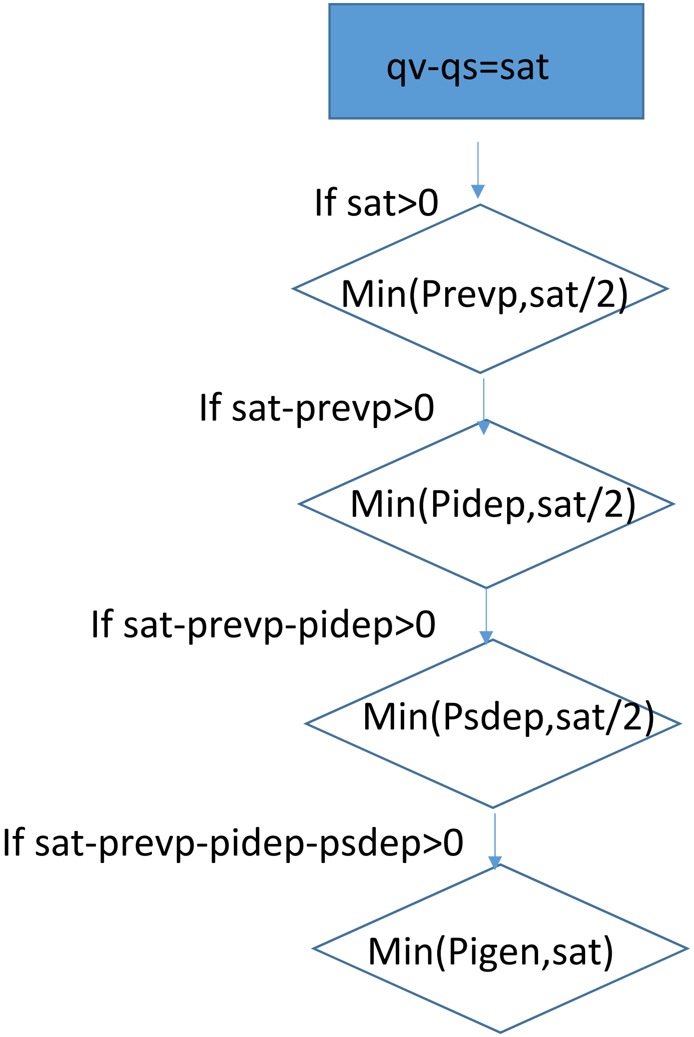
當水氣壓超過飽和水氣壓，計算水氣混合比超出飽和混合比之量: **qv-qvs=sat**

調整第一步 ，檢查是否有過飽和水氣，若存在過飽和，
檢查是否有**雨滴**存在，若有雨滴存在，計算prevp(qv>>qr)，
但凝結量限制不超過sat/2

調整第二步，檢查過飽和水氣是否被消耗完，若仍存在過飽和，
檢查是否有**雲冰**存在，若有雲冰存在，計算pidep(qv>>qi)，
但凝結量限制不超過sat/2

調整第三步，檢查過飽和水氣是否被消耗完，若仍存在過飽和，
檢查是否有**雪**存在，若有雪存在，計算psdep(qv>>qs)，
但凝結量限制不超過sat/2

調整第四步， 檢查過飽和水氣是否被消耗完，若仍存在過飽和，
計算**雲冰**產生量，pigen(qv>>qi)，
但凝結量限制不超過sat



qv-qs=sat

If sat>0

Min(Prevp,sat/2)

If sat-prevp>0

Min(Pidep,sat/2)

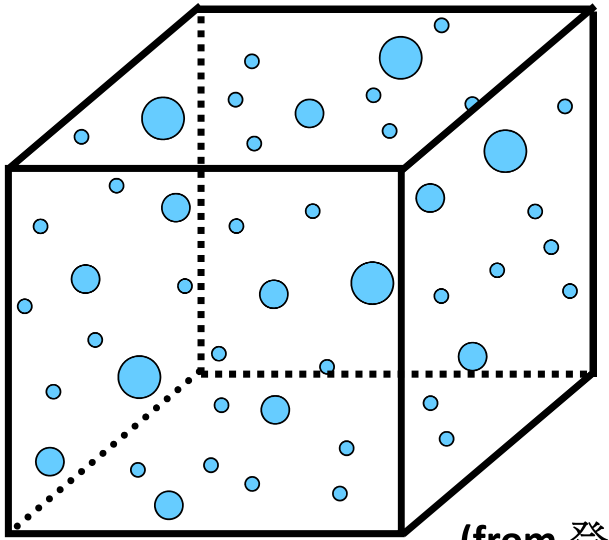
If sat-prevp-pidep>0

Min(Psdep,sat/2)

If sat-prevp-pidep-psdep>0

Min(Pigen,sat)

- **Nearly all cloud microphysical processes are size dependent**



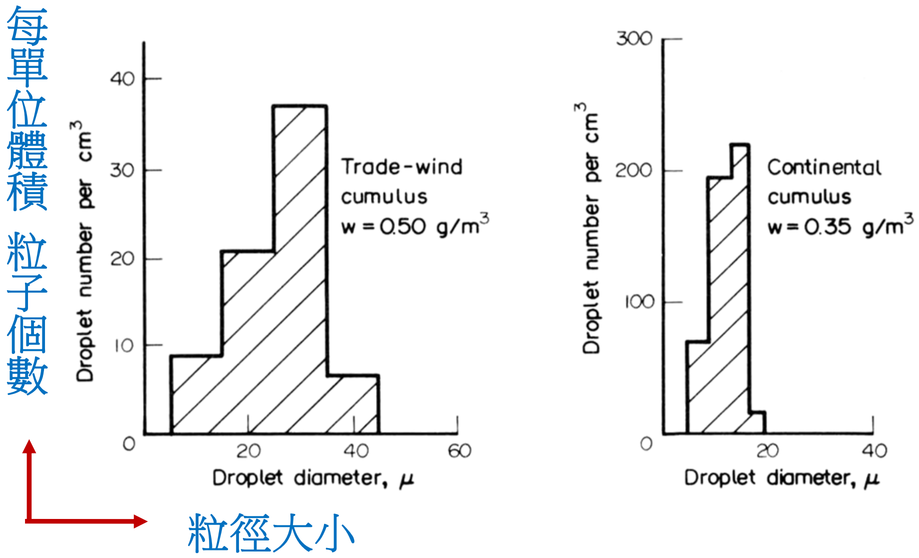
(from 登舜)

$1\ m^3$
(unit volume)

粒徑分布(粒徑譜)

Maritime cloud

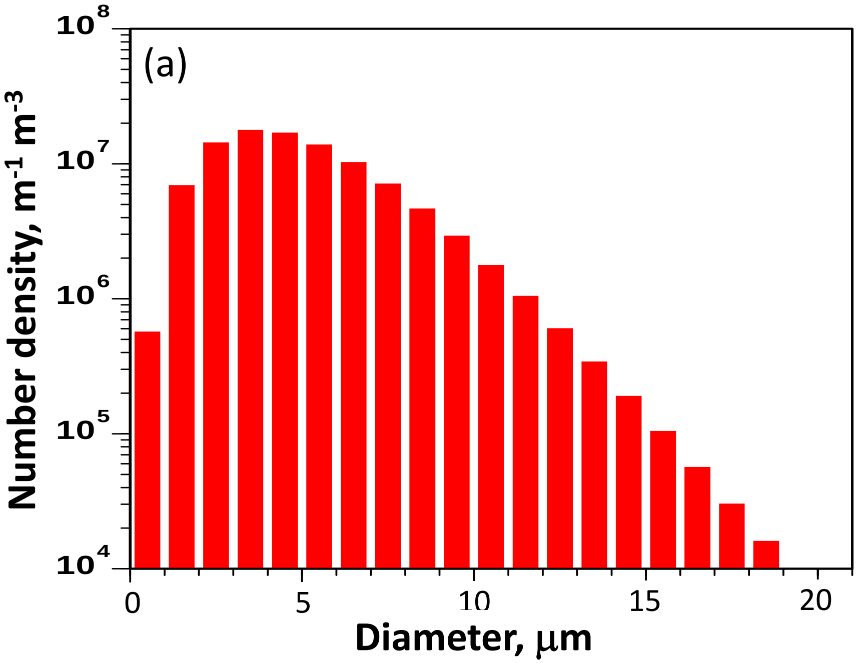
Continental cloud



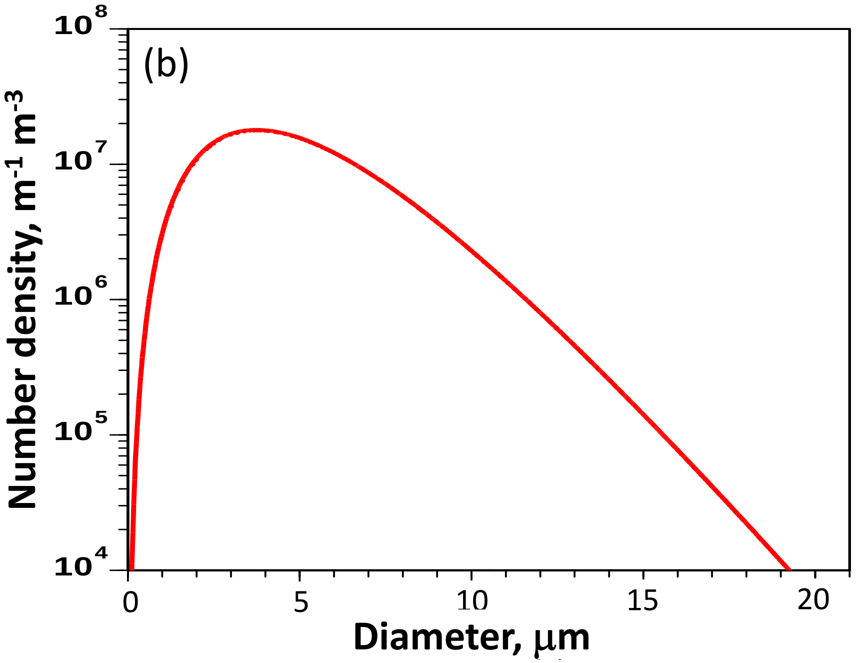
https://eosweb.larc.nasa.gov/ACEDOCS/images/cpi/mis5_incld1_3.gif

如何處理不同粒徑的雲物理過程

--- different modeling approach



Spectral



Bulk

(from 陳正平)

Fall speed in WSM5

- refer to Lin et al. (1983)

Rain, Snow, cloud ice 終端速度

$$V_t(\text{rain}) = a_v \times \frac{\Gamma(4+b_v)}{6} {\lambda_r}^{b_v} \left(\frac{\rho_0}{\rho}\right)^{0.5}$$

$$V_t(\text{snow}) = a_v \times \frac{\Gamma(4+b_v)}{6} {\lambda_s}^{b_v} \left(\frac{\rho_0}{\rho}\right)^{0.5}$$

Parameter		WSM5
Cloud	a_v	X
	b_v	
Rain	a_v	841.9
	b_v	0.8
snow	a_v	11.72
	b_v	0.41
Cloud ice	$V_t(\text{ice})=3.29(\rho q_i)^{0.16}$ *Heymsfield and Donner(1990)*	

Bulk method Parameterization

Step 1 Size distribution representation

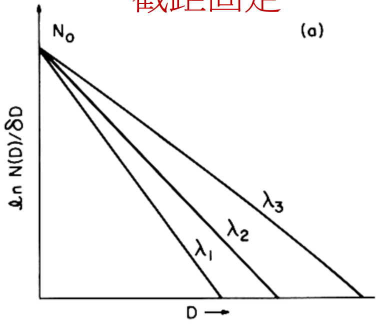
Marshall–Palmer distribution

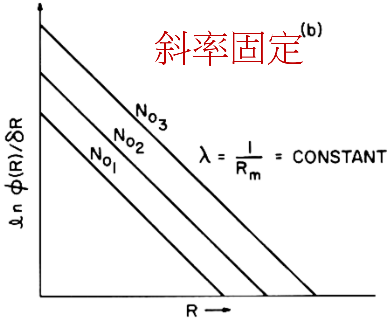
rain drop $N_r(D) = \boldsymbol{n_{0r}}\exp(-\boldsymbol{\lambda_r}\mathrm{D})$

$\boldsymbol{n}_{0r}$ **為截距參數** $= \mathbf{8 \times 10^6}$

$\boldsymbol{\lambda_r}$ **為斜率參數**

截距固定




斜率固定

- **Total number concentration** - the 0^rd^ moments of a size distribution

$$total\ \mathrm{N}_r = \int N_r(D)dD = \int D^0 N_r(D)dD$$

- **Mass Mixing ratio -** the 3^rd^ moments of a size distribution

$$total\ q_r = \int q(D)dD = \frac{\pi}{6}\frac{\rho_r}{\rho}\int D^3 N_r(D)dD$$

$q(D) = \frac{4\pi}{3}\left(\frac{D}{2}\right)^3 N_r(D)\left(\frac{\rho_r}{\rho}\right)$ for D to D+dD

Bulk method Parameterization step

Step 2 Get slpoe parameter λ

from Mass Mixing ratio - the 3rd moments of a size distribution2

=Γ(4)

$$\boxed{q_r = \int q(D)dD = \frac{\pi}{6}\frac{\rho_r}{\rho}\int D^3 N_r(D)dD} = \frac{\pi}{6}\frac{\rho_r}{\rho}\frac{\left(\int_0^\infty (\lambda_r D)^3 n_{0r} \exp(-\lambda_r D)\, d(\lambda_r D)\right)}{{\lambda_r}^4}$$

$$= \frac{\pi}{6}\frac{\rho_r}{\rho}\frac{n_{0r}}{{\lambda_r}^4}\Gamma(4)$$

$$\lambda_r = \left(\frac{\pi\rho_r n_{0r}}{\rho q_r}\right)^{\frac{1}{4}}$$

q_r為預報變數，可反求得到 λ

– single moment

增加 q_r (mass mixing ratio)的預報， q_r同時是粒徑分布函數的一個矩量(3rd)