

Quel futur pour le schéma microphysique ?

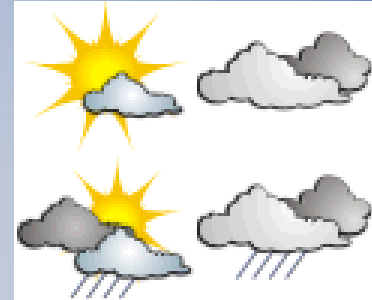
Frédéric Chosson
Paul A. Vaillancourt
Jason A. Milbrandt
Ayrton Zadra



Les schémas microphysiques

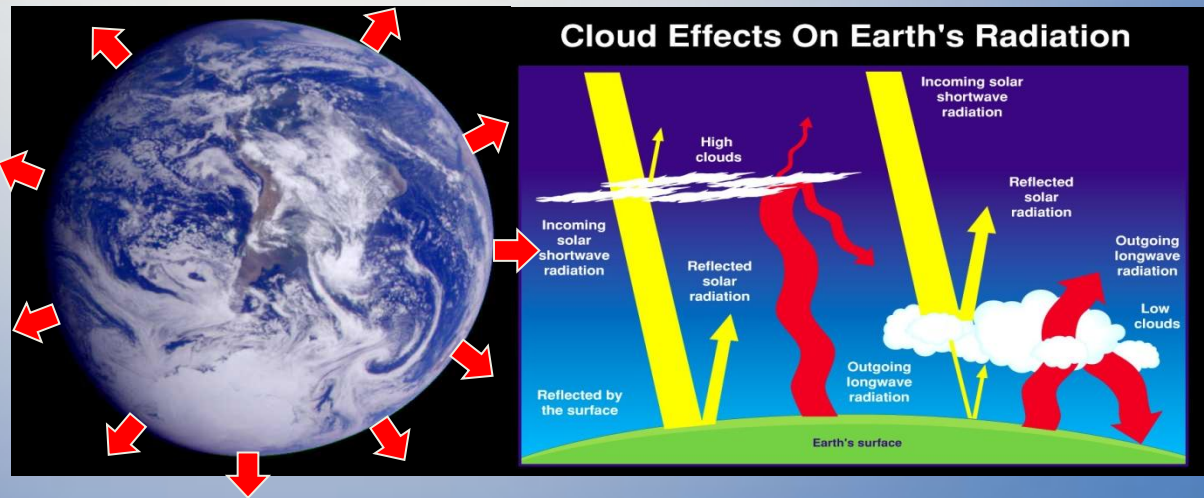
- **Modèles de prévisions numérique:**

- Fraction nuageuse
- Précipitations



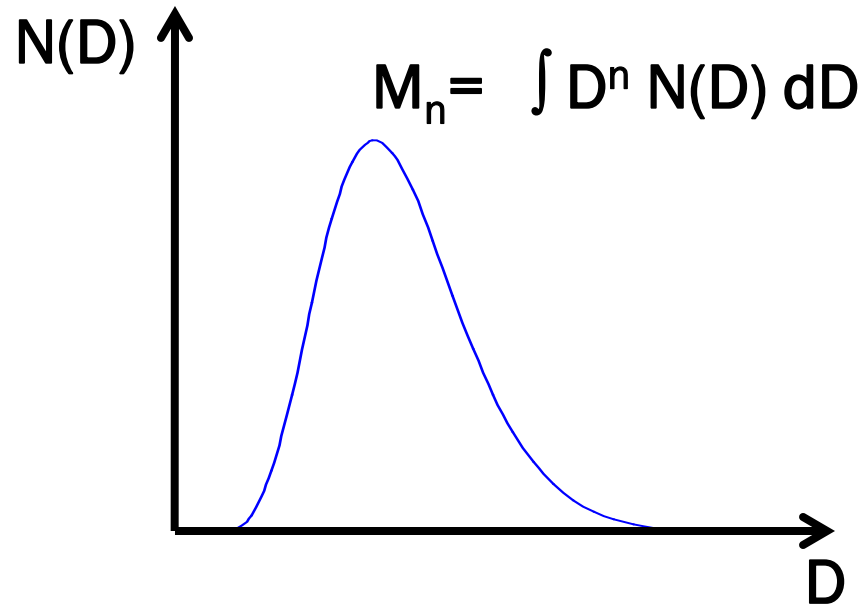
- **Modèles de climat**

- modulation du bilan radiatif ($\approx 67\%$ albédo planétaire)
- cycle de l'eau



Les schémas microphysiques

Fonction de Distribution des Particules



- $M_0 \rightarrow$ concentration totale
- $M_1 \rightarrow$ taille caractéristique
- $M_2 \rightarrow$ vitesse de sédimentation, extinction
- $M_3 \rightarrow$ rapport de mélange
- $M_3/M_2 \rightarrow$ rayon effectif
- $M_5 \rightarrow$ précipitations
- $M_6 \rightarrow$ réflectivité radar

Les schémas microphysiques

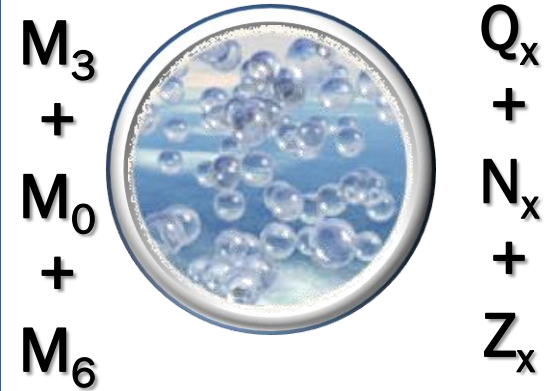
Simple Moment



Double Moment



Triple Moment



Complexité, nombre d'équation, champs advectés et coût numérique



Q_{tot}



Q_c

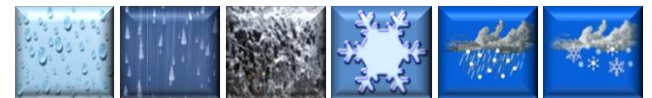


Q_i



Q_r

Q_s



Q_h

Q_g

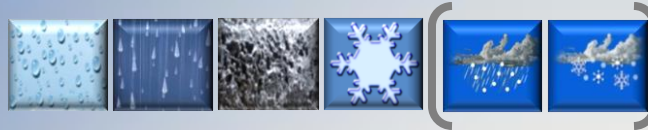
Classes d'hydrométéores

Les schémas microphysiques

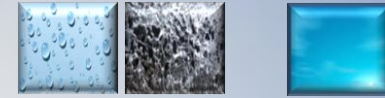
Simple

Double

Triple



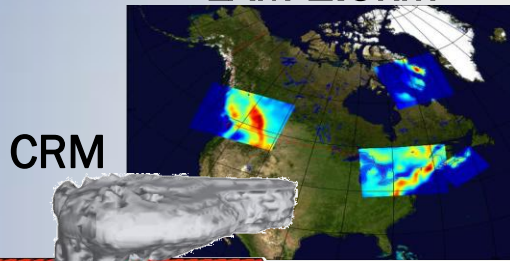
LAM-2.5km



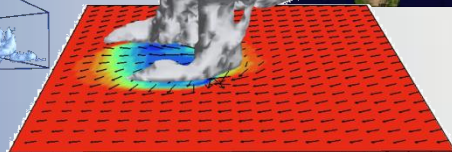
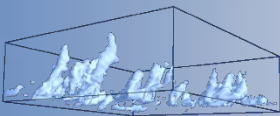
LAM-REG

Simple

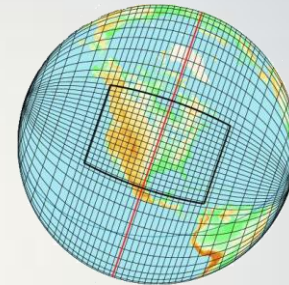
CLIMAT



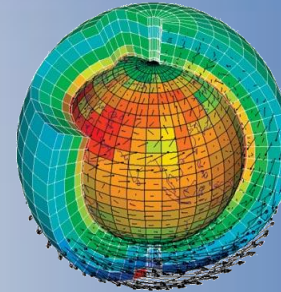
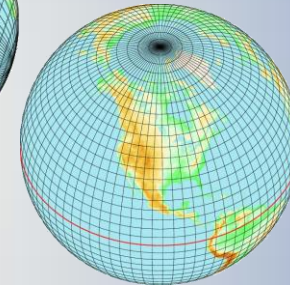
CRM



3MT ds ALARO?
(Gérard, 2007) 15km



GLOBAL



LES

CRM

GCM

100m 500m 1km 2.5km 4km 10km 30km 100km

+

Schéma de cumulus/CL

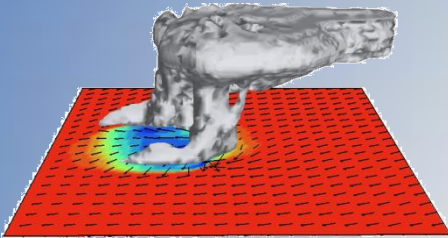
+

Schéma de convection profonde

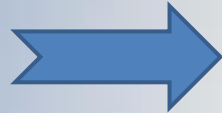
Fraction Nuageuse

Défi: Quel Schéma Microphysique?

Le schéma microphysique du Futur









Cohérence avec les petites échelles : les leçons des CRM



représentations des processus microphysiques en jeu dans les phénomènes convectifs, les lignes de grains et les épisodes de précipitations intenses imposent un nombre de classe d'hydrométéores suffisant:

Nb Classes ≥ 5

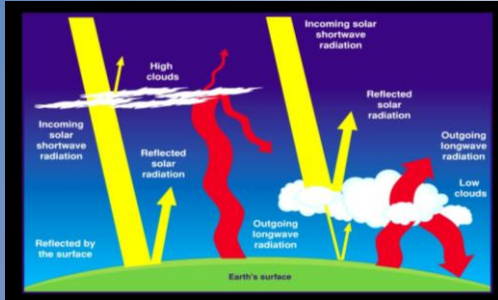
<u>phase liquide:</u>	eau nuageuse	Q_c	
	pluie	Q_r	
<u>phase solide:</u>	classe "glace"	Q_i	
	classe "neige"	Q_s	
	neige roulée et/ou grêle	Q_g / Q_h	 



Double Moment

Schéma double moment meilleur que simple moment conceptuellement et par comparaison avec les obs. (e.g. Lim and Hong, 2009; Morrison et al., 2009; Milbrandt et al., 2009?)

Le schéma microphysique du Futur



Cohérence avec le transfert radiatif :

Double Moment

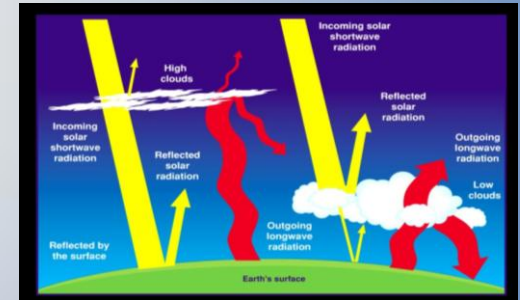
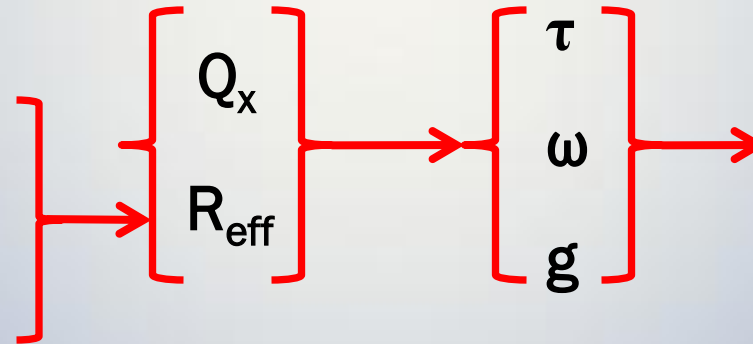
Q_x
 N_x
Forme

Nb Classes glace ≥ 2

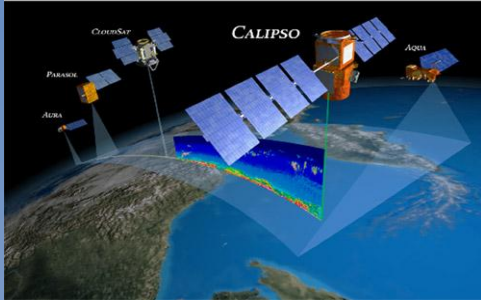
Paramètres microphysiques

Paramètres optiques

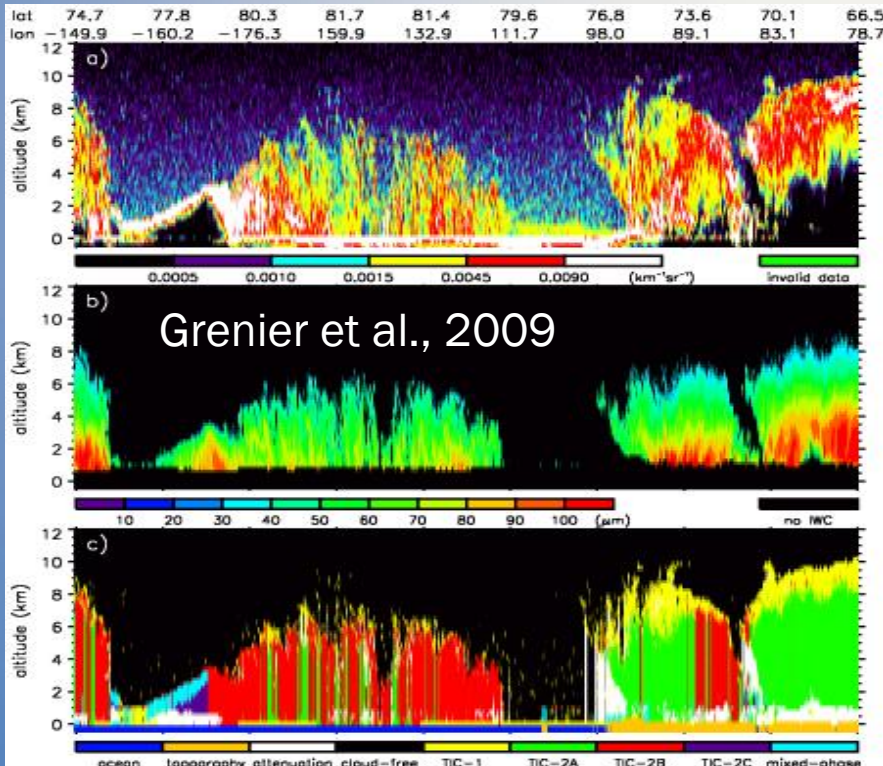
Transfert radiatif



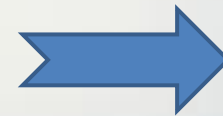
Le schéma microphysique du Futur



Cohérence avec les observations :
A-train, E-train, GPM, radar et lidar
au sol, mesure des précips...



Pour comparaison/validation et
correction à des échelles de plus
en plus compatibles

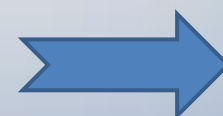


Restitution Q_x et $R_{\text{eff}} (N_x)$

Double (Triple) Moment



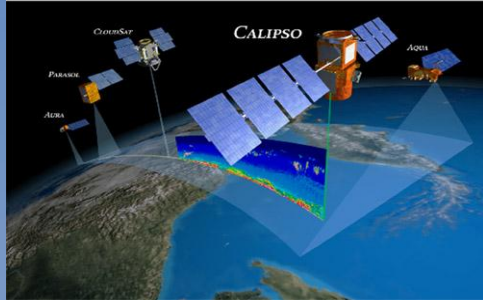
Restitution de la classe
d'hydrométéore (masques)



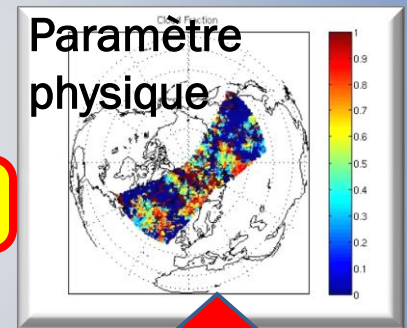
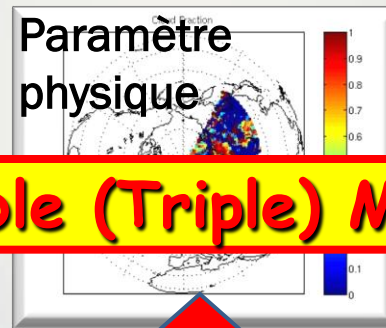
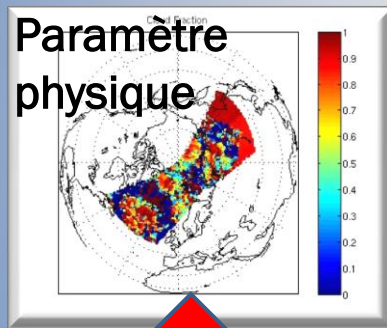
Restitution des profils de
précipitations

Nb Classes ≥ 5

Le schéma microphysique du Futur



Cohérence avec les observations :
simulateurs d'observables et
schémas de restitution

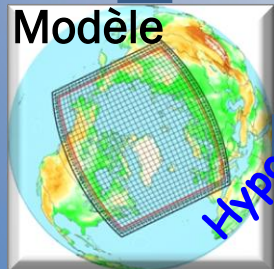


Double (Triple) Moment

Restitution

Nb Classes suffisant

Restitution



Obs. simul.
Radiances

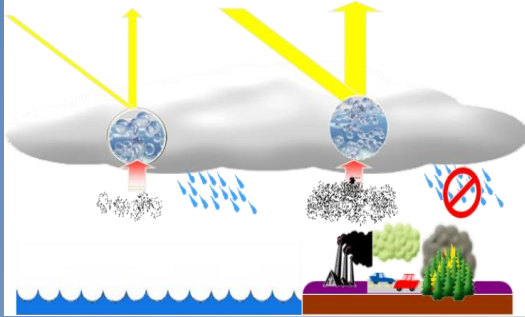


Hypothèses

Hypothèses

Hypothèses

Le schéma microphysique du Futur



Cohérence avec les développements actuels ou futurs:



Implémentation de modules d'aérosols dans les modèles de qualité de l'air. Activation des aérosols!

Double Moment



Prise en compte de la chimie hétérogène dans les nuages (AURAMS, GEM-MACH)

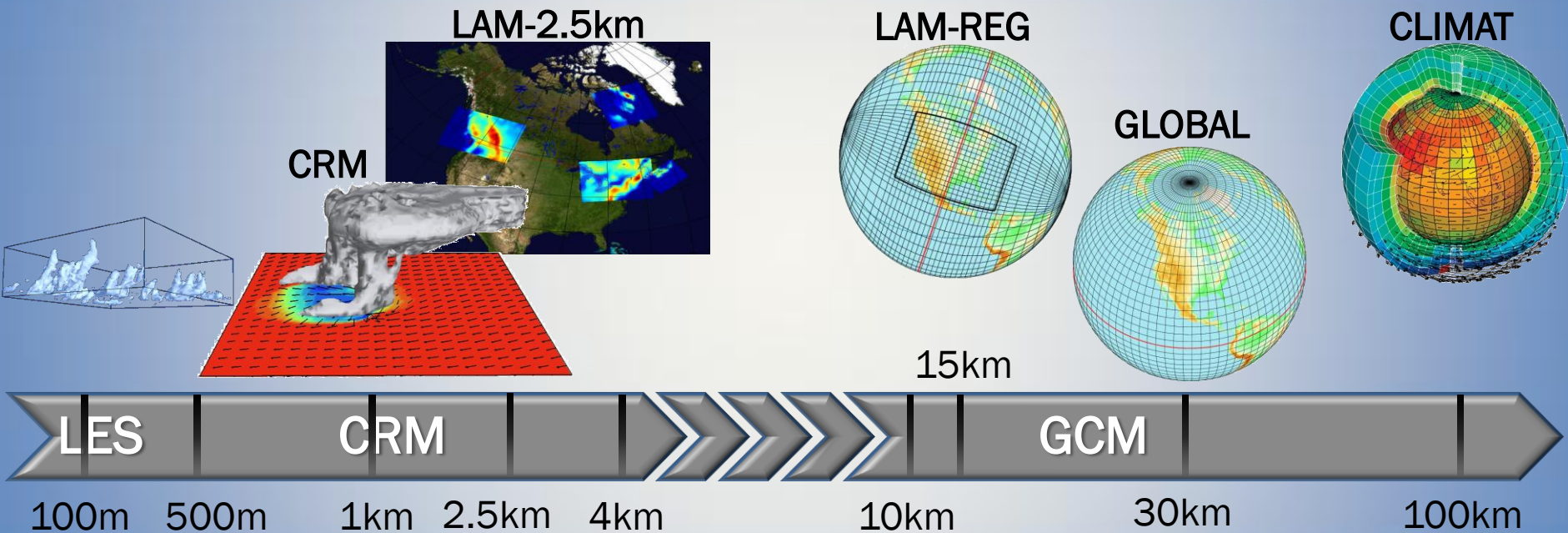
Classes neige pluie



Mode climat: possibilité de tester certaines hypothèses sur les effets indirects des aérosols.

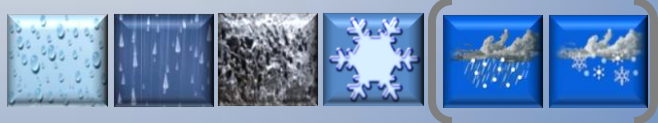
(e.g. dehydration-greenhouse feedback in Arctic, Blanchet and Girard, 1994)

Le schéma microphysique du Futur



Quel Schéma Microphysique?

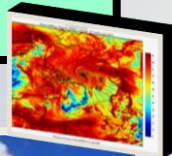
Double Moment



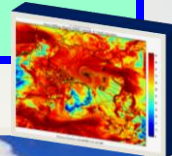
Schémas microphysiques dans GEM

SCHEMAS MICROPHYSIQUES

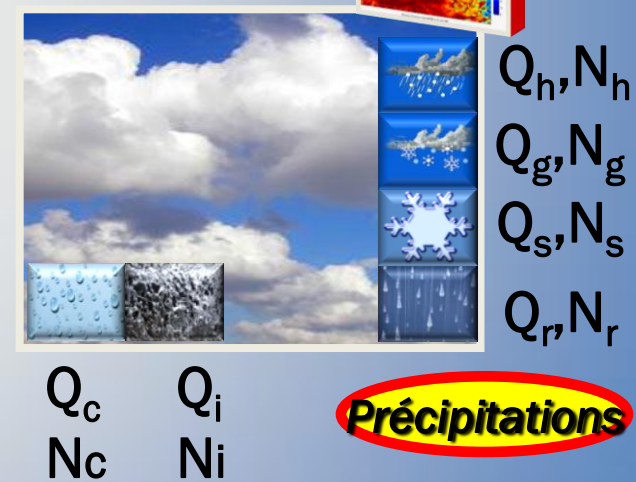
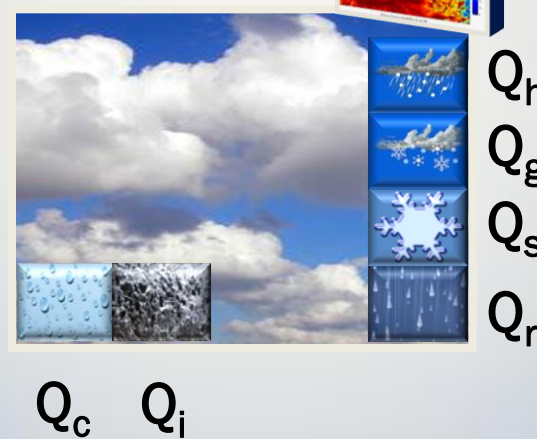
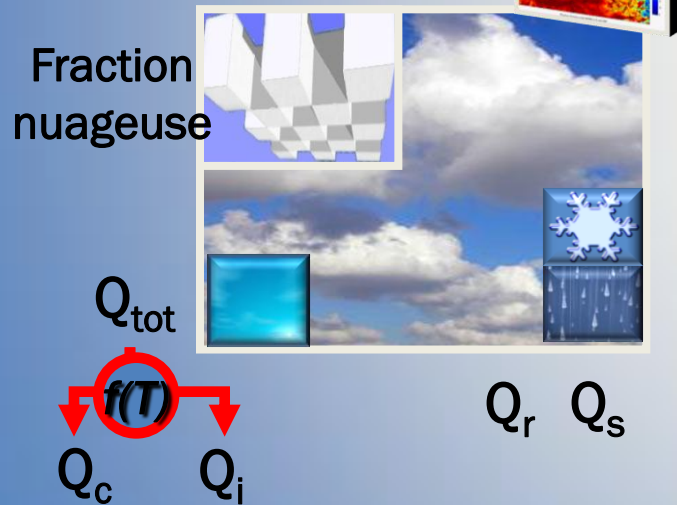
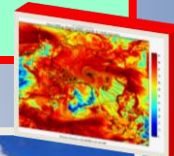
Sundqvist et al.
Simple Moment
(1989)



Milbrandt and Yau
Simple Moment
(2005)



Milbrandt and Yau
Double Moment
(2005)



Précipitations

Condensats

Précipitations

Condensats

Précipitations

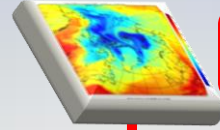
Condensats

(Diagnostiques)

(Prognostiques)

(Prognostiques)

Le système POLAR-GEM

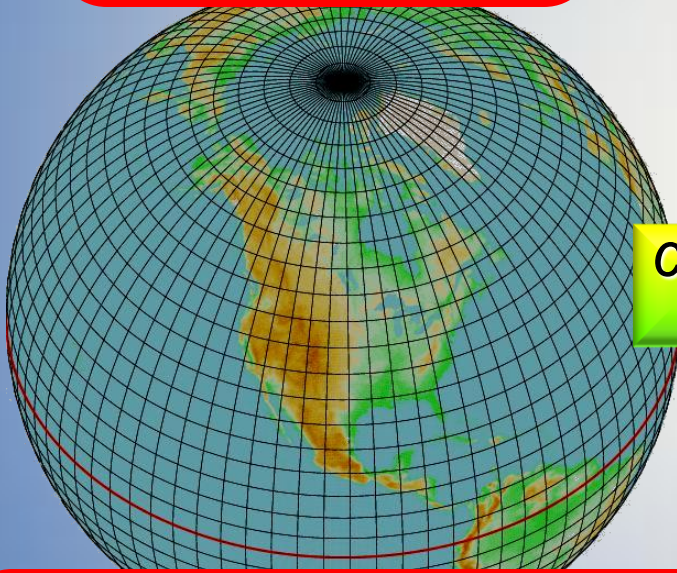


Réanalyses GEM global 2

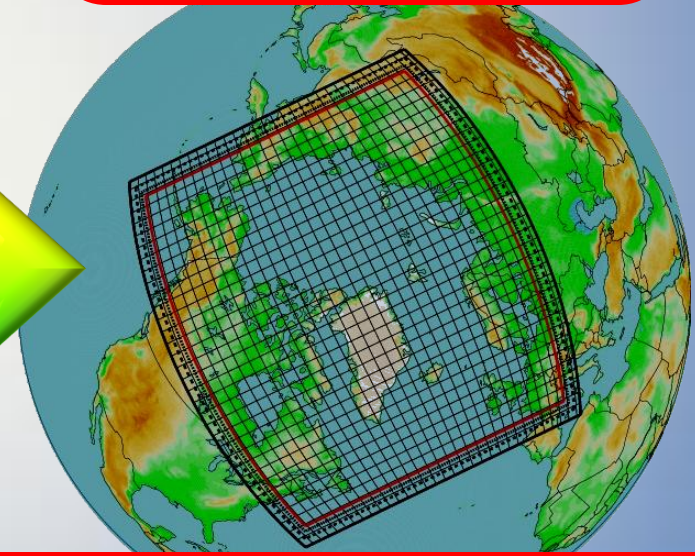
GEM "GLOBAL"



Polar-GEM "LAM"



Conditions aux limites

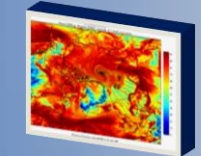
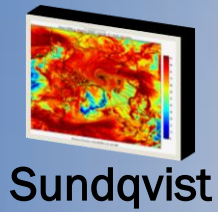


- Version modèle: **GEMDM 3.3.2 dyn /4.7.2 phys**
- Grille: **600 x 800 x 58**
- Résolution: **~33 km**
- **Cubes Creux** sortie chaque pas de temps
- Pas de temps modèle **15 min**

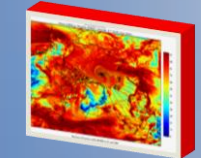
- Grille: **504 x 539 x 58**
- pilotage (**12 pts**) & zone mélange (**10 pts**)
- Résolution: (0.1375 deg.) **~15 km**
- **Cubes Creux** (V. Lee & M. Desgagné)
- Pas de temps modèle **7.5 min**

la fraction nuageuse et condensats

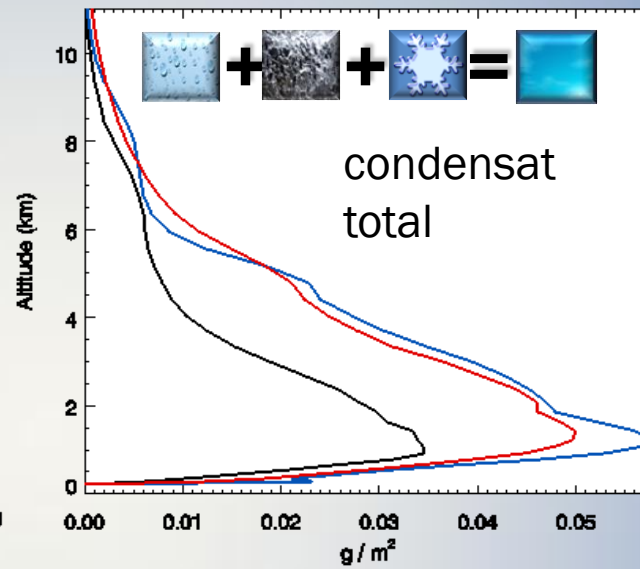
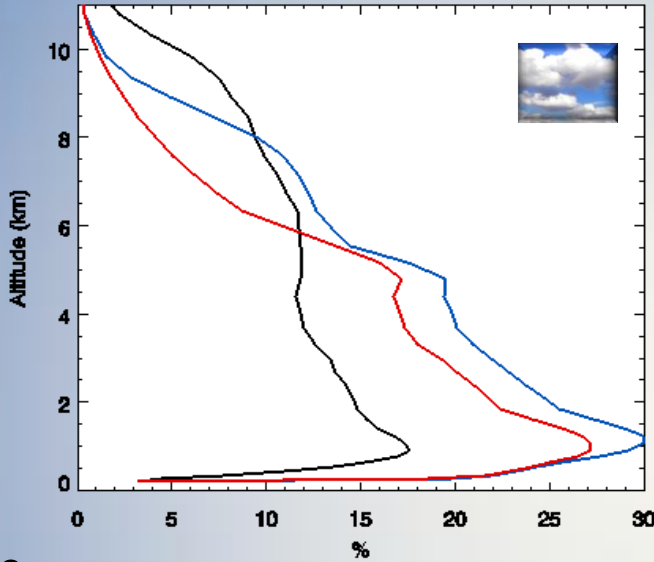
Cas d'été (1^{er} Juillet 2008), simulation de 48h



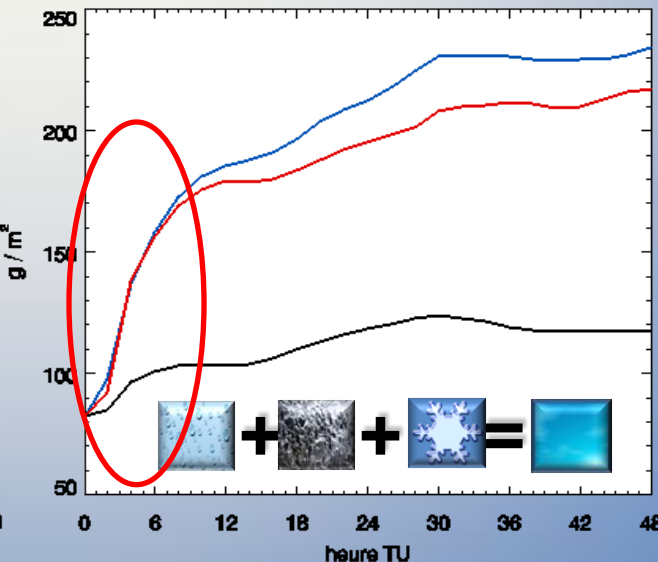
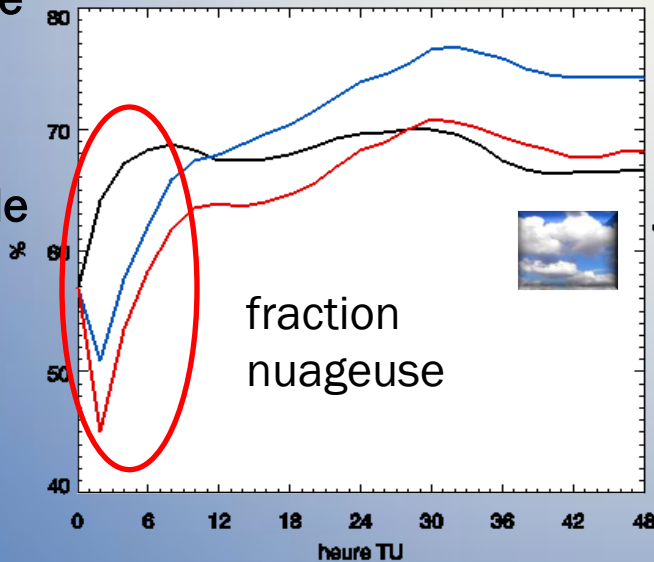
M&Y simple



M&Y double



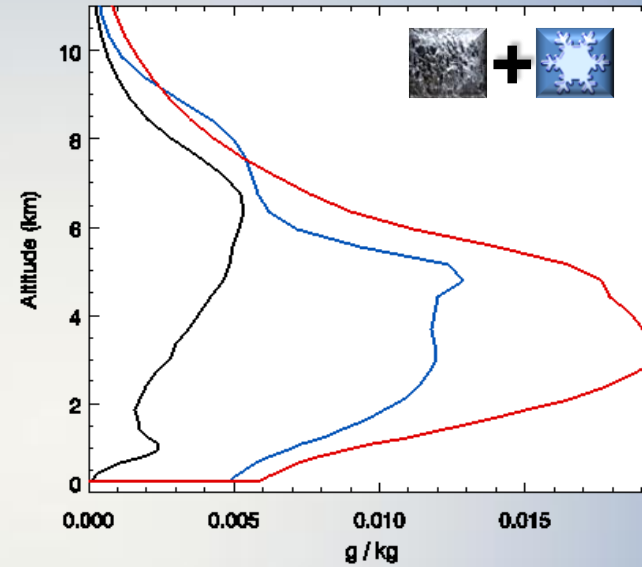
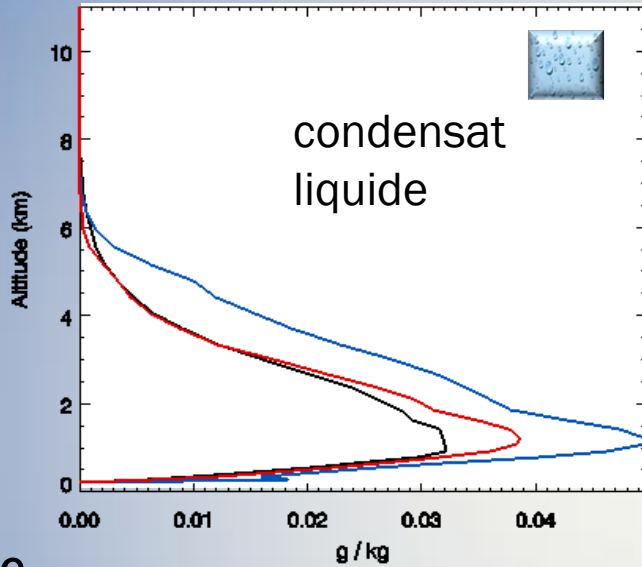
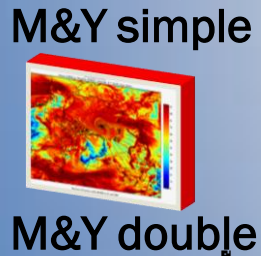
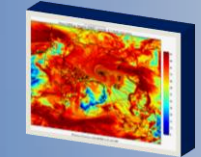
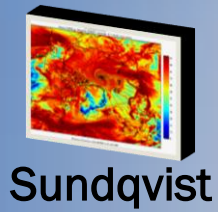
Profils verticaux
moyenne
spatiale
et temporelle



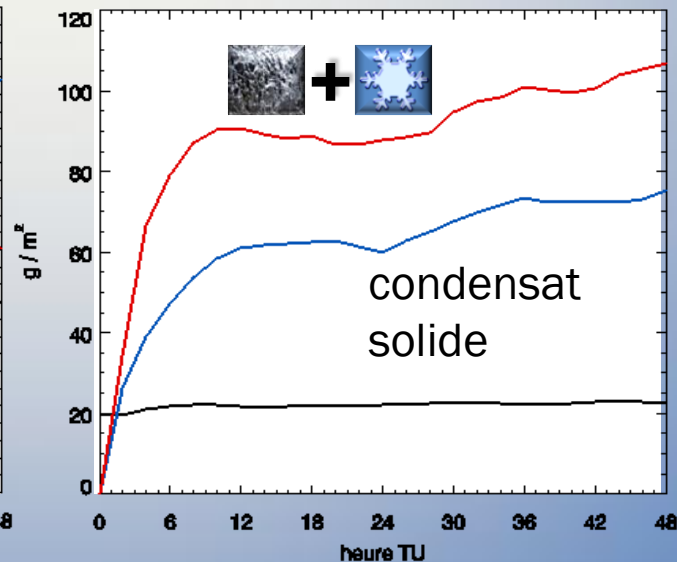
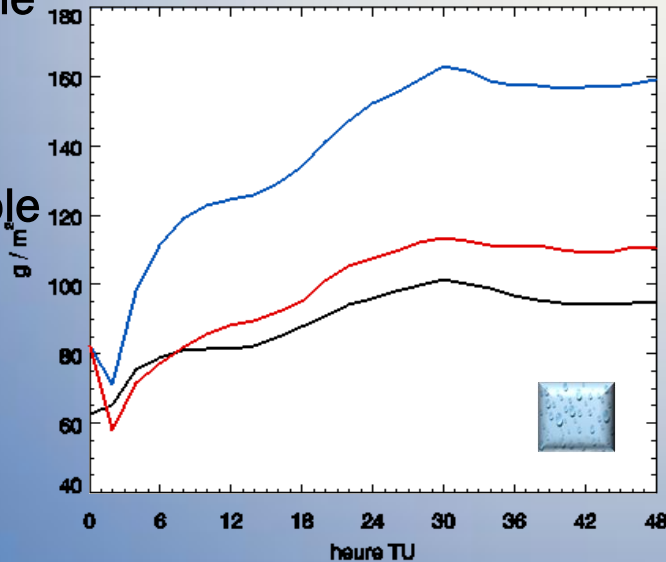
séries tempo.
de la moyenne
sur le domaine

la fraction nuageuse et condensats

Cas d'été (1^{er} Juillet 2008), simulation de 48h

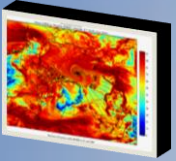


Profils verticaux
moyenne
spatiale
et temporelle



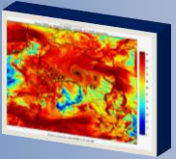
séries tempo.
de la moyenne
sur le domaine

la fraction nuageuse et condensats



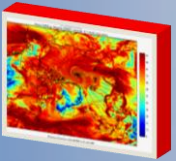
Sundqvist

plus de nuages hauts (fraction nuageuse)



M&Y simple

plus de nuages bas et intermediaires
fraction nuageuse totale légèrement supérieure
beaucoup plus de condensat



M&Y double

M&Y simple moment : plus d'eau liquide
M&Y double moment : plus de glace
Spin-up plus long

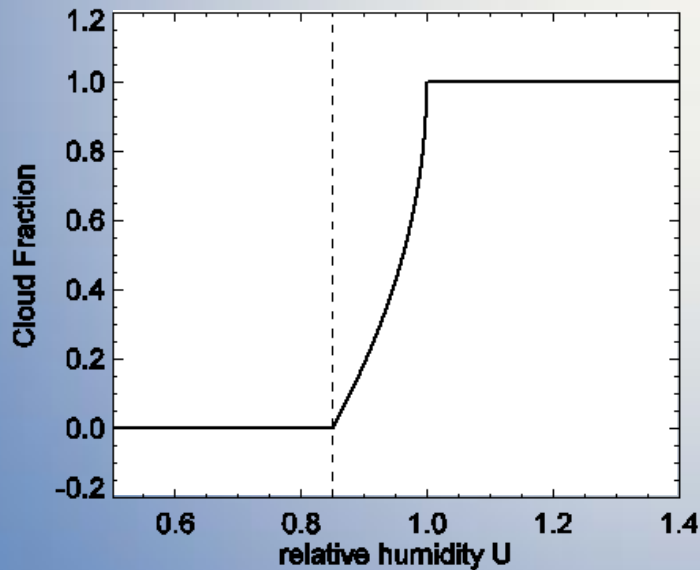
fraction nuageuse sous-maille

fraction nuageuse

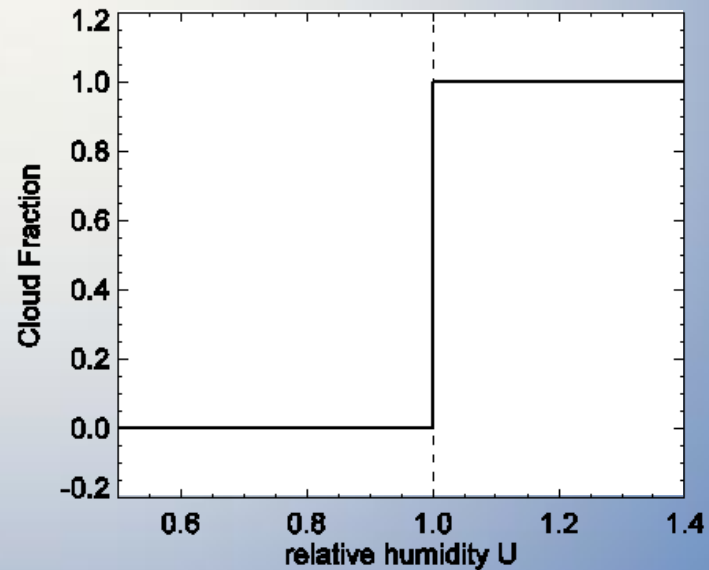
$$b = 1 - \sqrt{\frac{1-U}{1-U_{00}}}$$

*pour $U > U_{00}$ et $b = 0$ pour $U < U_{00}$
avec $0.85 \leq U_{00} \leq 0.975$ et $U_{00} = f(S, T)$*

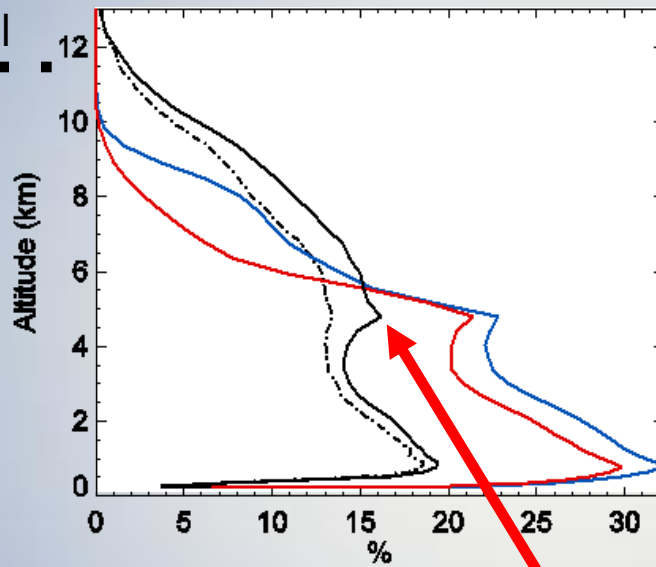
Exemple: $U_{00} = 0.85$



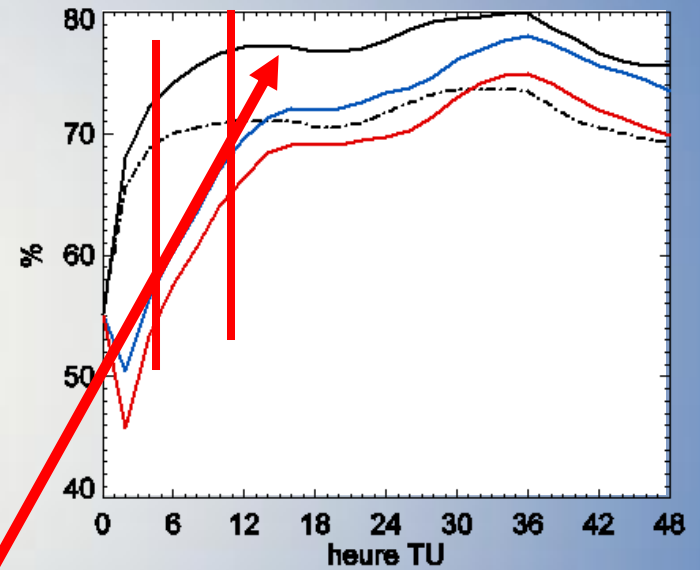
Test: $U_{00} = 0.9999$



fraction nuageuse sous-maille



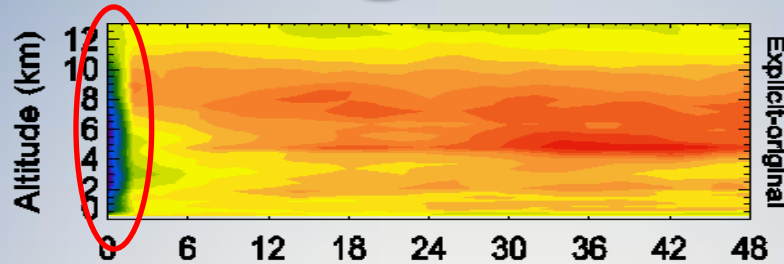
Spin-up plus long



Pas de fraction nuageuse sous-maille = plus de nuages!?

fraction nuageuse sous-maille

fraction nuageuse

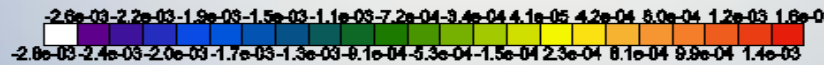
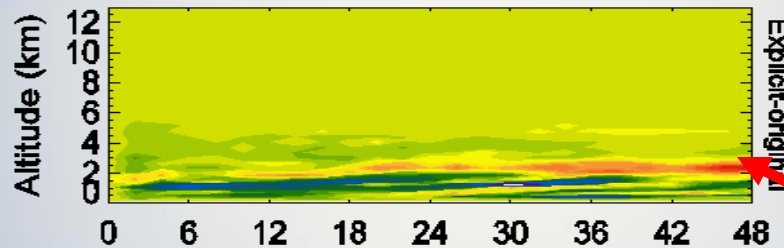


“Sans CF”

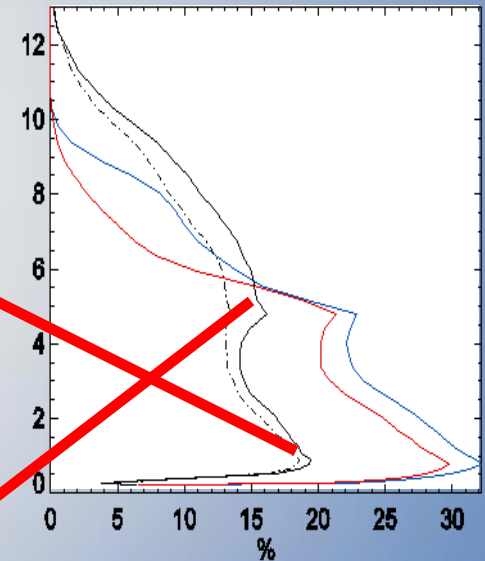
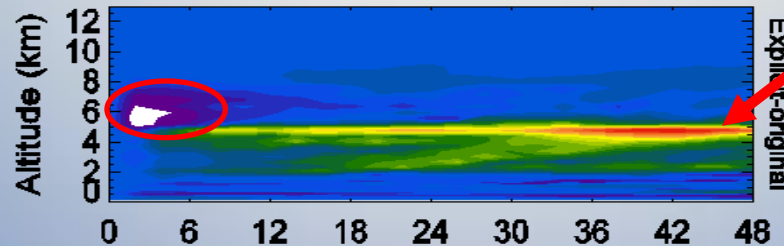


“original”

condensat liquide



condensat solide

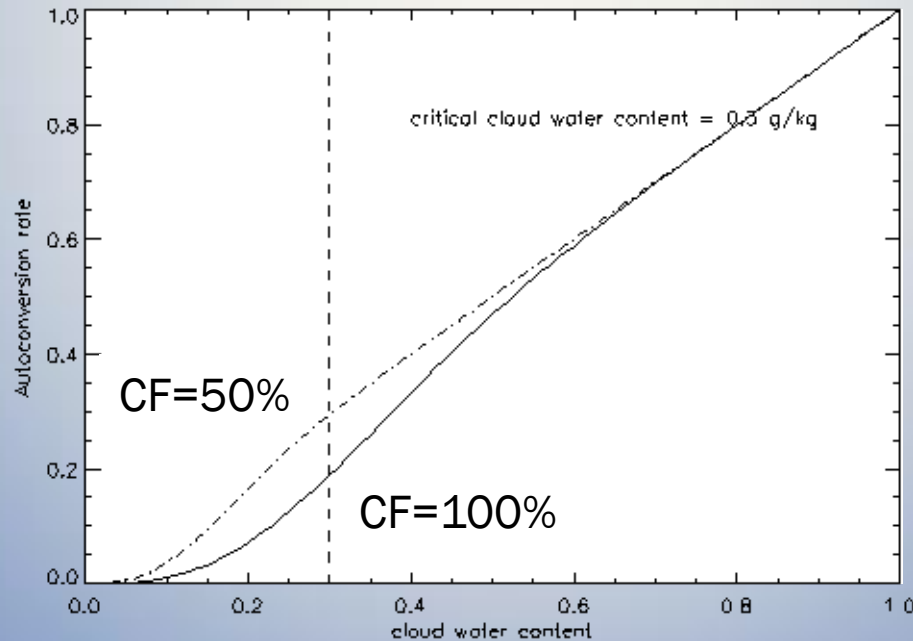


fraction nuageuse sous-maille

taux
d'autoconversion
(Sundqvist)

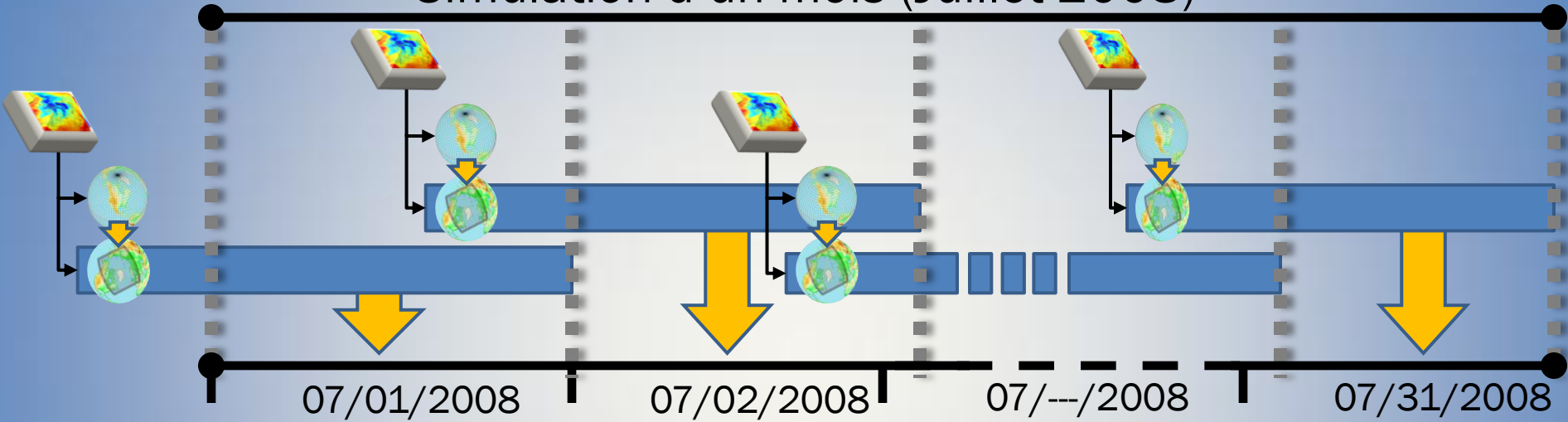
$$G_p = c_0 Q_x \left[1 - \exp \left(- \left(\frac{Q_x}{b \cdot Q_x^{crit}} \right)^2 \right) \right]$$

(déclenchement
des
précipitations)

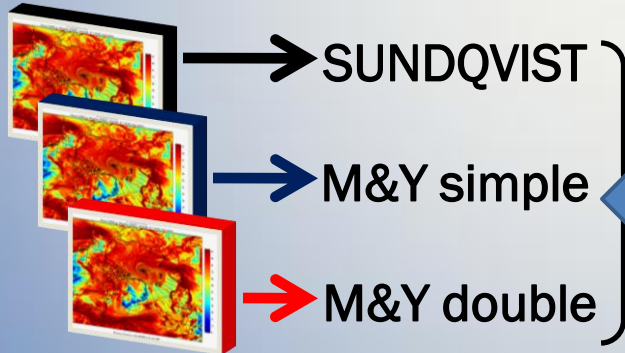


Les précipitations

Simulation d'un mois (Juillet 2008)



Champs simulés

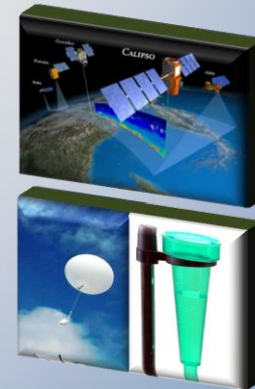


SUNDQVIST

M&Y simple

M&Y double

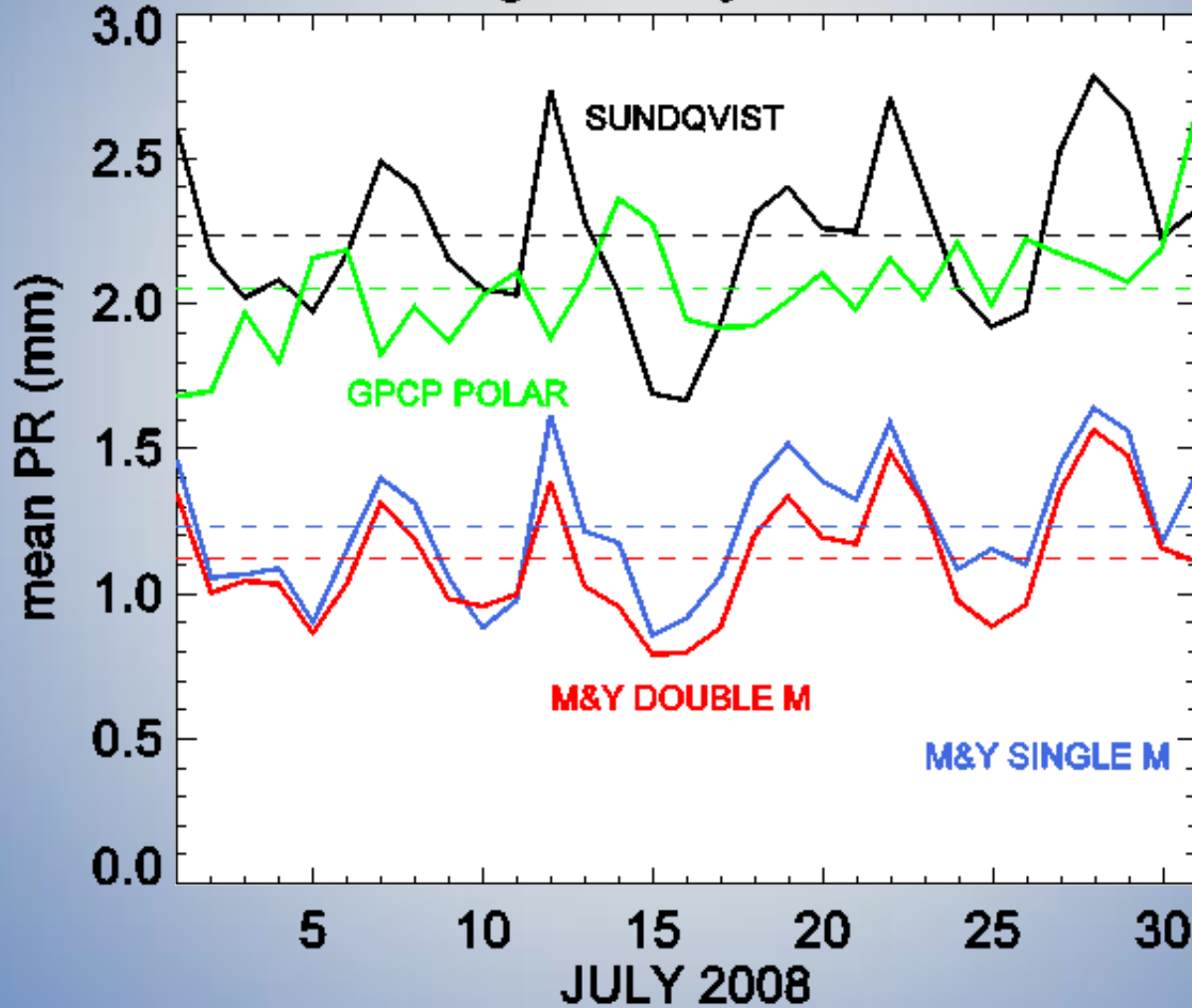
Données GPCP



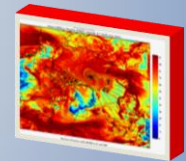
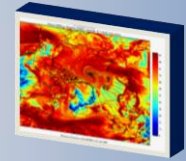
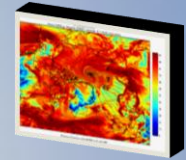
Champs observés

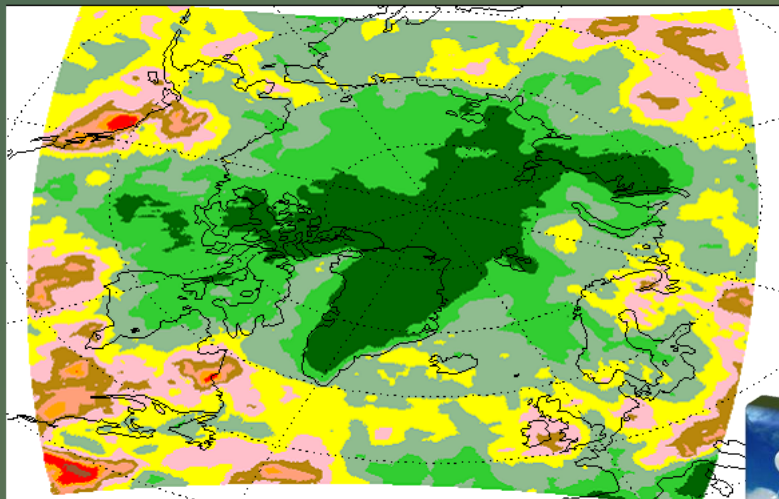
Les précipitations

Area averaged daily accum. tot. PR

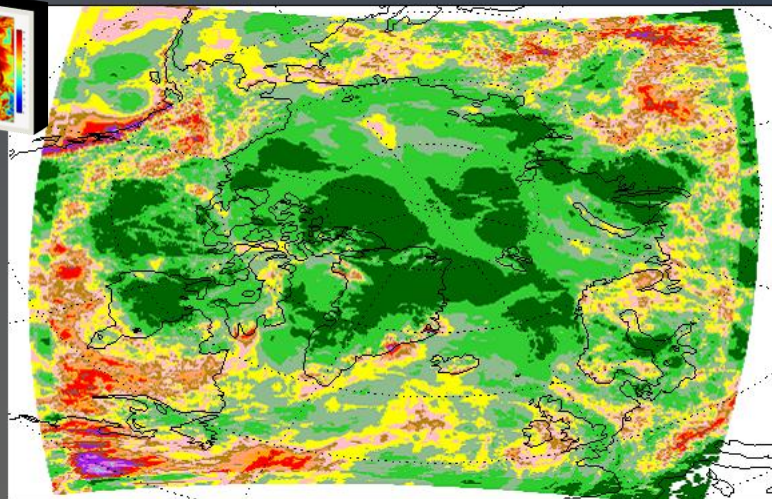
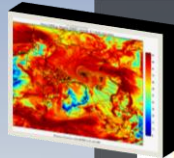


GPCP
merged
Obs.

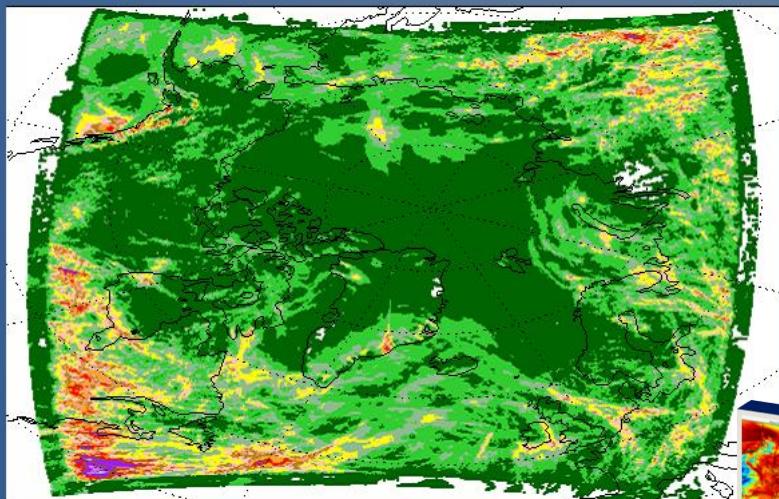




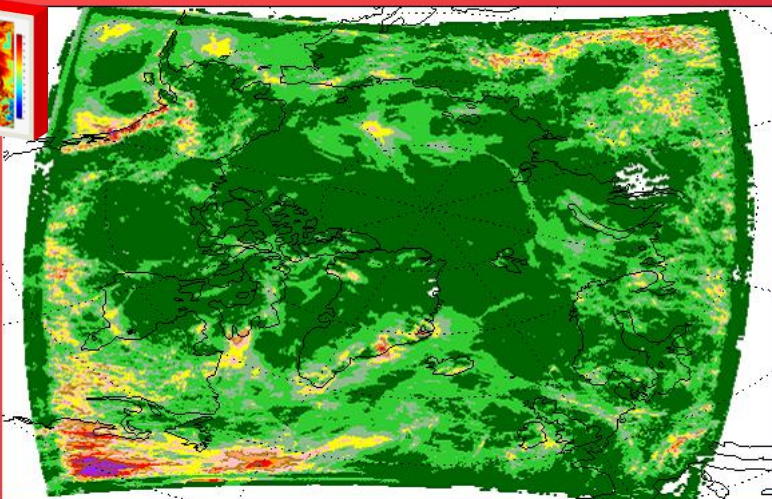
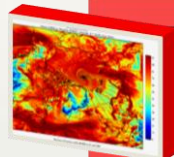
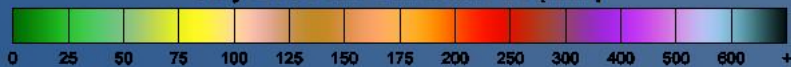
July 2008 GPCP total PR (mm)



July 2008 SUND total PR (mm)



July 2008 MYSM total PR (mm)

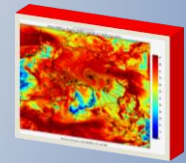
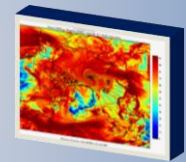
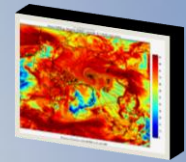
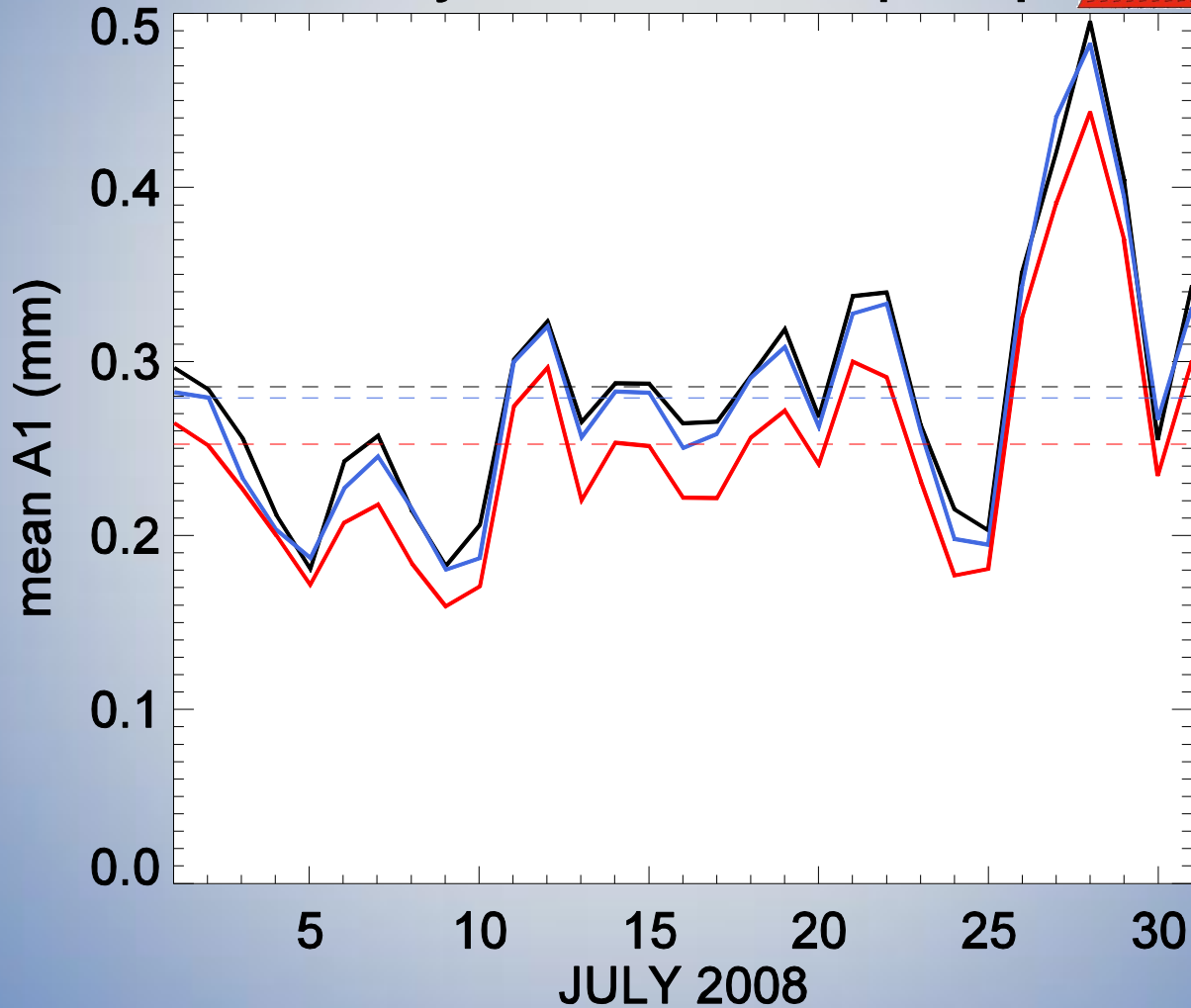
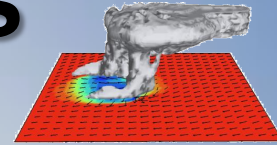


July 2008 MYDM total PR (mm)



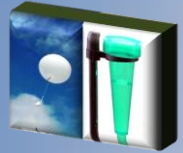
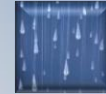
Les précipitations

daily accum. conv. precip

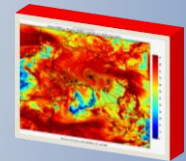
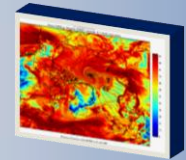
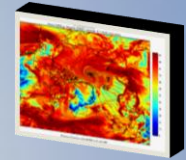
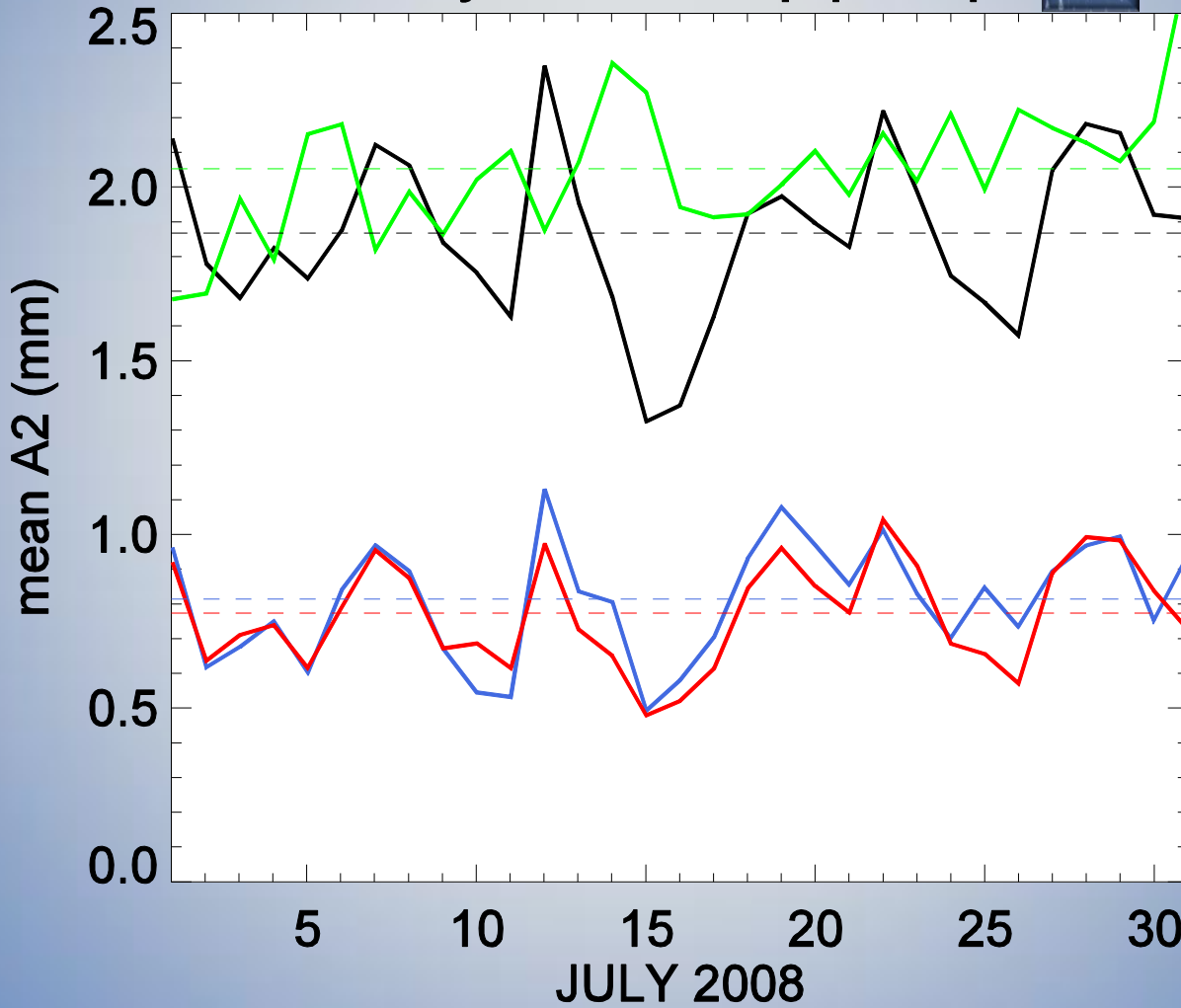


Les précipitations

daily accum. liq. precip

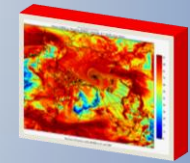
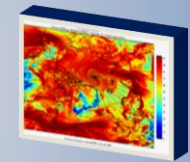
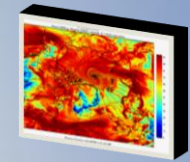
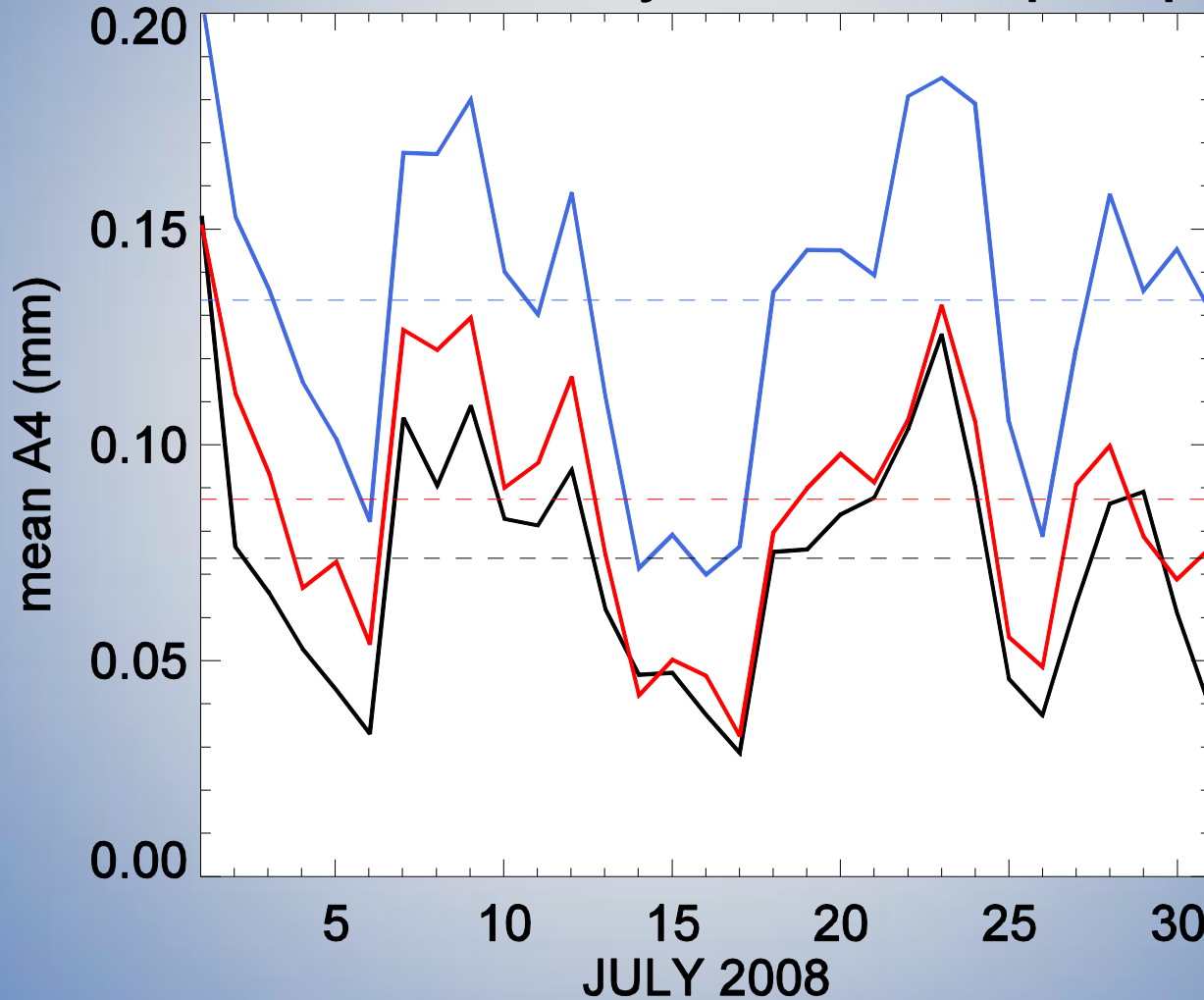


GPCP
merged
Obs.



Les précipitations

Mean Area daily accum. ice. precip



Les précipitations

taux
de production
de précipitations:
COALESCENCE !

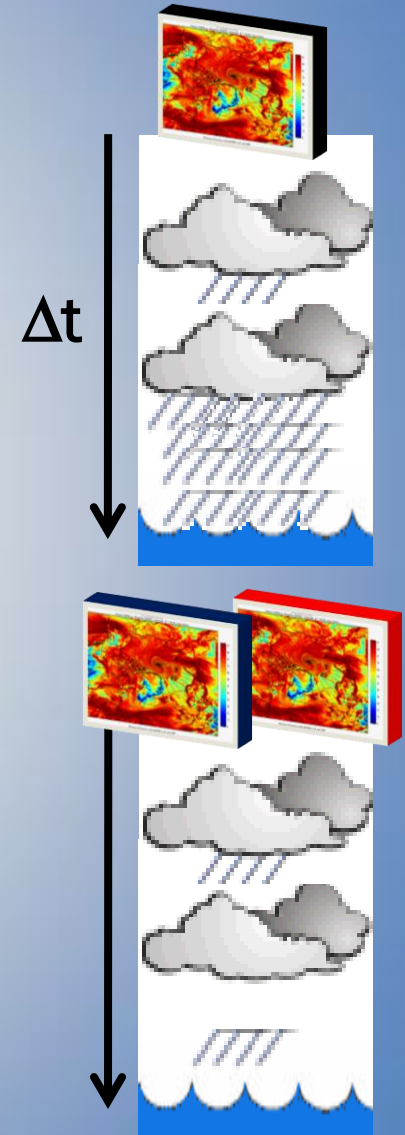
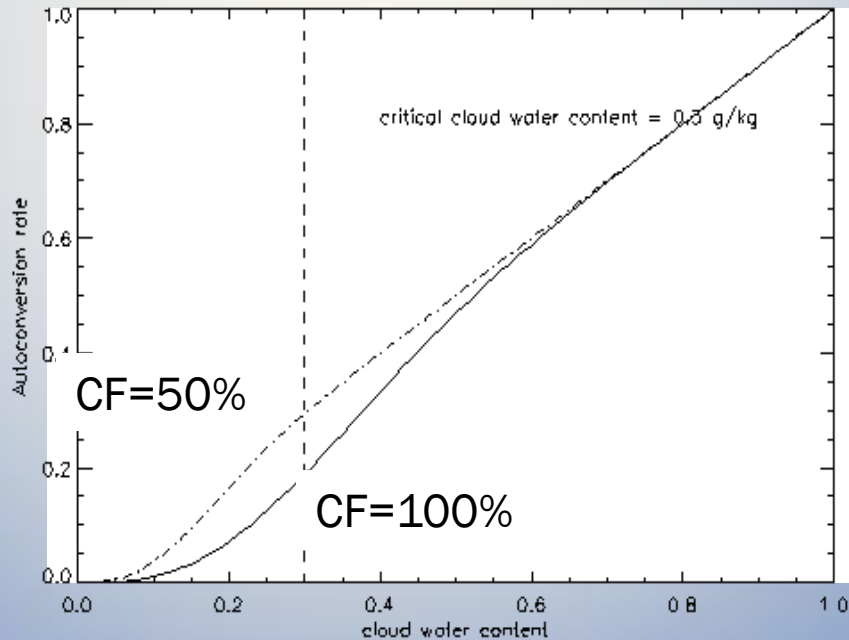
$$G_p = c_0 Q_x \left[1 - \exp \left(- \left(\frac{Q_x}{b \cdot Q_x^{crit}} \right)^2 \right) \right]$$

$$c_0 = c_0^* F_1 F_2$$

$$Q_x^{crit} = Q_x^{crit*} F_1 F_2$$

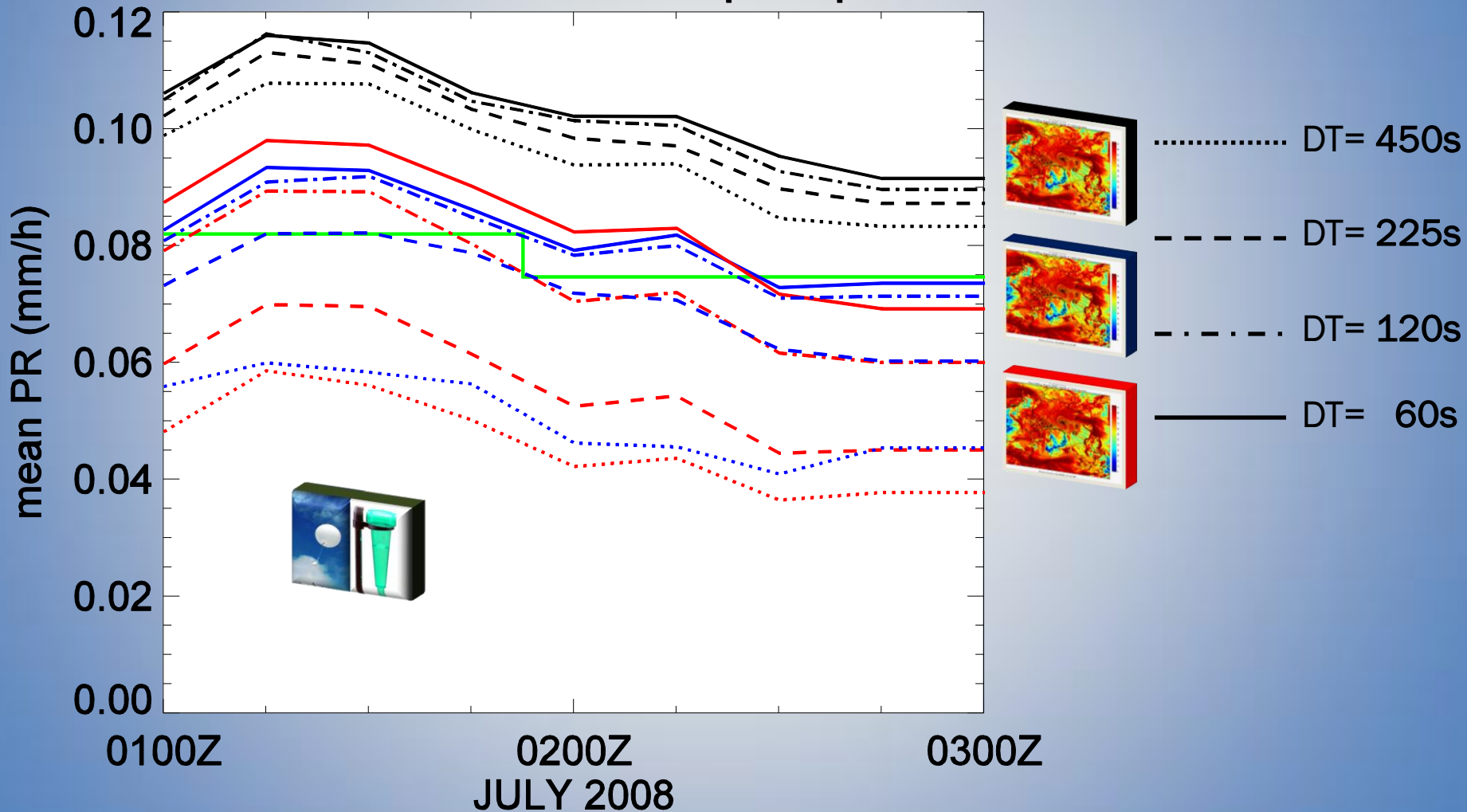
$$F_1 = 1 + b_1 \sqrt{P_{loc}}$$

$$b_1 = 300 \text{ kg} \cdot \text{m}^{-2} \cdot \text{s}^{-1}$$



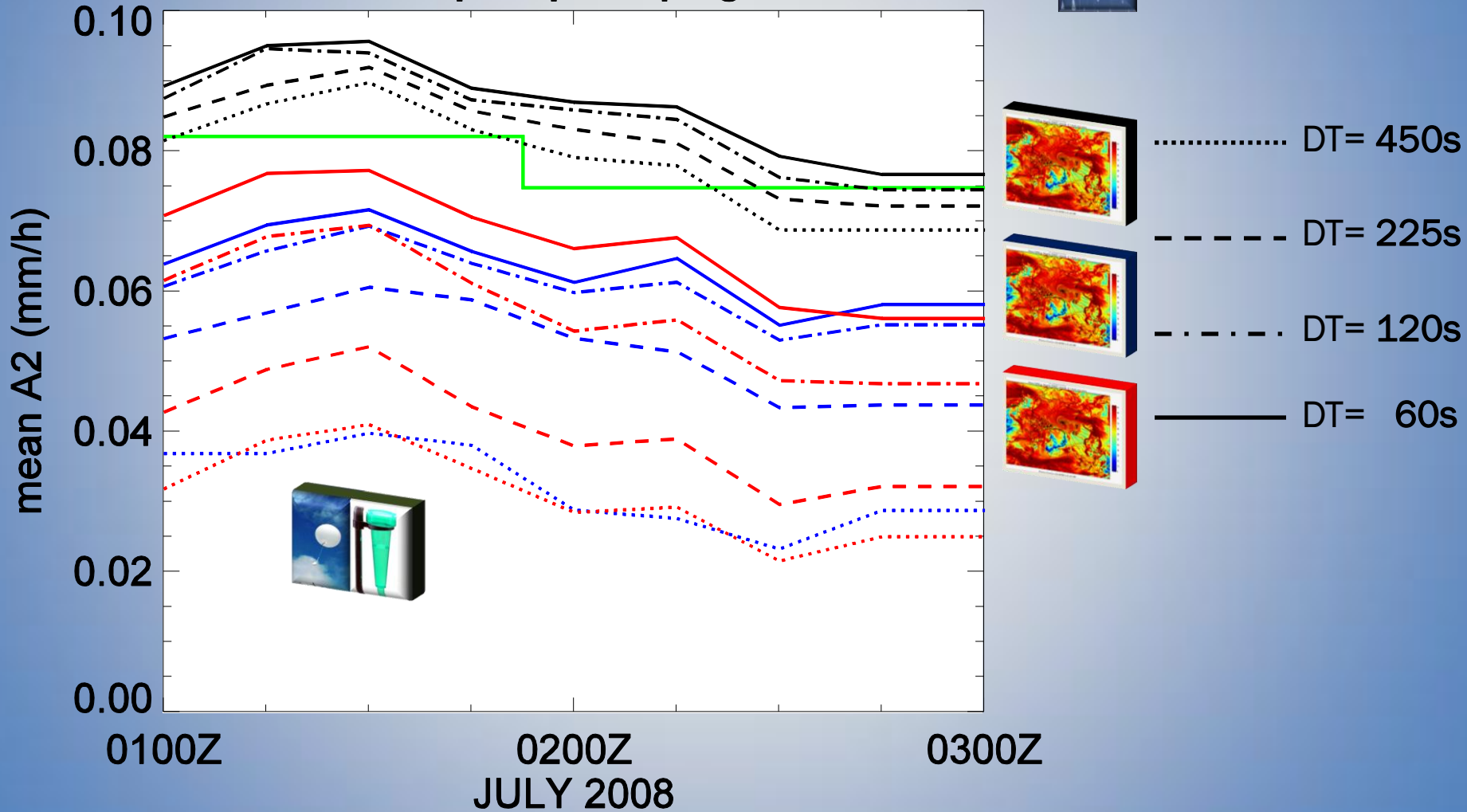
Le pas de temps microphysique

PR: accum. of total precip.



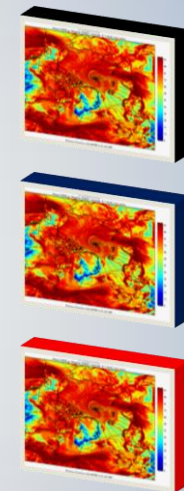
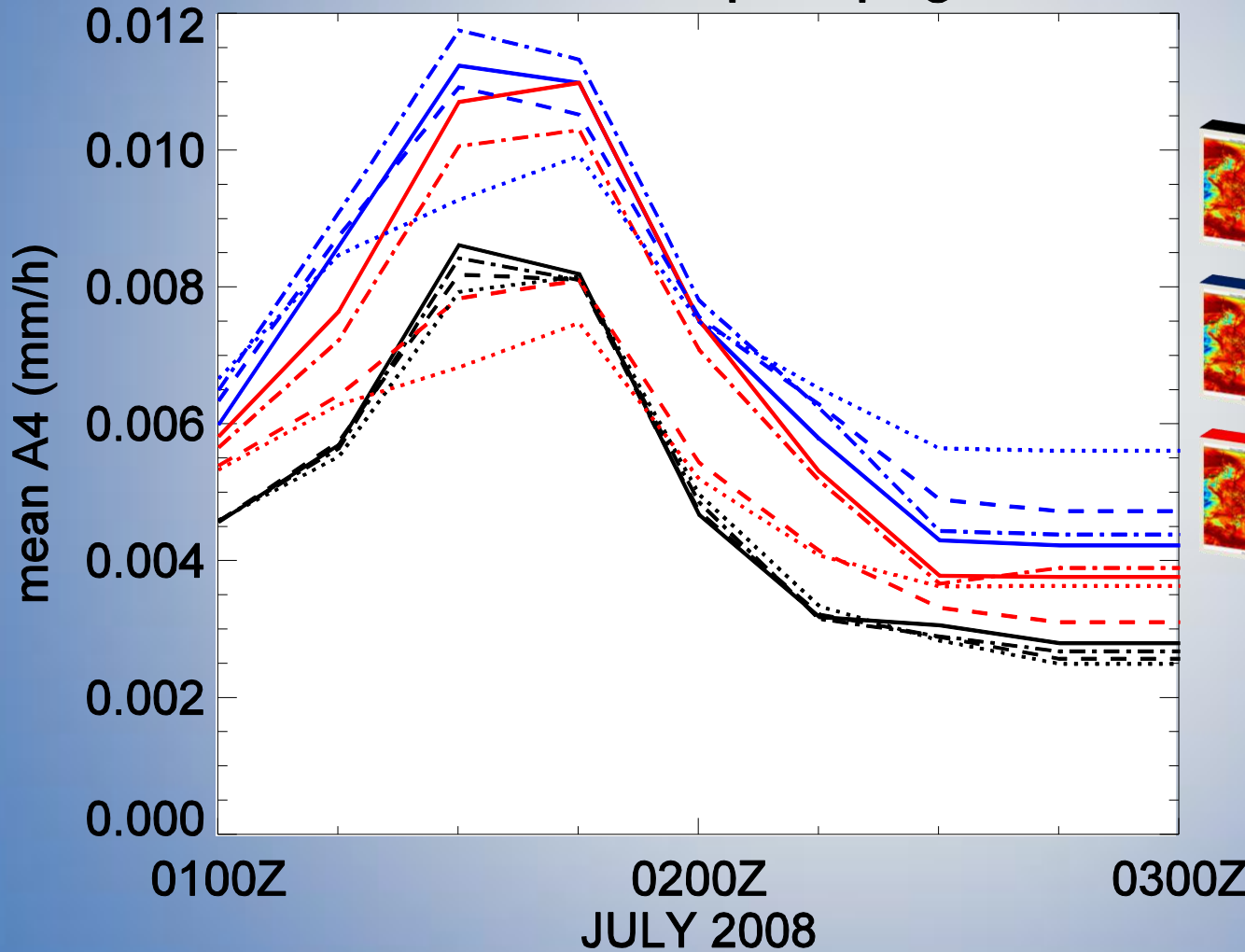
Le pas de temps microphysique

A2: accum. of liquid precip, grid-scale conc



Le pas de temps microphysique

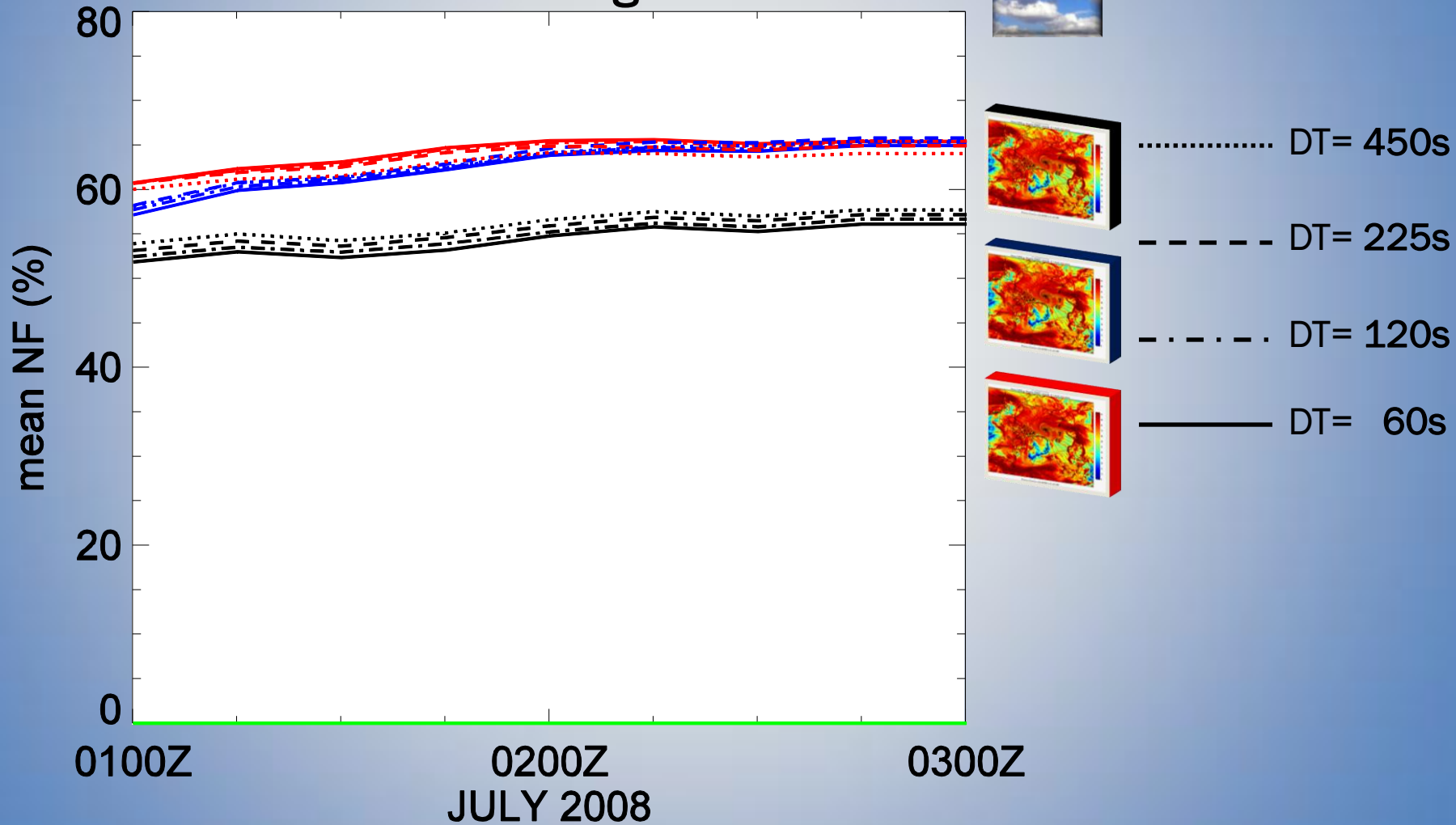
A4: accum. of total solid precip, grid-scale cc



- DT= 450s
- DT= 225s
- .-.-.- DT= 120s
- DT= 60s

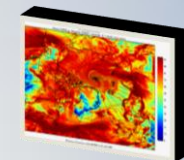
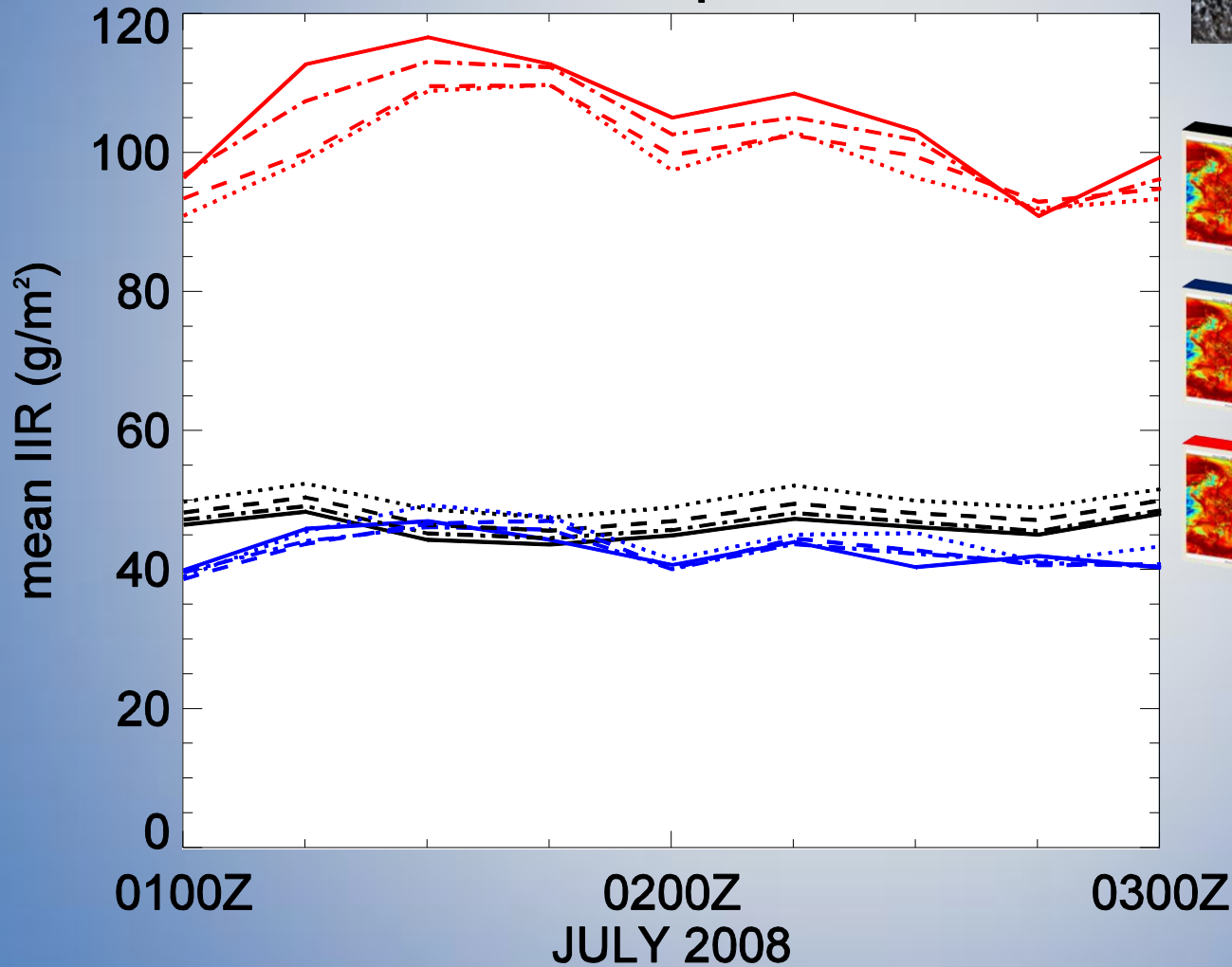
Le pas de temps microphysique

Fraction nuageuse

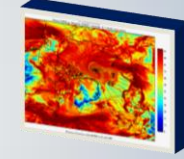


Le pas de temps microphysique

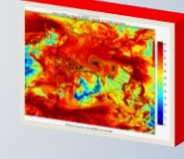
Condensat solide



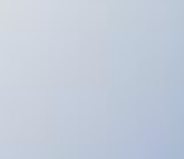
..... DT= 450s



----- DT= 225s



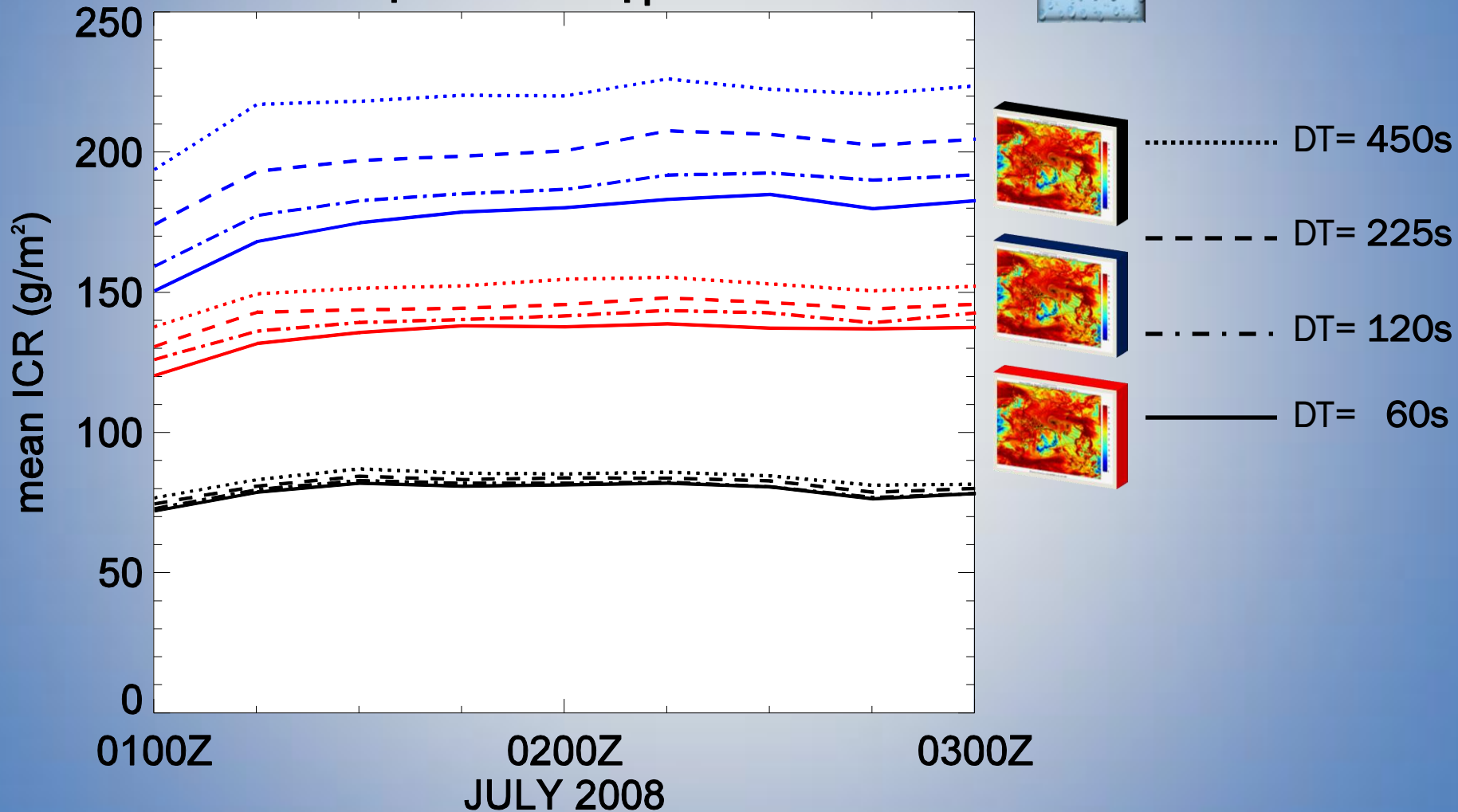
- . - . - . DT= 120s



————— DT= 60s

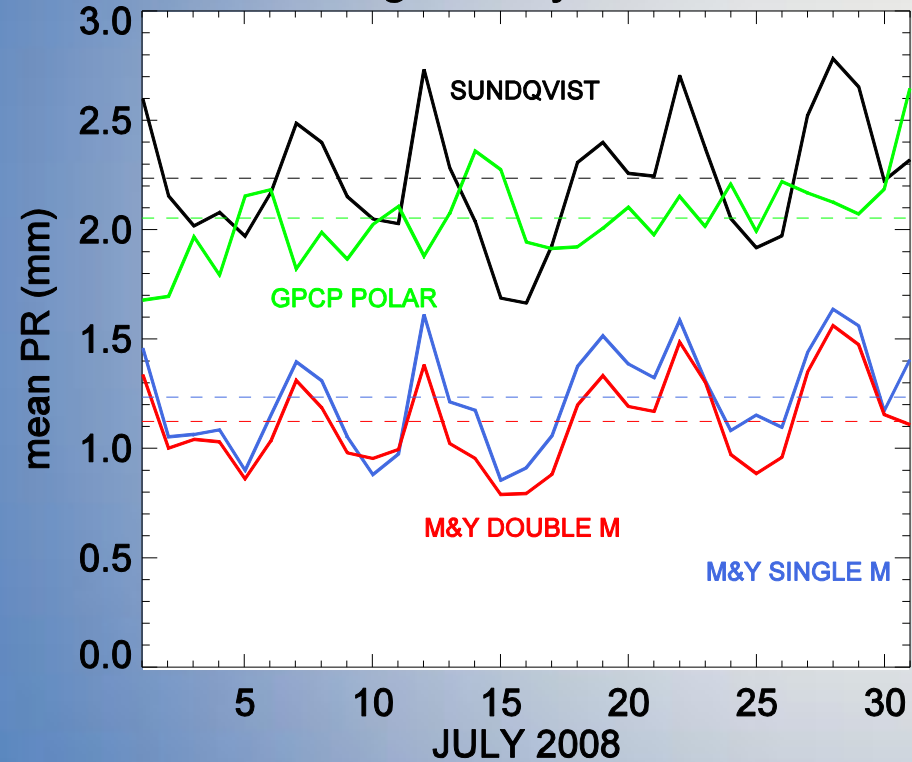
Le pas de temps microphysique

Condensat liquide



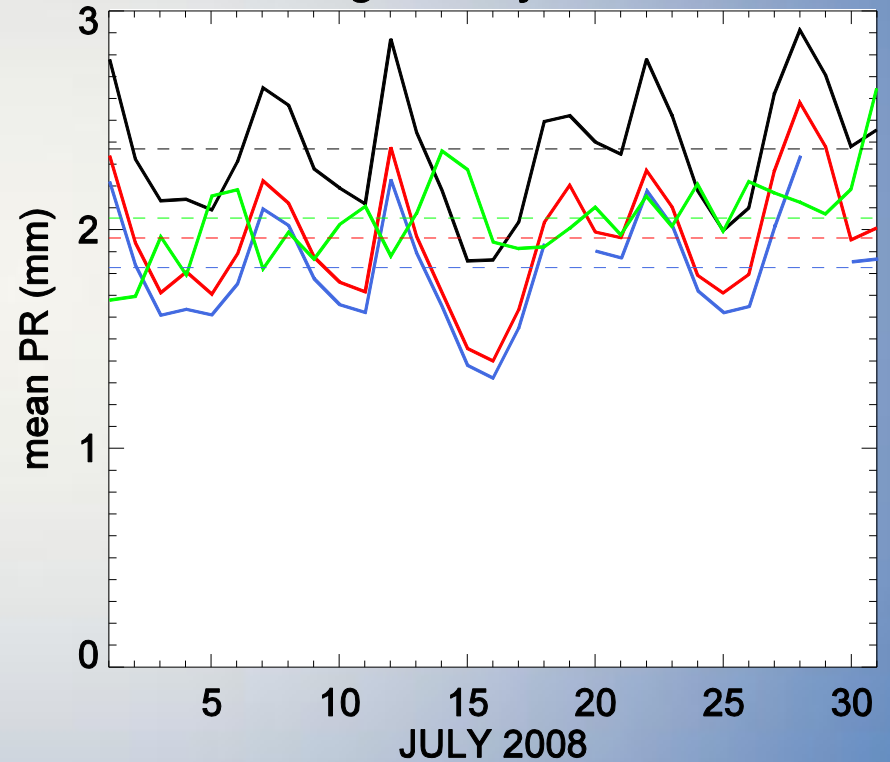
Le pas de temps microphysique

Area averaged daily accum. tot. PR

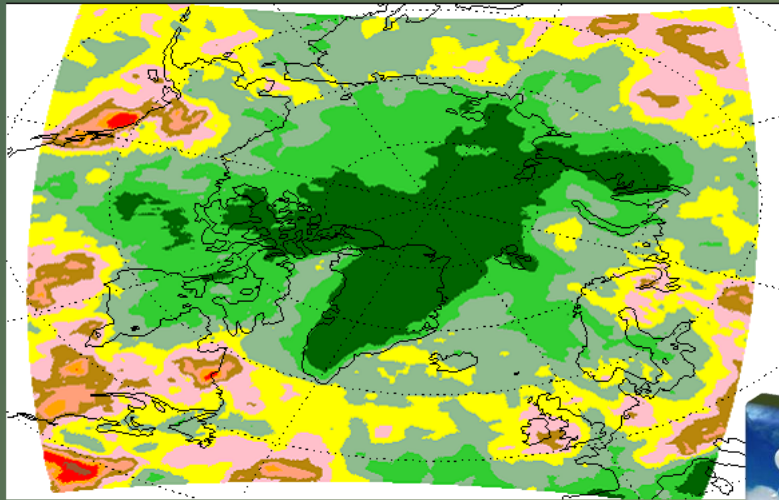


DT = 450 sec

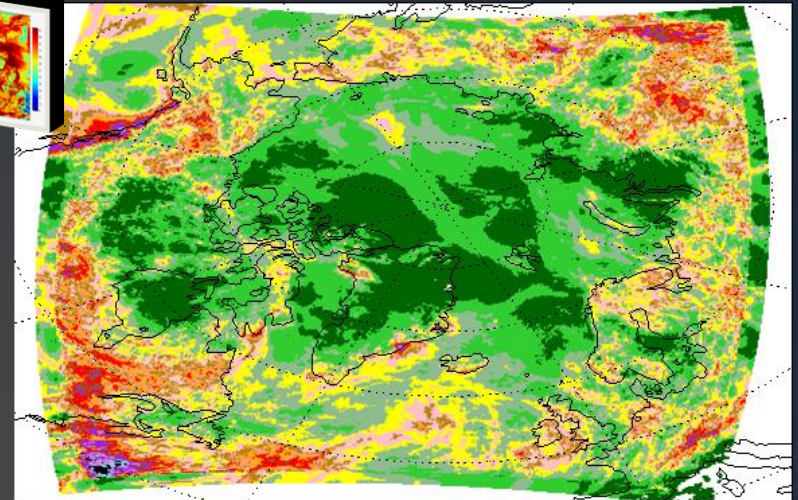
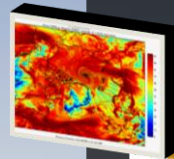
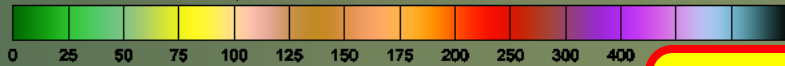
Area averaged daily accum. tot. PR



DT = 60 sec



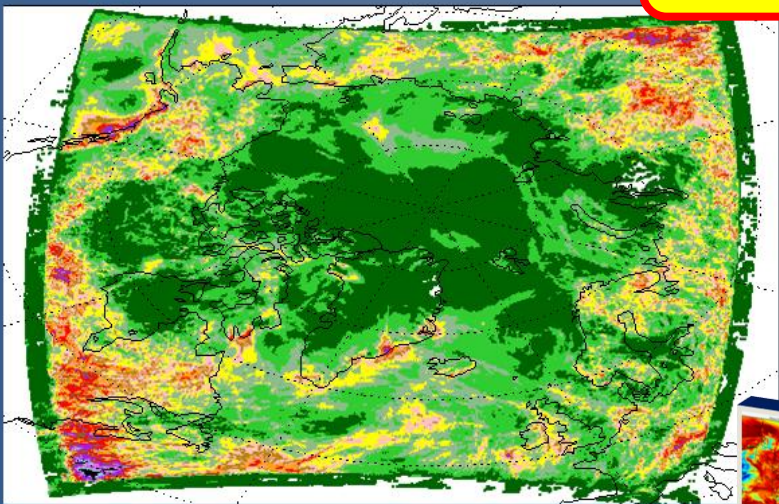
July 2008 GPCP total PR (mm)



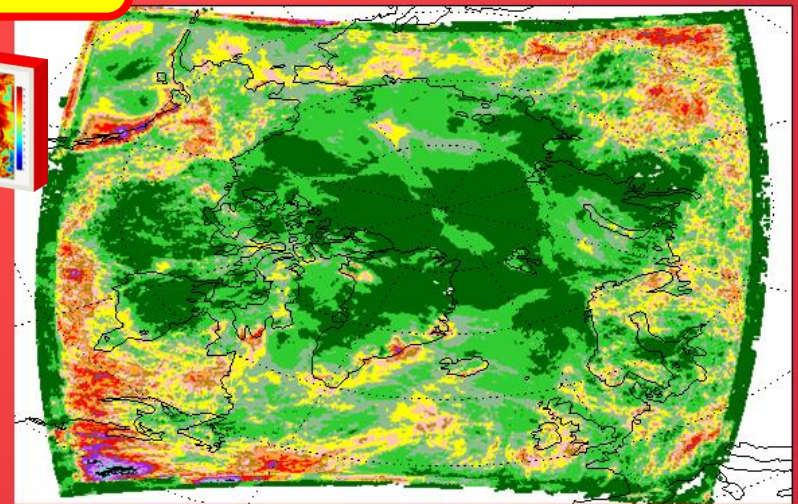
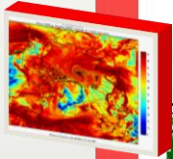
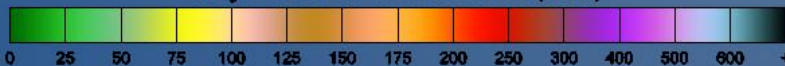
July 2008 SUND total PR (mm)



DT = 60 sec



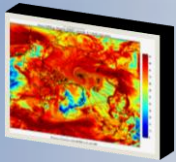
July 2008 MYSM total PR (mm)



July 2008 MYDM total PR (mm)

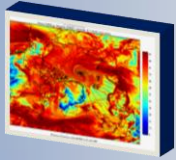


Le coût CP de la microphysique



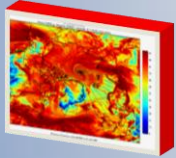
référence

x 7.7



x 1.2

x 11



x 1.2

x 10.1

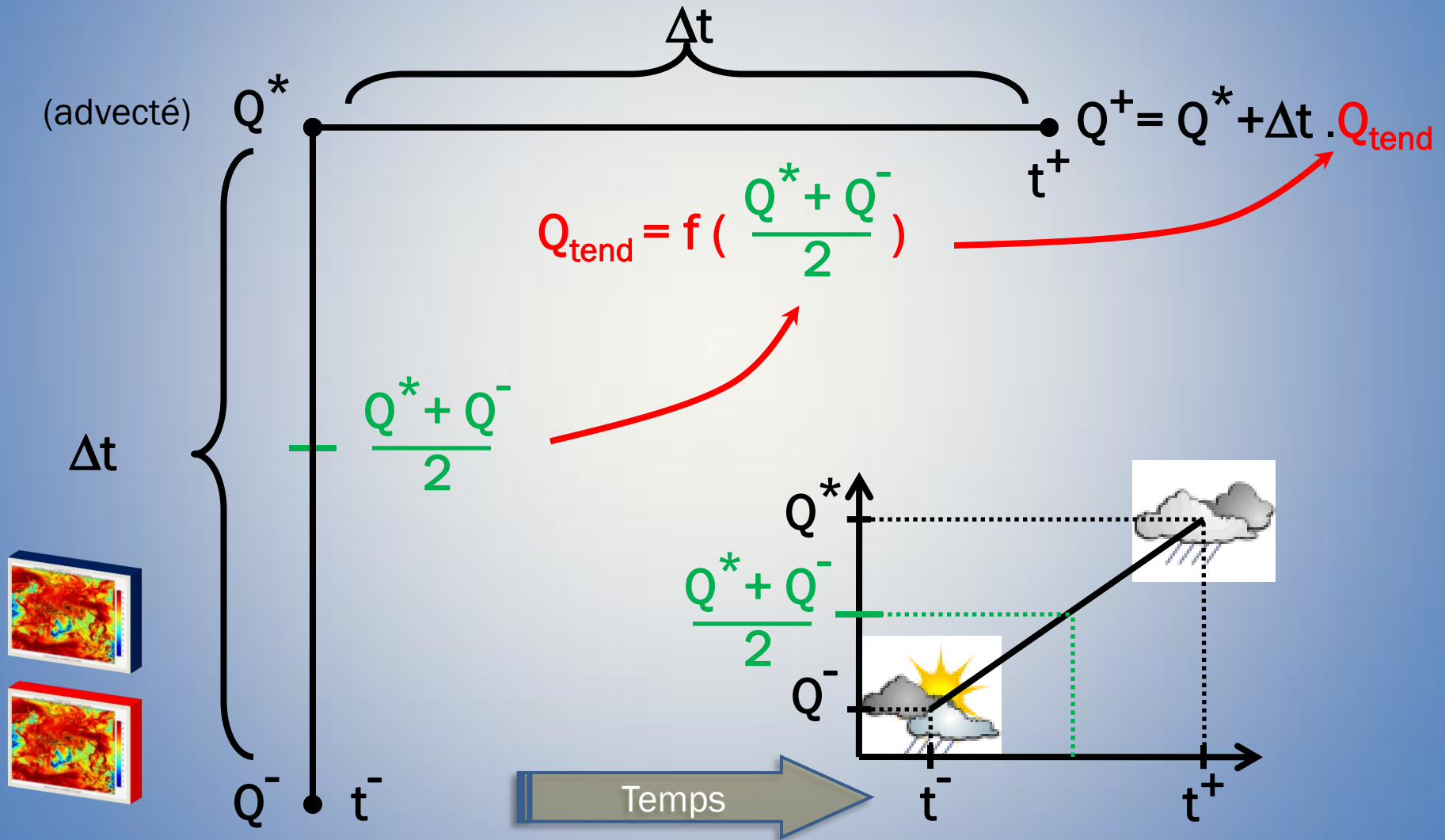
DT = 450 sec

DT = 60 sec

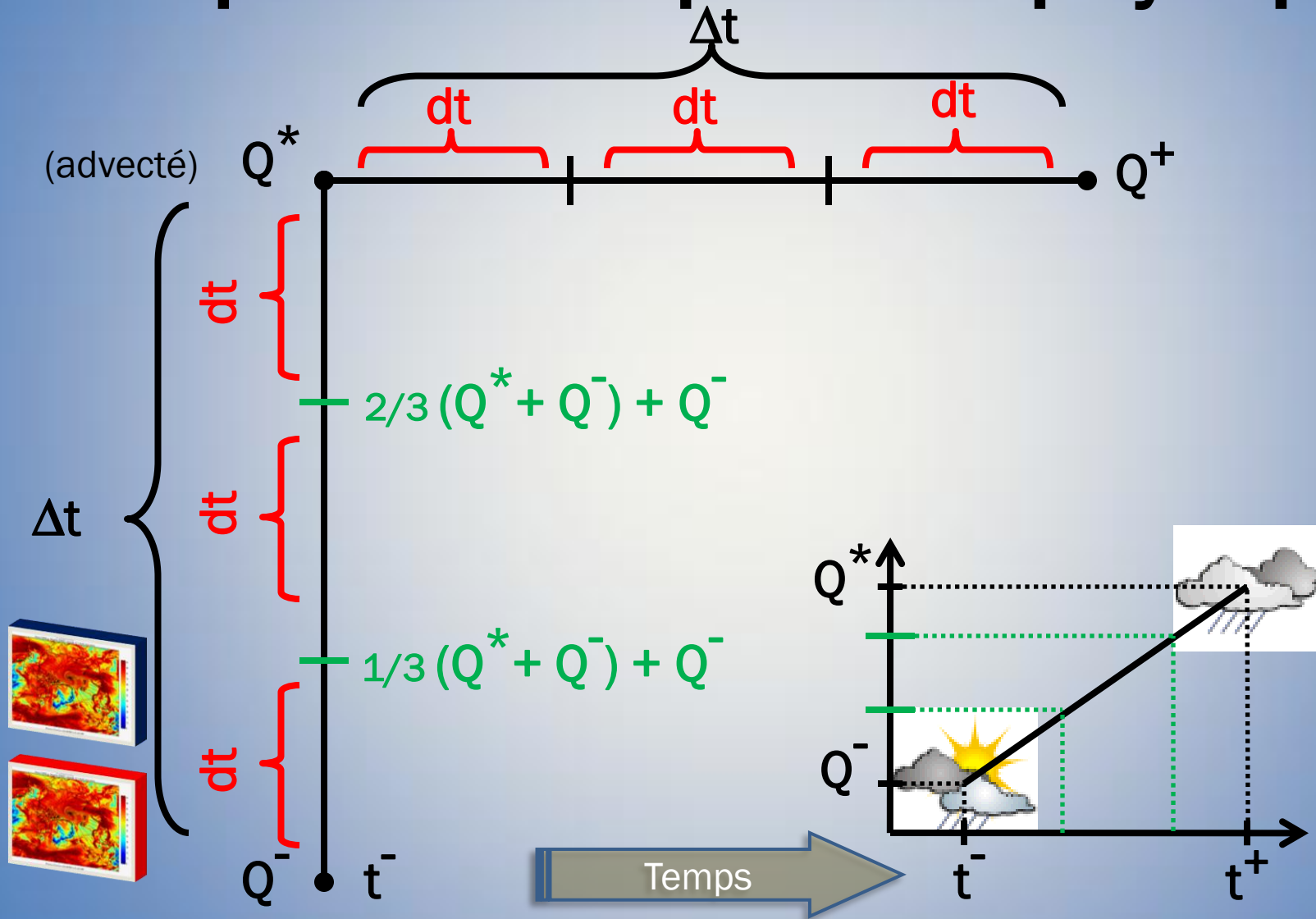


Réduire le coût, garder le concept

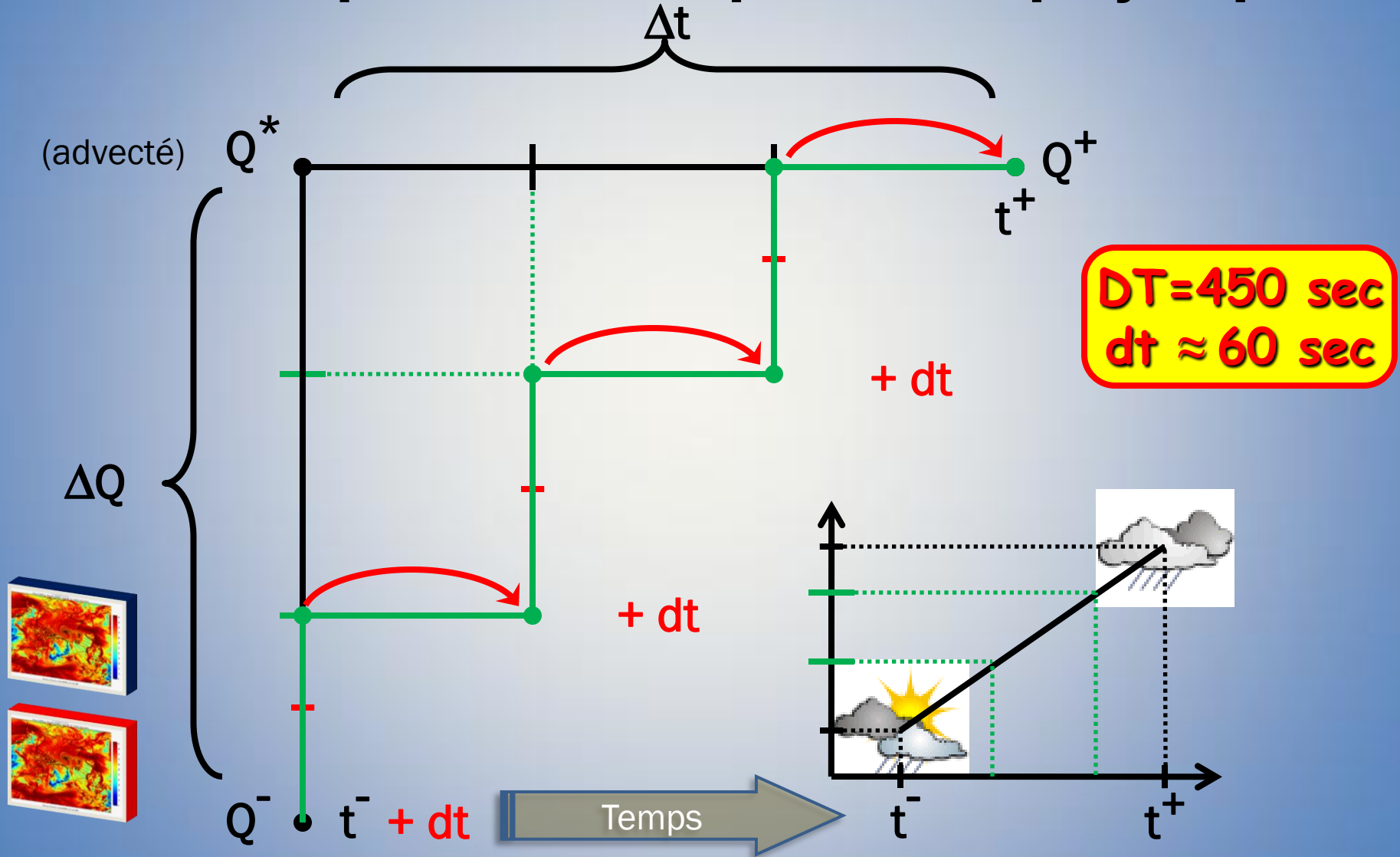
Le pas de temps microphysique



Le pas de temps microphysique

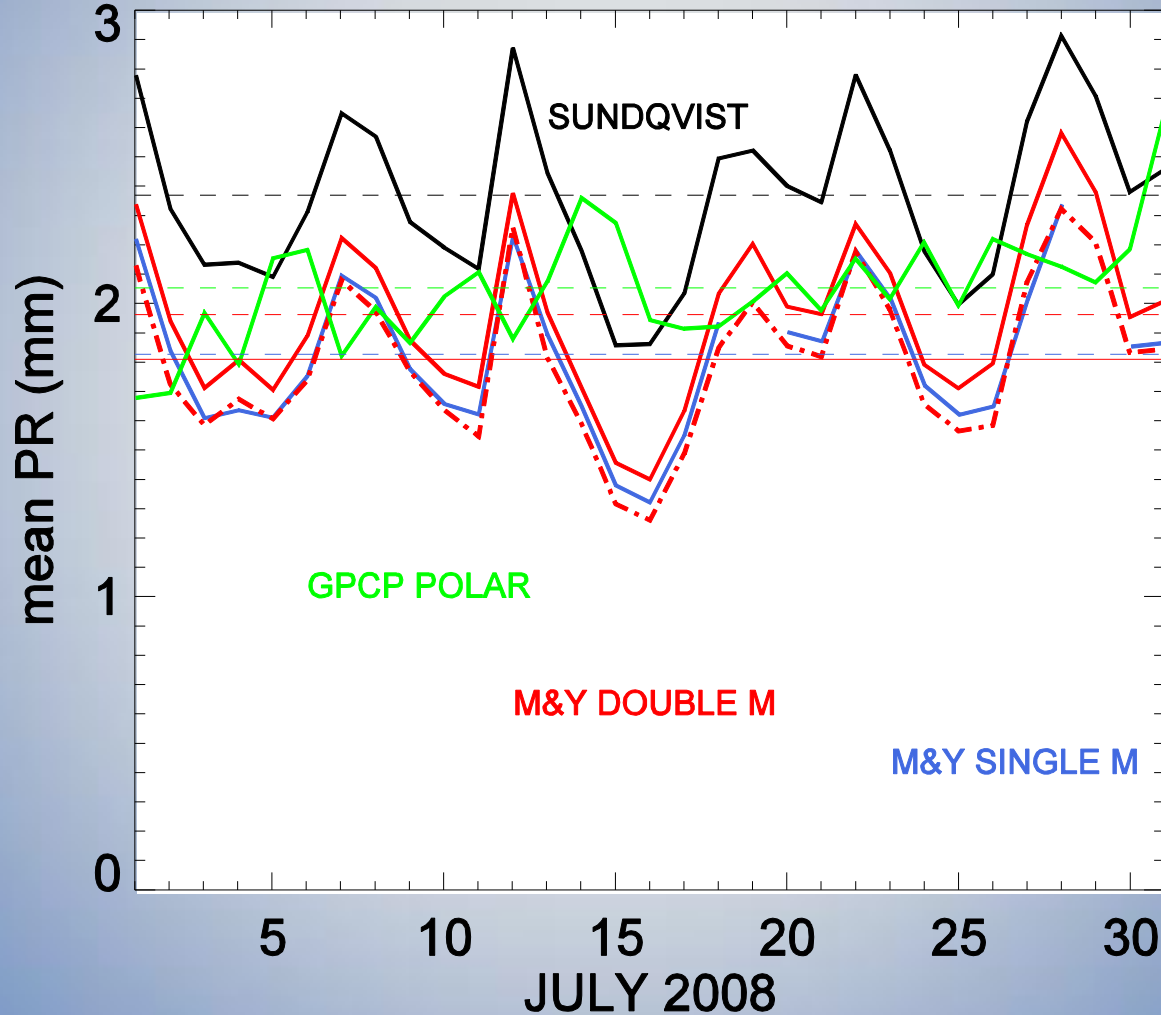


Le sous-pas de temps microphysique



Le sous-pas de temps microphysique

Area averaged daily accum. tot. PR



M&Y double:

DT=60 sec

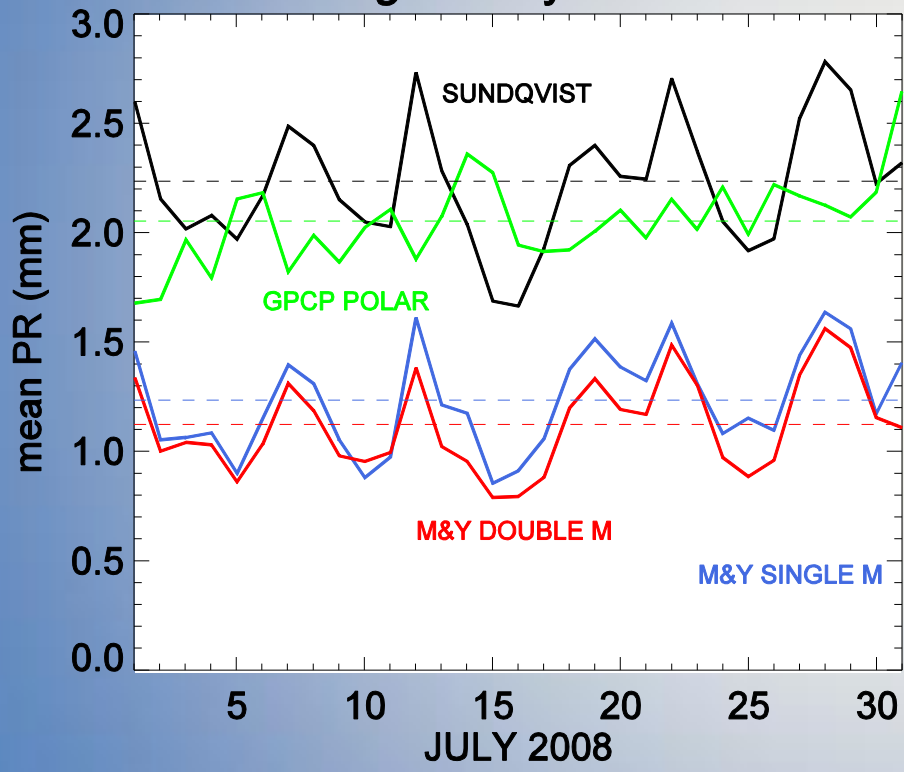
M&Y double:

**DT=450 sec
dt ≈ 60 sec**

M&Y double:

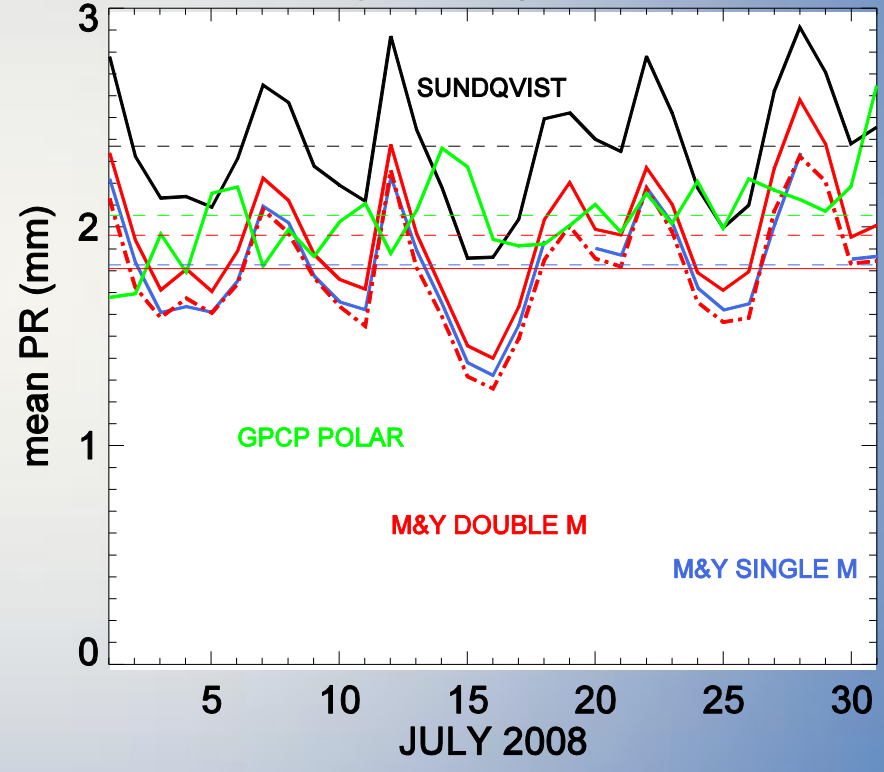
DT=450 sec
dt ≈ 60 sec

Area averaged daily accum. tot. PR



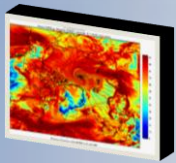
DT = 450 sec

Area averaged daily accum. tot. PR



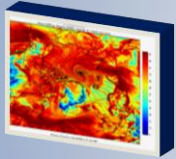
DT = 60 sec

Le coût CP de la microphysique



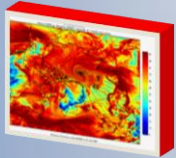
référence

x 7.7



x 1.2

x 11



x 1.2

x 10.1

x 2.3!

DT = 450 sec

DT = 60 sec

DT = 450 sec

dt_{micro} = 60 sec



Autres pistes?

Le coût CP de la microphysique



réduire le coût de la sédimentation

Espèces qui sédimentent:



Espèces qui ne sédimentent pas:



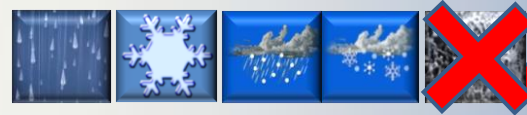
Le coût CP de la microphysique



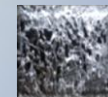
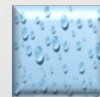
réduire le coût de la sédimentation

sédimentation: part la plus importante du coût total

Espèces qui sédimentent:

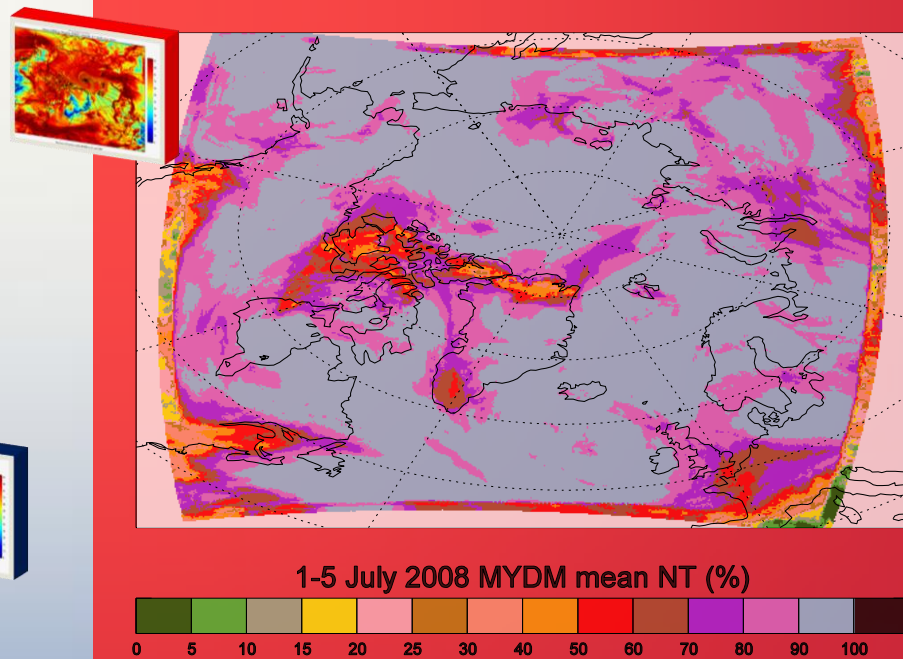
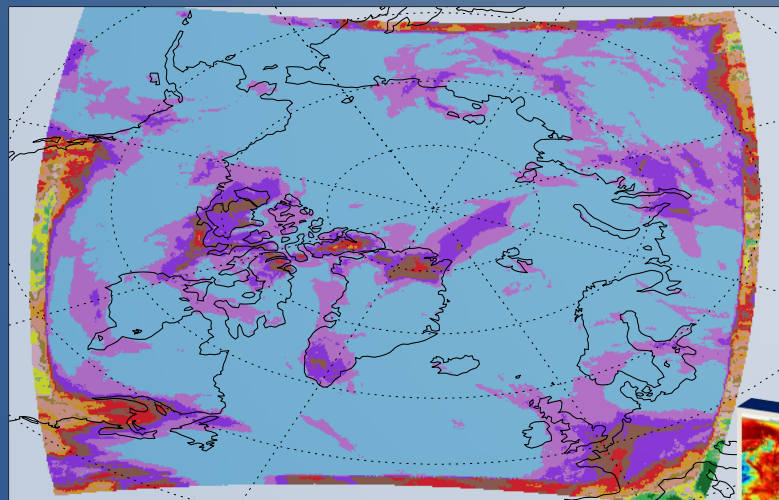
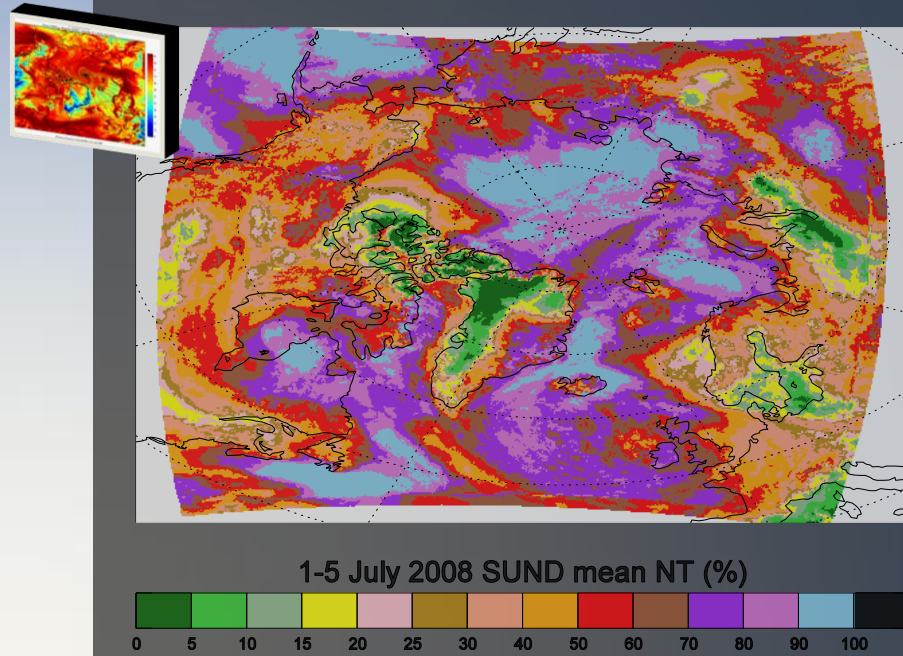
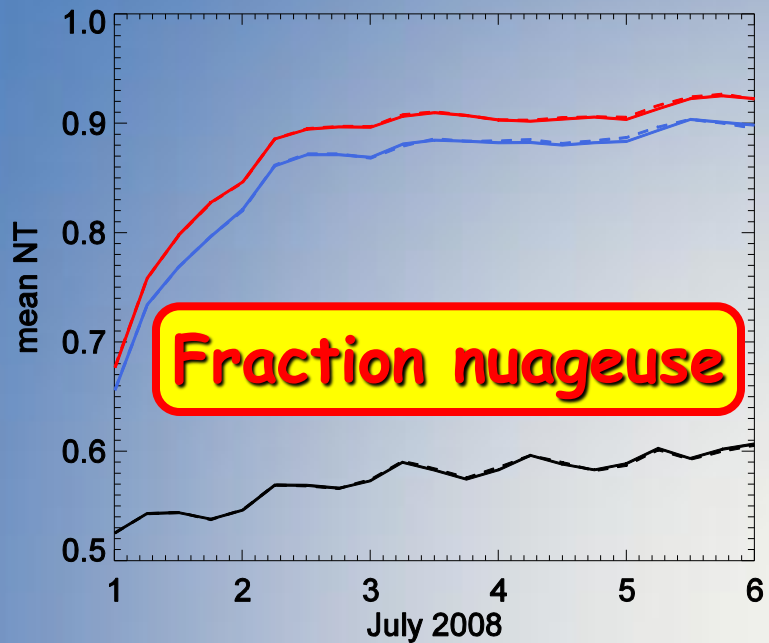


Espèces qui ne sédimentent pas:



petites particules
vitesse de sédimentation lente
impact faible dans les CRM

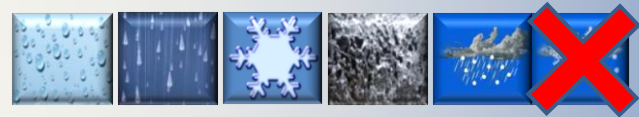
Q_i
 N_i



Le coût CP de la microphysique

➔ réduire le nombre de classes d'hydrométéores

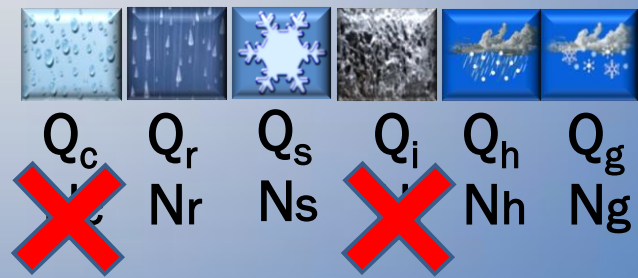
Supprimer grêle ou neige roulée:



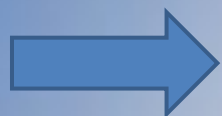
Fusionner certaines classes :



Supprimer le double moment pour certaines classes :



Résumé



Des schémas microphysiques différents donnent **des résultats très différents**

(fraction nuageuse, condensats, précipitations)



La fraction nuageuse sous-maille est indispensable

(diminuerait le spin-up, éviterait le problème d'accumulation, altérerait la fraction nuageuse, augmenterait les précipitations)



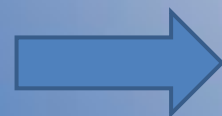
Un schéma microphysique **réaliste** donne des réponses **non linéaires et complexes**



Un schéma microphysique est très sensible au pas de temps



Il est **possible** de trouver des moyens de **diminuer le coût numérique** des schémas complexes



Un schéma microphysique **complexe** présente de **nombreuses possibilités de tuning** mais **doit conserver sa cohérence physique** (cas de la sédimentation de la classe "glace")

Conclusion

Schéma à double moment, multi-classes,
multi-échelles...

*Dans la course pour le
schéma microphysique du futur:
le défi peut-être relevé!*

Perspectives

- Intégrer un schéma de condensation sous-maille
- Améliorer l'activation des aérosols (CCN et ICN)
- Réfléchir sur l'intégration de la convection dans le schéma microphysique
- Identifier et ajuster les paramètres réglables
- Réduire le coût numérique

Les schémas microphysiques

- à Simple moment et à condensat total (Sundqvist, 1978-1989, Kessler, 1969)
- à Simple moment et plusieurs classes d'hydrometeores
- à Simple moment + Part. nb. conc. diagnostiques (Thompson et al., 2005-2008)
- à double moment (plusieurs classes)(Seifert and Beheng, 2005; Morrison et al., 2005)
- à triple moment

En parallèle: schémas de convection (Cu, Cb)

Type Kuo (1965), Kain-Fritsch(1993), Tiedke (1993).