A Fourier transform technique to generate cloud fields: Description and validation of the SITCOM model

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(with the contribution of A.M. Tompkins)

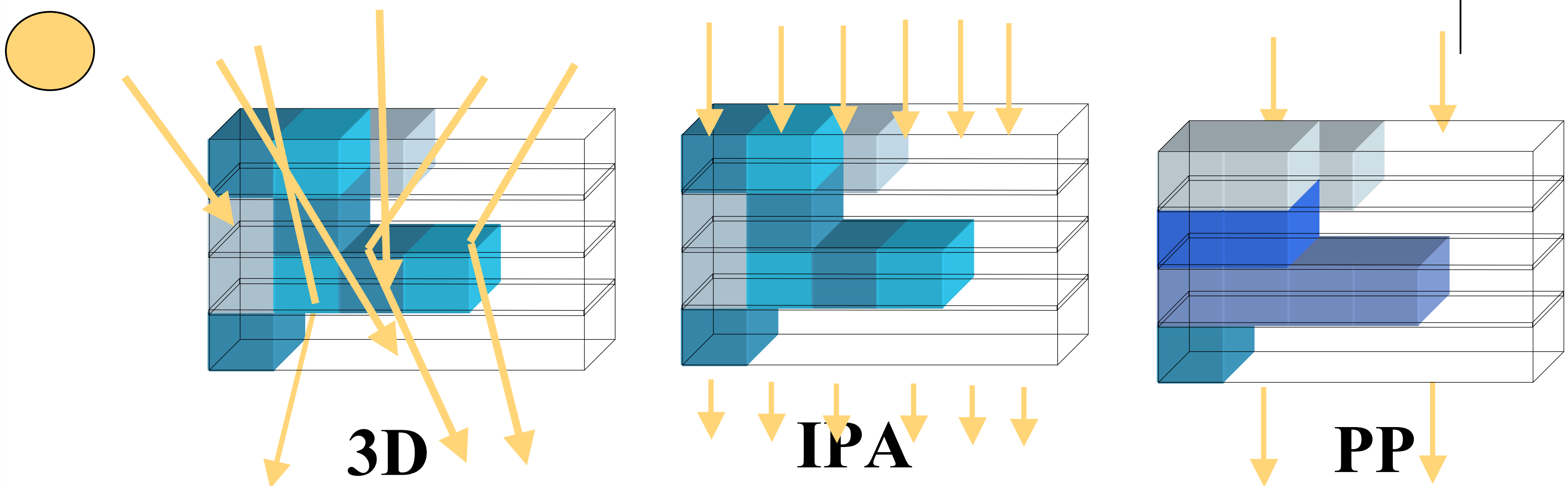
Problem

- GCMs do not explicitly resolve three dimensional cloud structures therefore only partial information are passed to the radiation scheme which provides biased flux calculations
- To correctly estimate this radiative bias (and correct it) we need
    1. Good diagnostics able to relate the bias to particular cloud field characteristic (eg. Cloud geometry, in-cloud inhomogeneities)
    2. Good 3D cloud proxy ideally both realistic and with as many as possible controllable parameters to allow sensitivity studies.

OUTLINE

- Radiative diagnostic
- How to model 3D cloud fields ?
- The Fourier approach and the model SITCOM
- Validation of SITCOM using Aircraft data
- Two applications of the SITCOM model
  - Radiative bias dependance on scale of LWC variability
  - Radiative bias dependance on unresolvable vertical structure
- Conclusions

Diagnostics



- **3D – IPA**: 'IPA bias'→ effect of neglecting *horizontal* fluxes
  sensitive to *geometrical* arrangement of clouds
- **IPA – PP**: 'PP bias'→ effect of neglecting *horizontal* optical
  dishomogeneities sensitive to *optical variability*

Cloud field Sources

Summary

- <u>Cloud field as output of dynamical Models</u> (CRM, LEMs)

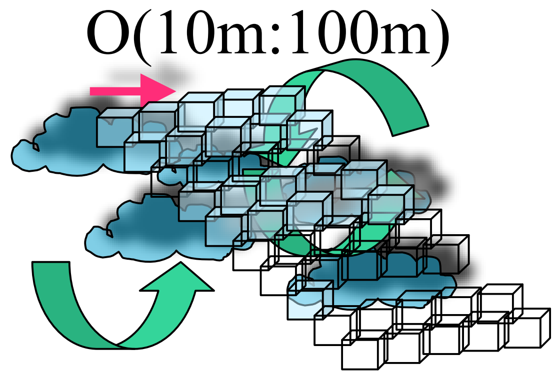
In-cloud variability and geometrical arrangement explicitly resolved

Problems:

Expensive to run, difficult to control cloud form via BCs

Dimensionality of the cloud representation (2D vs 3D)

(e. g. Fu et al, JAS99)



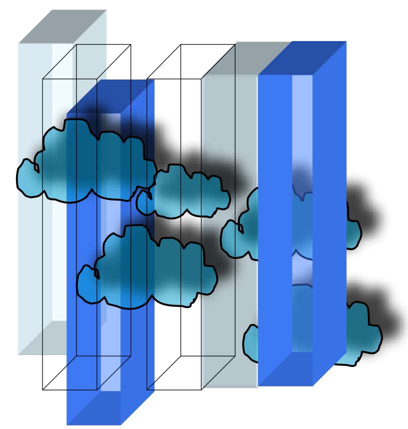
- <u>Cloud field derived from observation (satellite, radar)</u>

Problems:

Only 2D view (no vertical structure!)

Not an independent source for radiative studies

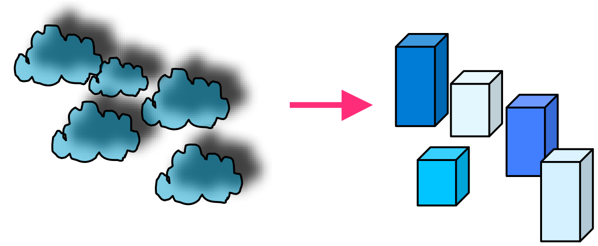
3D smoothing effect (O'Hirok and Gautier JAS98)



- <u>Cloud field generated by idealised approach (cascade models,geometrical models)</u> can usefully supplement the above

Idealised approaches as source of 3D cloud fields

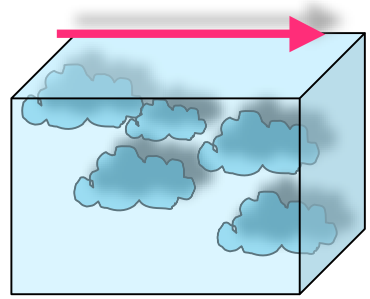
- Geometrical Approach (e.g Weilicki and Welch, JAS84) Clouds are represented using highly idealised geometrical shape such as cubes

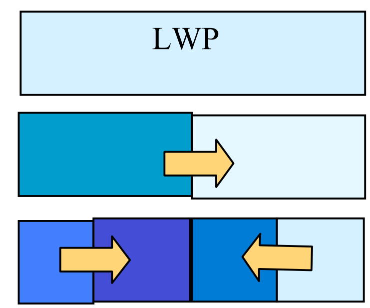


Problems:

- Realism
- Many degrees of freedom
- difficult to perform systematic studies

- Statistical models Cascade Models (e.g Cahalan and Snider, JAS89) Try to reproduce the right ‘horizontal’ variabiliy of the cloud redistributing the mean LWC according to statistical rules.



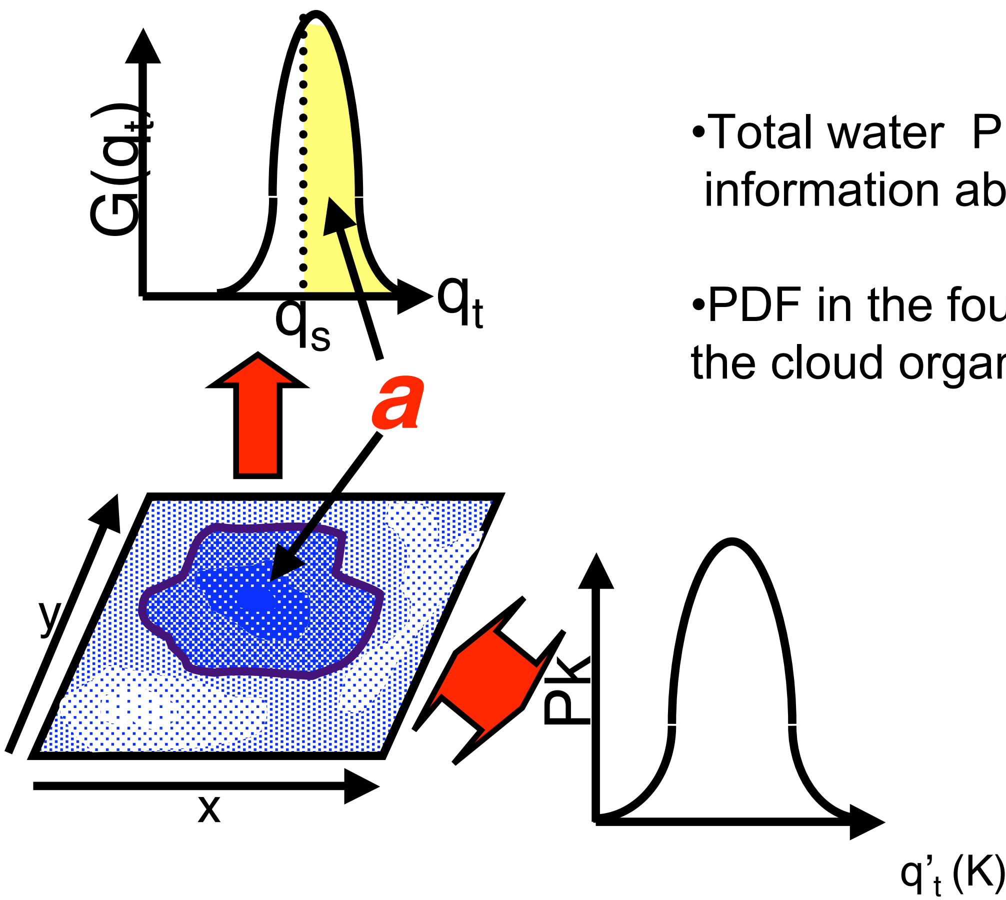


Problems:

- Broken clouds are difficult to simulate
- The largest scale of variability is equal to the domain length L
- No vertical cloud structure included

Fourier technique – The philosophy of the approach

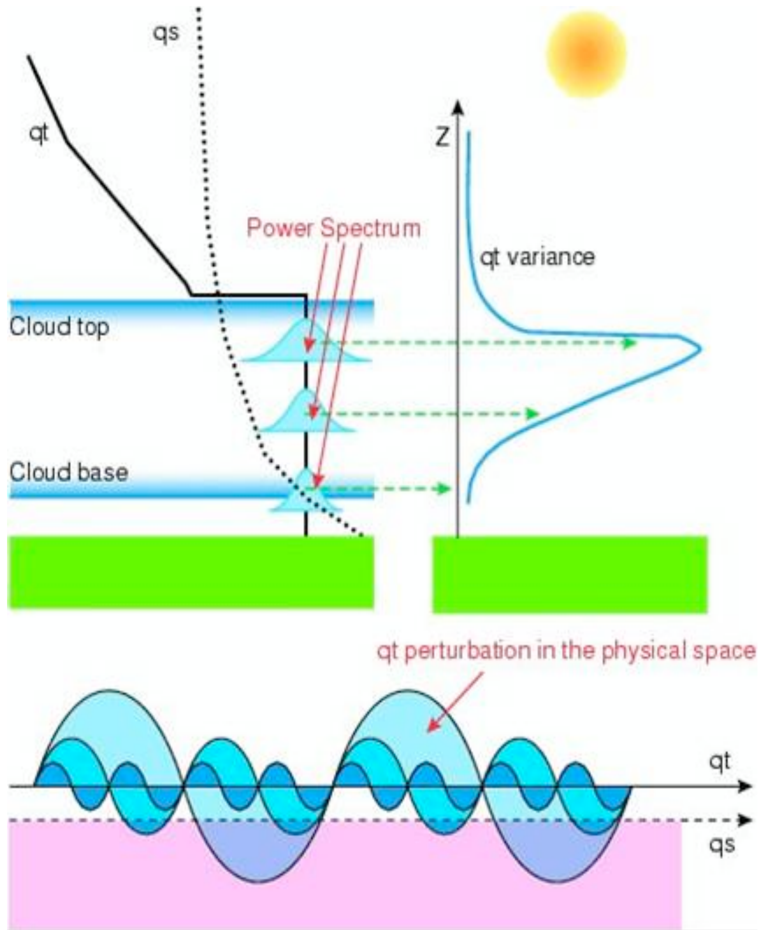
- Use **total water (q_t) variability** instead of liquid water (q_l) to generate in-cloud inhomogeneities and to control cloud cover
- Define the total water variability in **Fourier space** instead of physical space to be able to control the scale of cloud organization
- Include vertical structure by scaling the q_t variability to a prescribed variance.



•Total water PDF in physical space does not prov
information about the cloud Organization

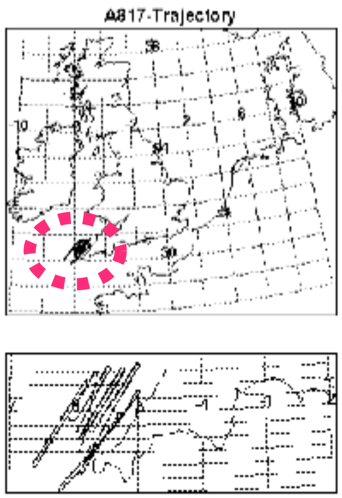
•PDF in the fourier space allows one to control the cloud organization

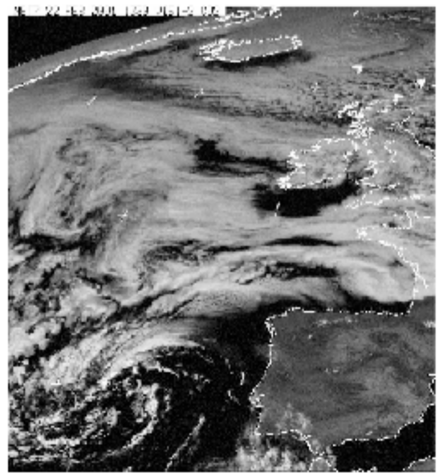
The Spectral Idealised Thermodynamically Consistent Model- SITCOM

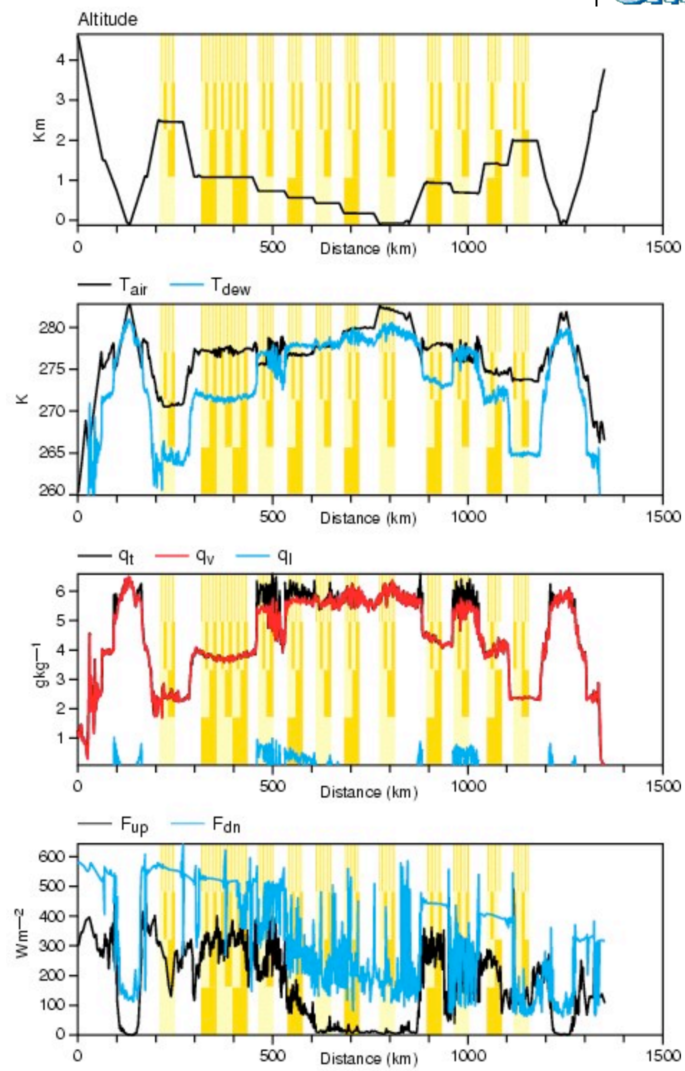


- Define the mean state of the atm through the definition of the vertical profile of total water and temperature.
- Define a total water 'perturbation' function in the frequency space (Pw). The area under the curve Pw represents the variance of the total water horizontal field
- Scale the perturbation (area under Pw) to give the right variance in the real space.
- Define the vertical overlap

SITCOM Validation







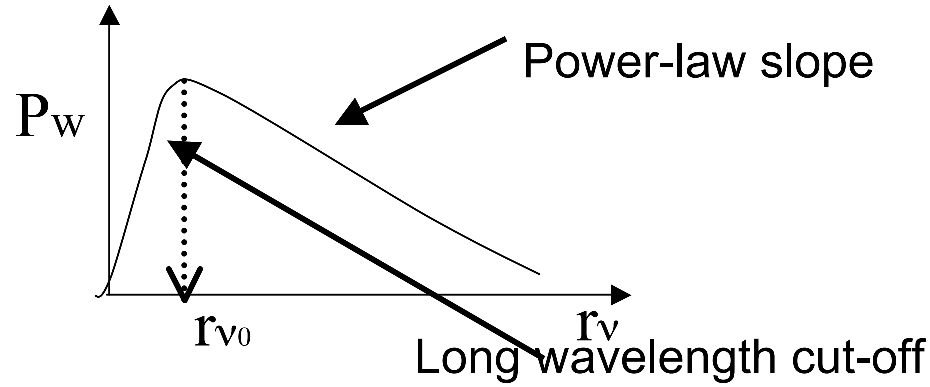
Flight A817: 22 February 2001 (courtesy of Met-Office research flight centre)

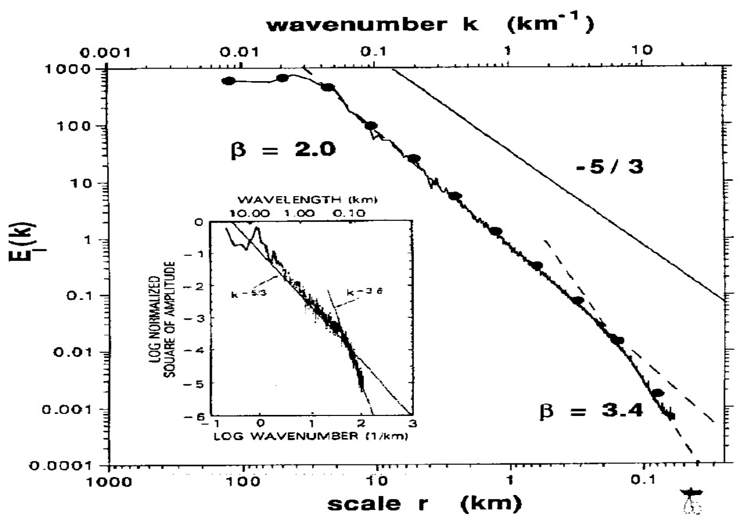
Cloud microphysics: King Probe+FSSP
Radiative fluxes:Precise Spectral Pyranometer

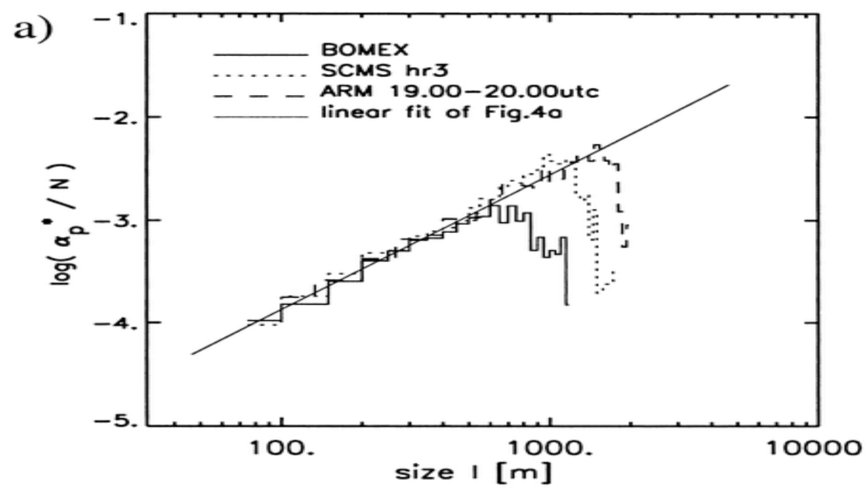
StCu prescribed variability

$$\mathcal{P}_w(r_v) \approx \sigma_{q_t}^2 r_v^{-\beta} e^{-\left(\frac{r_{v_0}}{r_v}\right)^n}$$

$$r_v = \sqrt{v_x^2 + v_y^2}$$





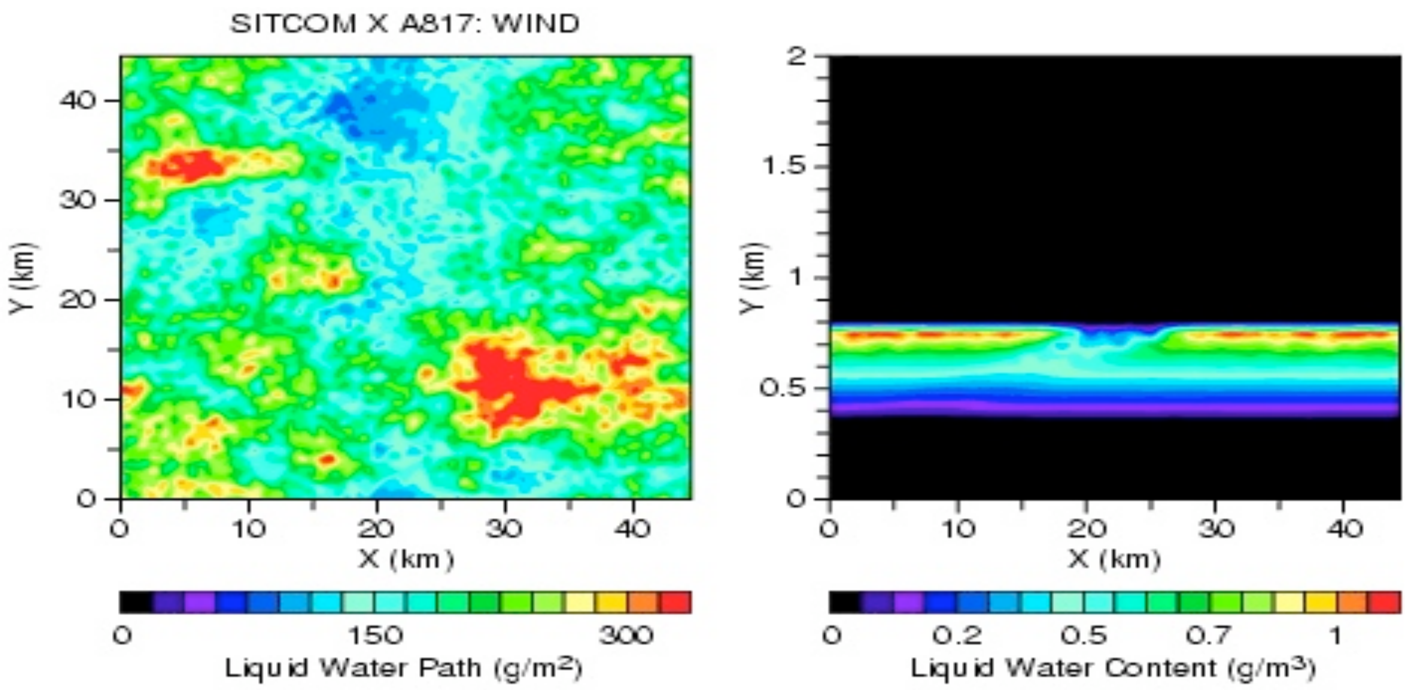


Other observational studies on StCu (Cahalan et al, JAS 94) Other observational studies on StCu (Niggen et al, JAS 03)

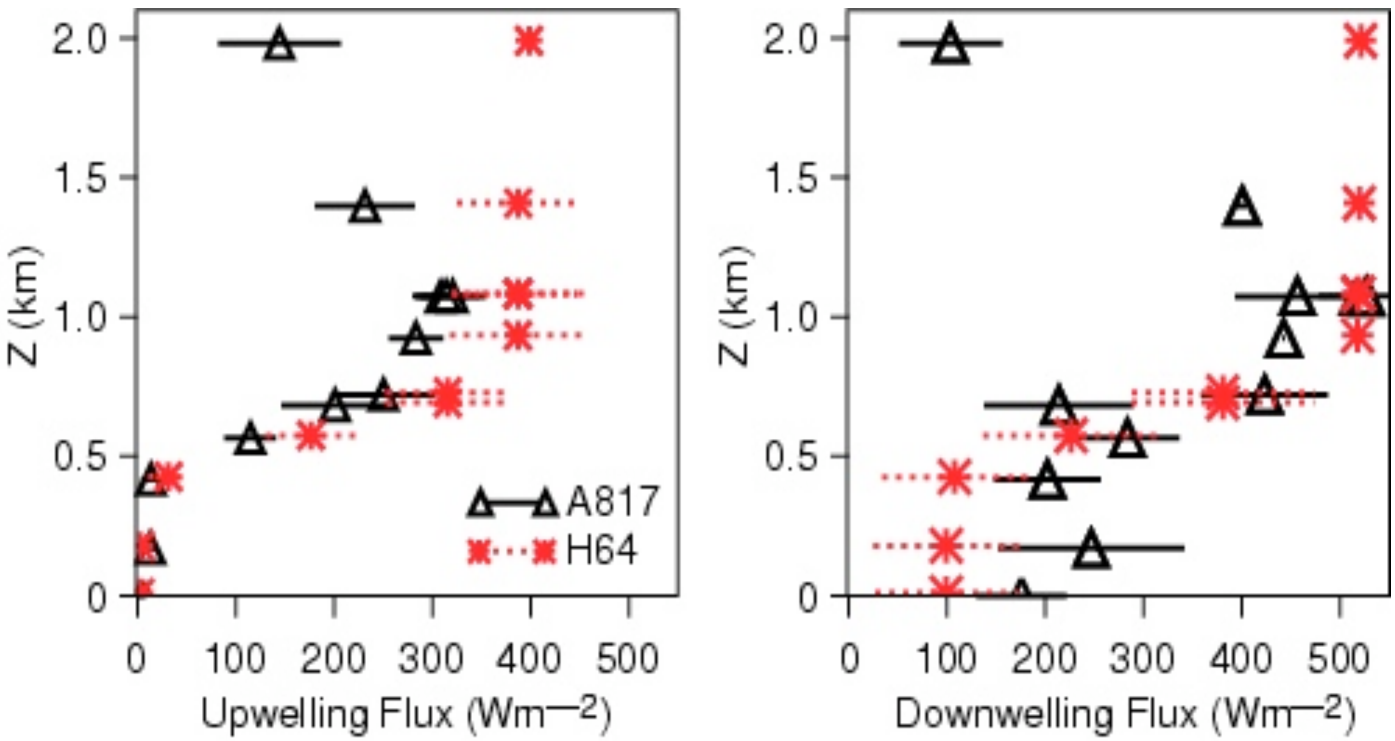
SITCOM reconstructed field

r_{ν_0}=L
N=1
β=1.4

parameters set from experimental data

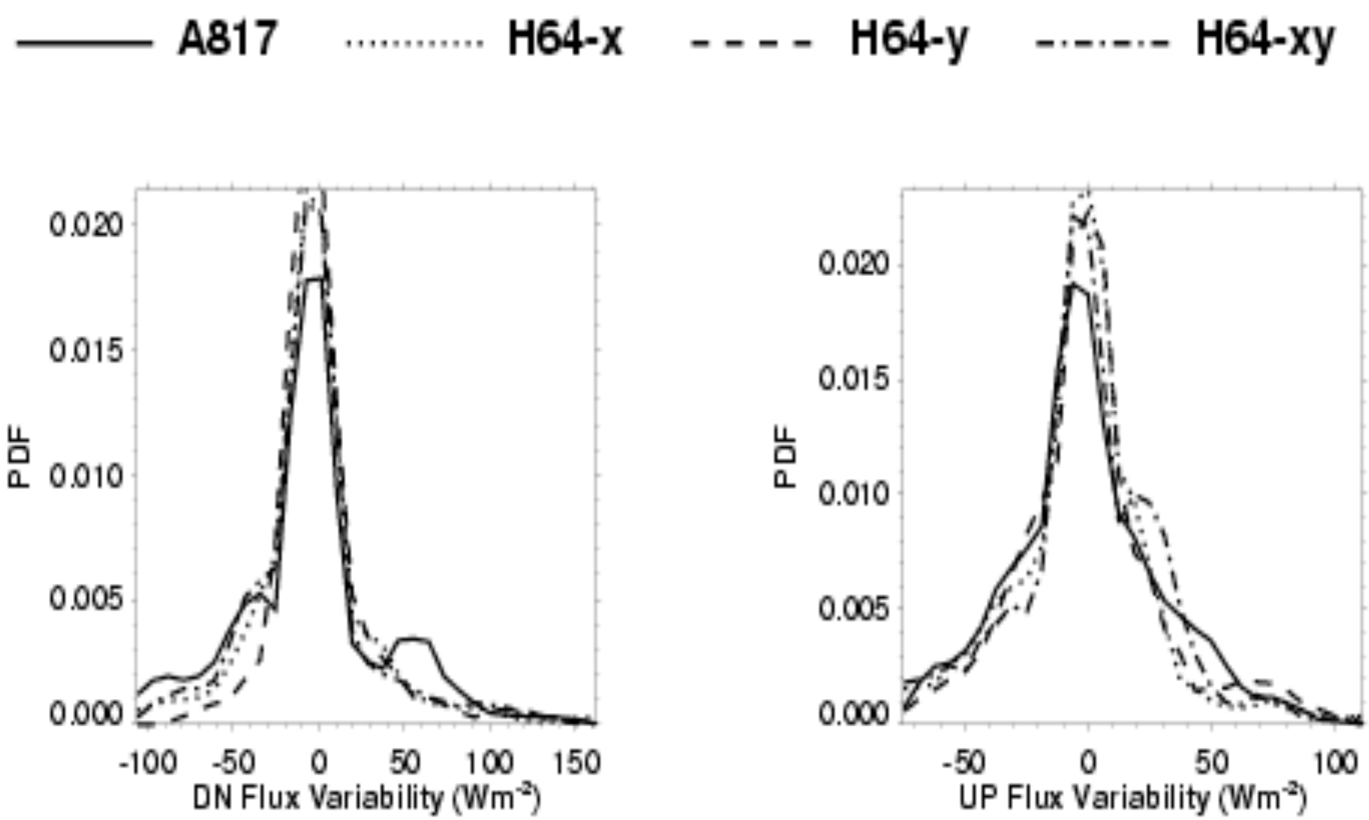


Comparison measured - simulated fluxes



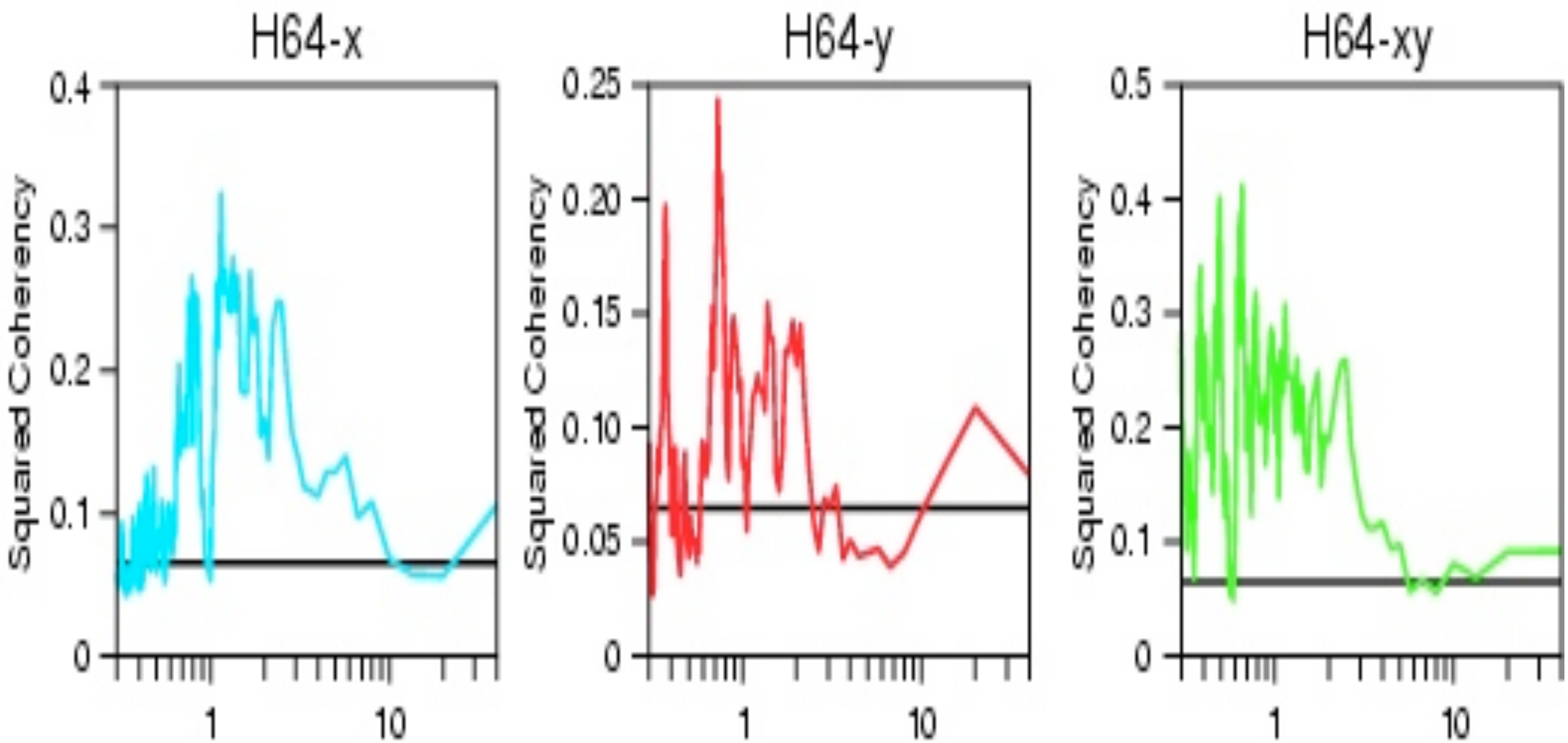
Comparison measured - simulated fluxes PDF

Probability density function of upwelling and downwelling fluxes for SITCOM
Generated fluxes using a MONTECARLO RT (GRIMALDI) code and measuraments during th



CROSS-Spectra correlation

Correlation between net fluxes calculated with SITCOM+Montecarlo and measurements



Example of SITCOM Application
Generation of cloud field with defined organisational scale.

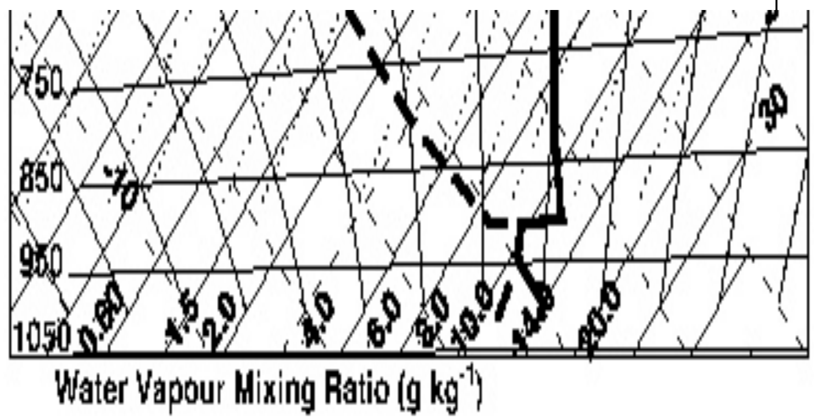
1 - Question:

- **Does the scale of organisation affects the bias of neglecting horizontal photon transport in stratocumulus clouds? If yes, in which measure?**

SITCOM is used to produce cloud fields with fluctuations expressed over a limited range of horizontal scales

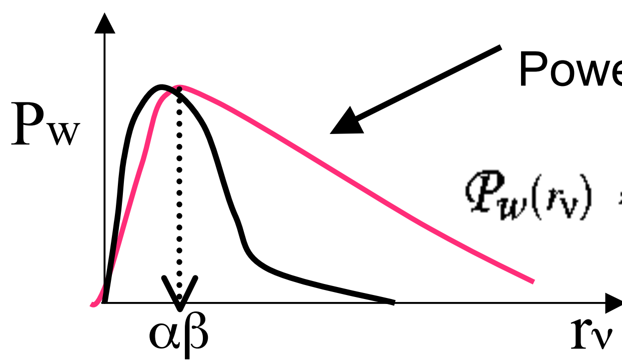
The 4 Ingredients for this recipe

1 The mean state of atm:
- q_t=const
- temperature inversion



2 Perturbation of qt in the frequency space

Band limited
Gamma function



Power-law slope

$$\mathcal{P}_w(r_v) \approx \frac{\sigma_{q_t}^2 \beta^{\alpha+1}}{\Gamma(\alpha+1)} r_v^{\alpha} e^{-\beta r_v}$$

Continue…

3 Variance for the q_t field

Derived from the mean atmospheric state by solving a Turbulent transport equation

$$-2\overline{w'q_t'}\frac{\partial \overline{q_t}}{\partial z} - \frac{\partial \overline{w'\sigma_{q_t}^2}}{\partial z} - \epsilon = 0.$$

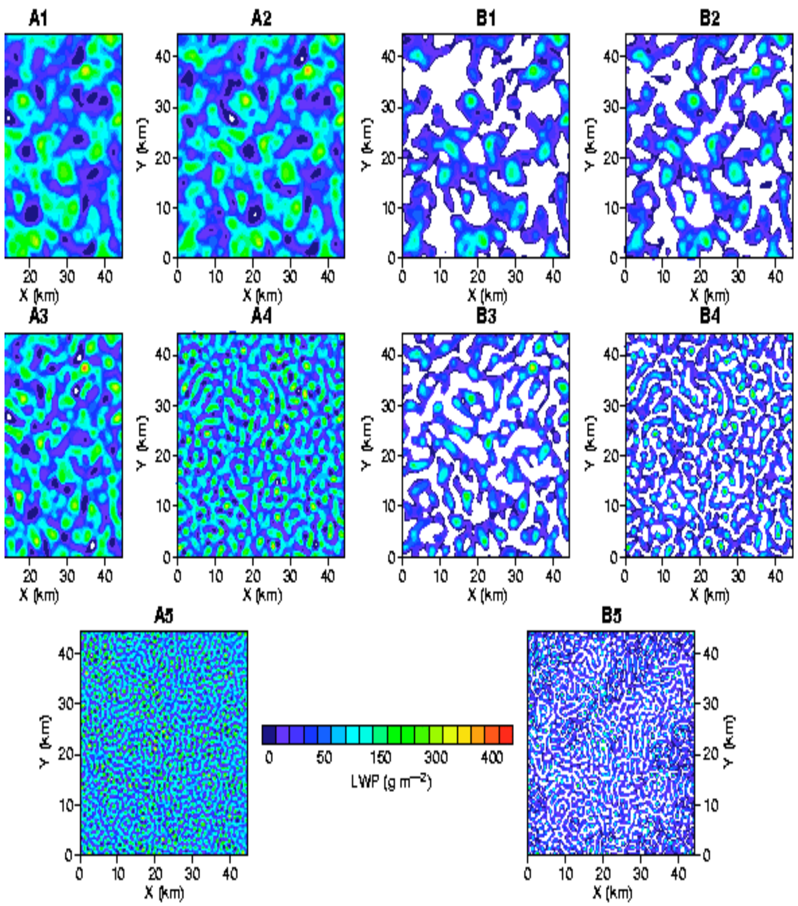
$$\overline{w'q_t'} = -K\frac{\partial \overline{q_t}}{\partial z}$$

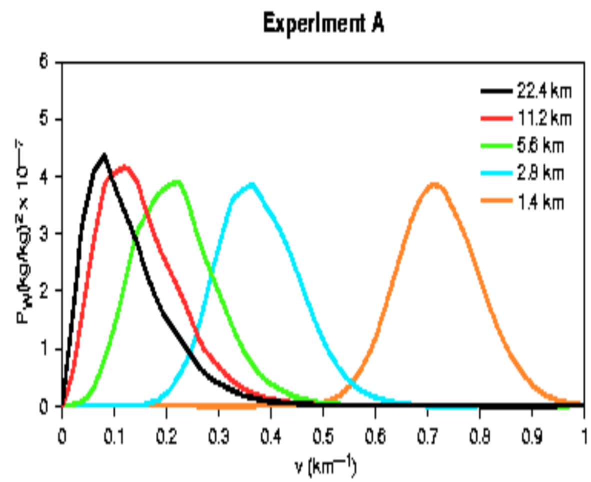
$$\overline{w'\sigma_{q_t}^2} = -K\frac{\partial \overline{\sigma_{q_t}^2}}{\partial z}$$

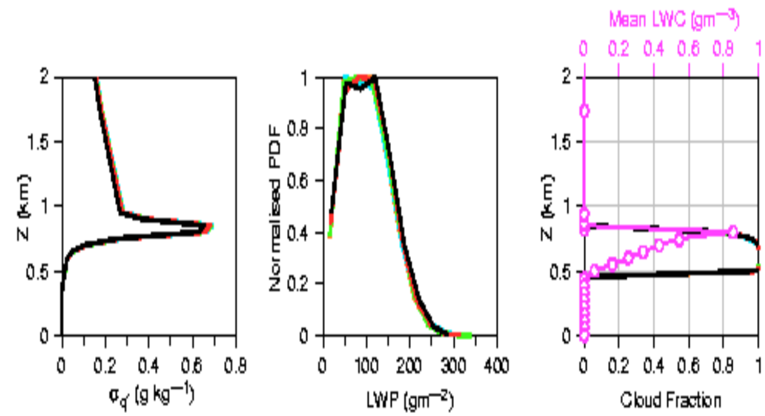
4 Overlap:

Maximum Overlap

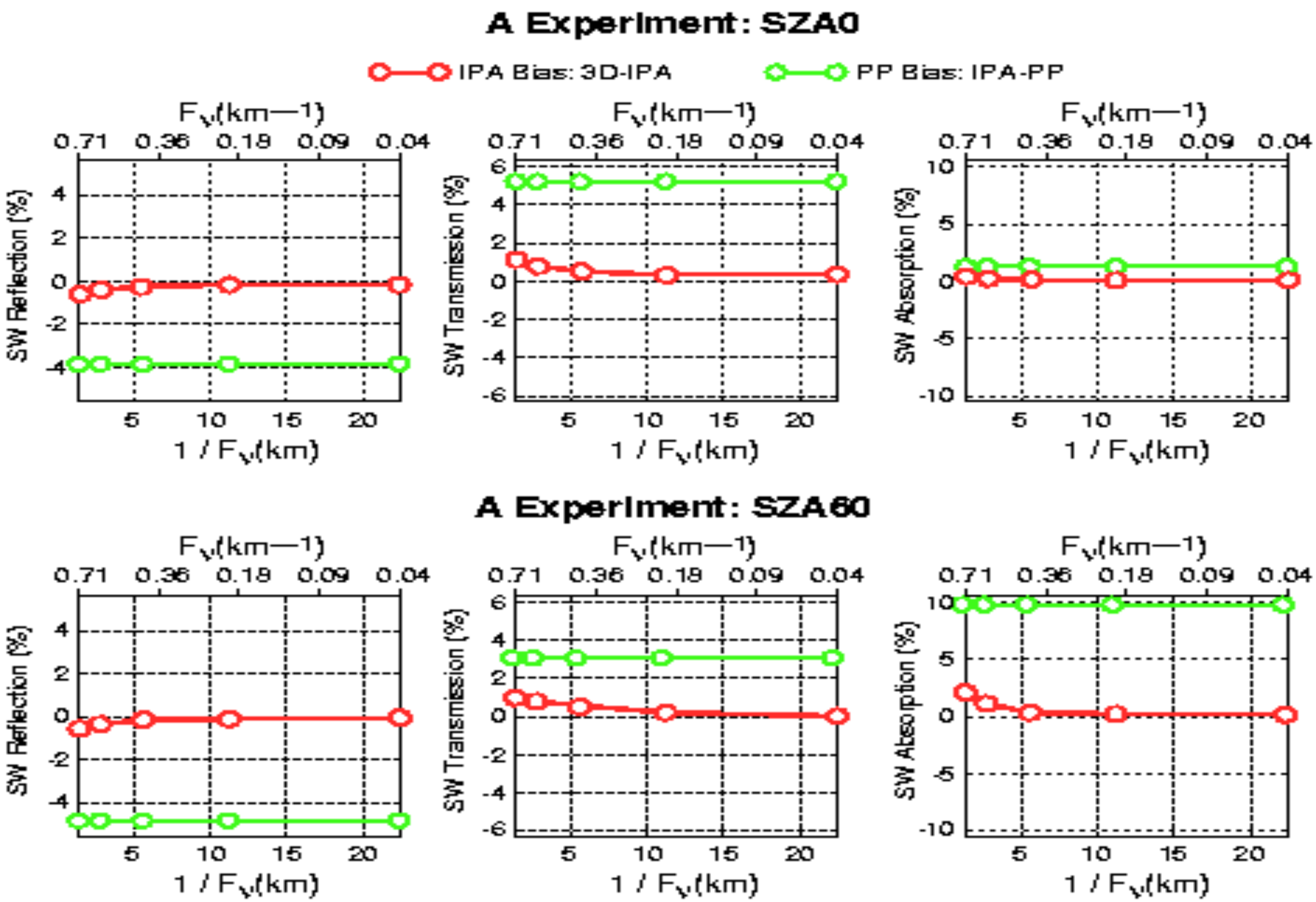
Cloud Fields





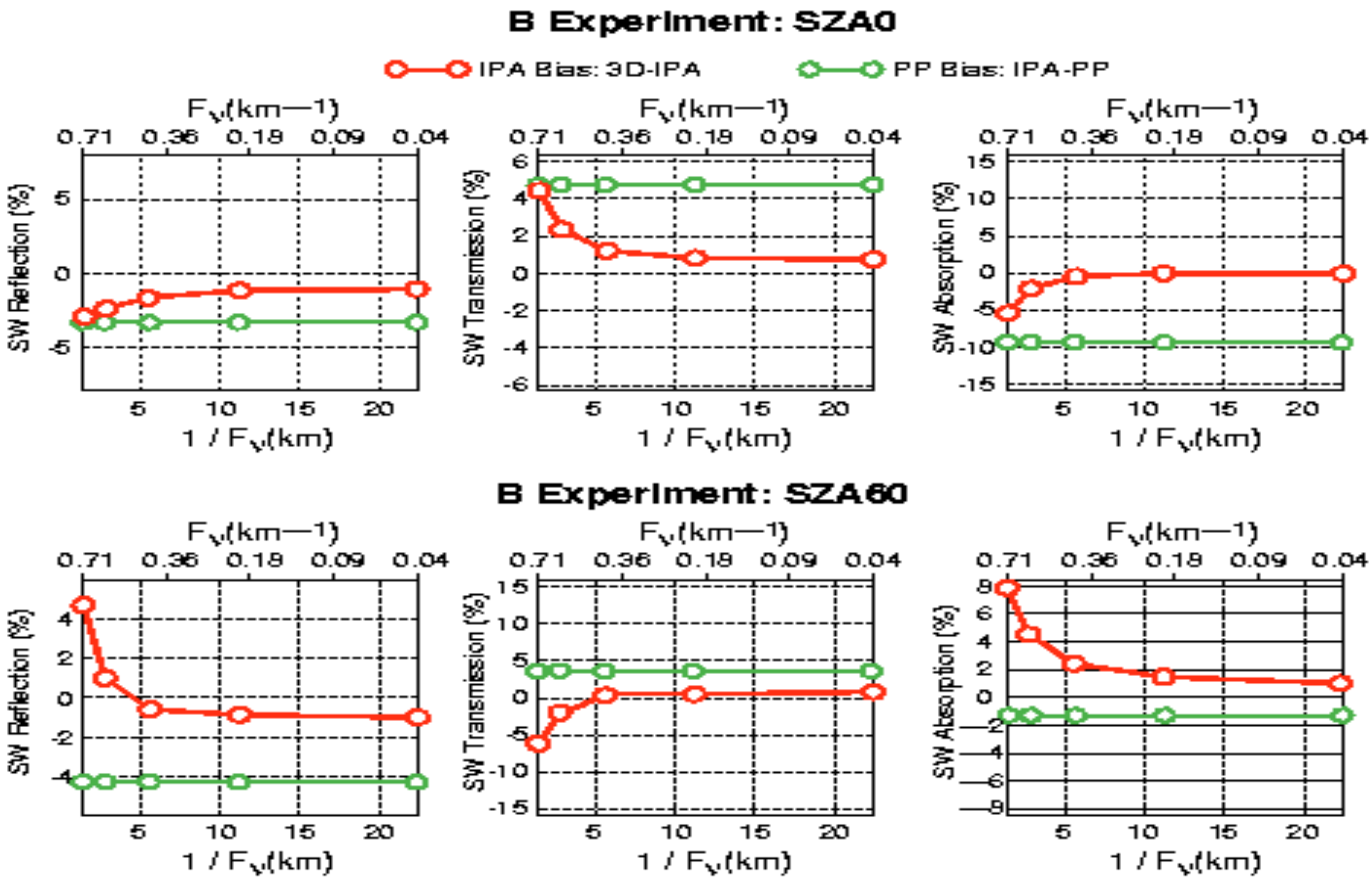


Radiative biases vs. scale of cloud organisation
exp. A *'OVERCAST'*



Radiative biases vs. scale of cloud organisation

exp. B *'Broken clouds'*



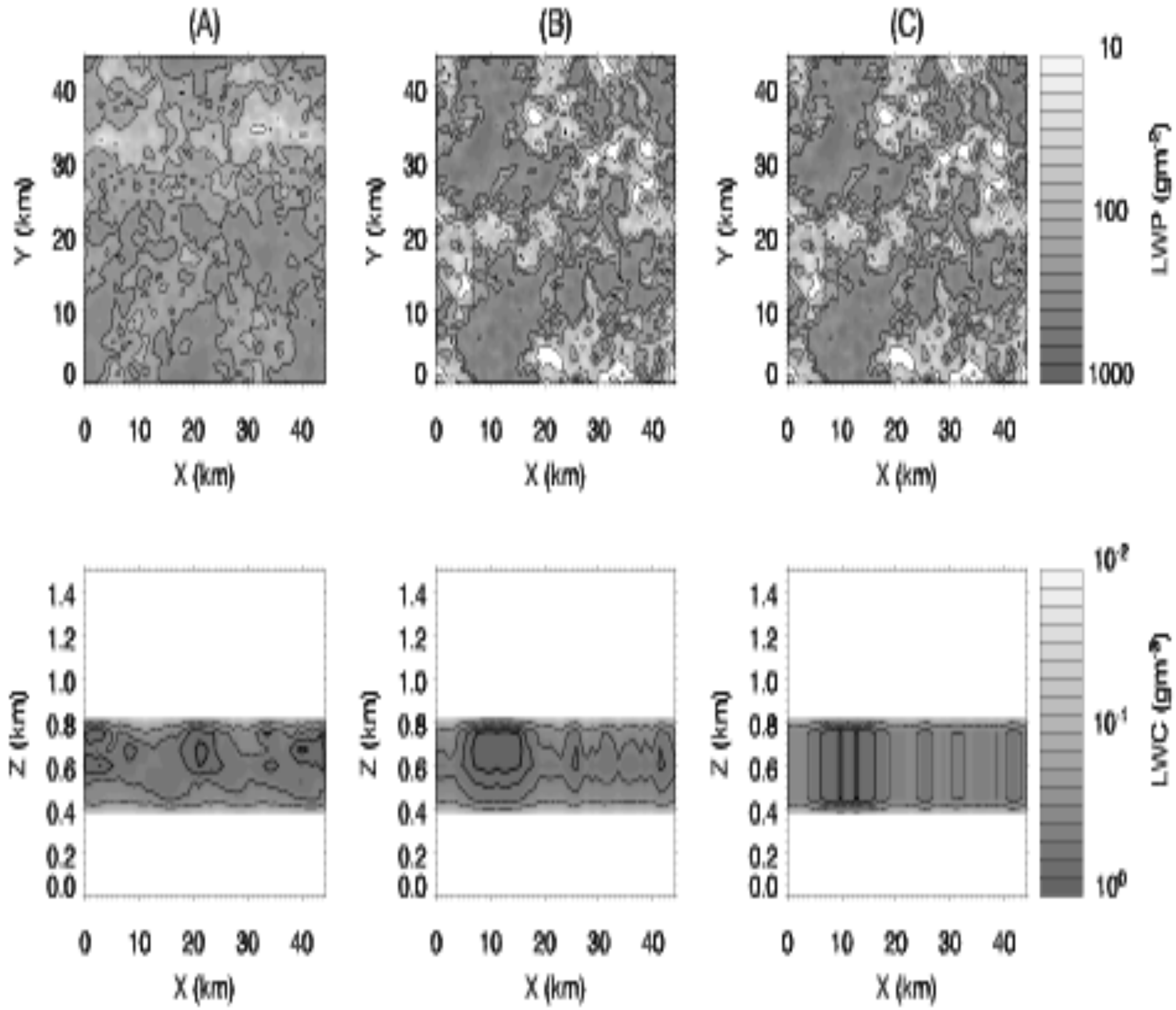
Example of SITCOM Application
Generation of cloud field with different vertical cloud structure

2 - Question:

- **How do features in the vertical cloud structure affect the radiative properties of StCu clouds? and therefore … How the assessment of 1D biases, that were mostly drawn for slab clouds, would change when the vertical cloud structure is included?**

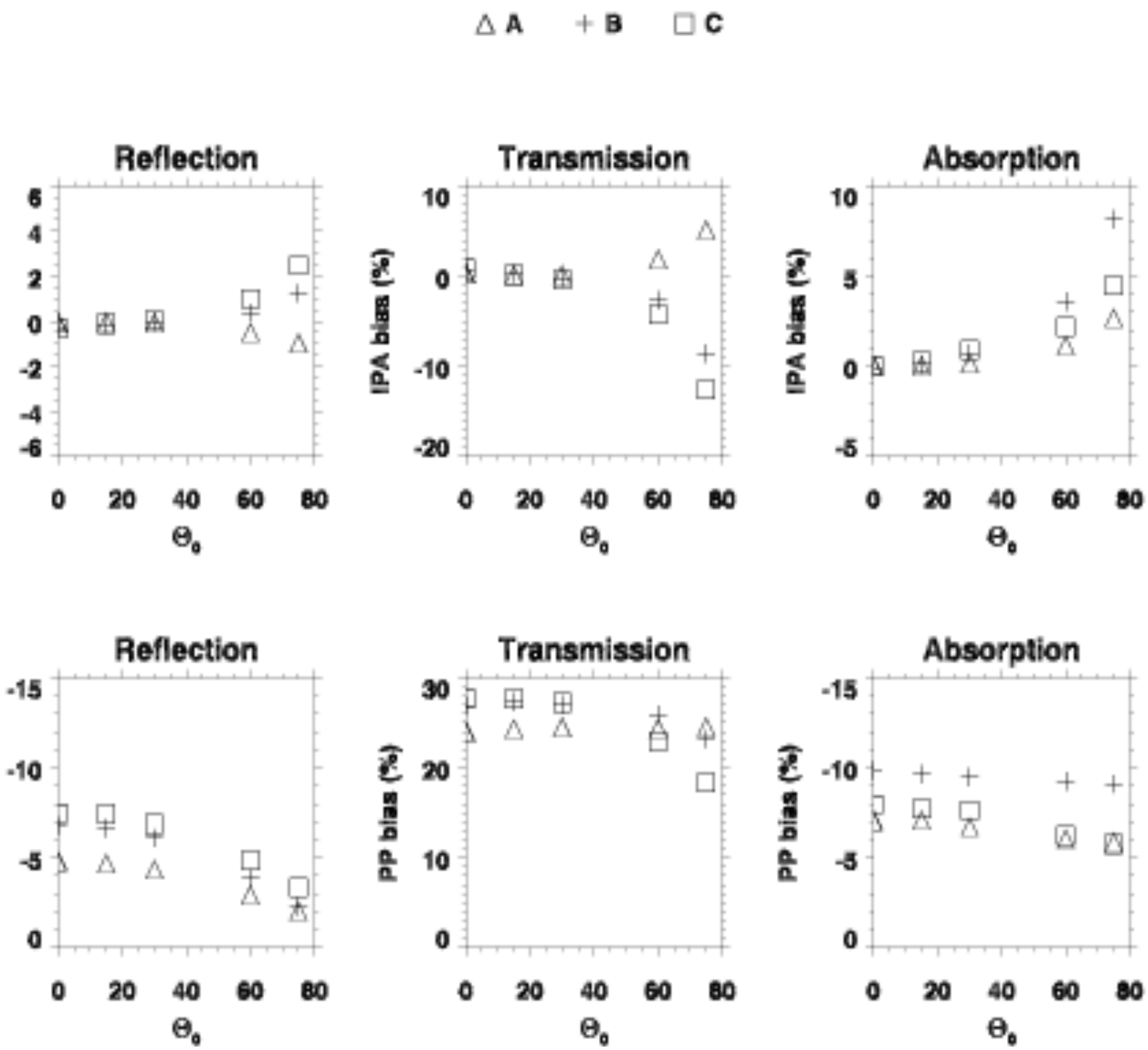
SITCOM is used to produce cloud fields in which information on the vertical cloud structure is progressively reduced

Cloud fields with different vertical structure representations



- EXP A vertical adiabatic profile and vertical decorrelation produced by wind shear
  - $\Delta x=(u(z_2)-u(z_1))*\Delta z/w$
  - U=horizontal velocity
  - W=vertical velocity
- EXP B remove wind shear
- EXP C remove adiabatic profile→ cloud reduce to a homogeneous slab

PP and IPA bias as a function of vertical cloud represantation



- PP bias tend to be much smaller for case A when compared to case C (which does not include vertical variability)
- The PP bias differences decrease for small solar zenith angles
- The IPA bias can become also important at small sun angle

Conclusions

- Simplified models can allow the investigations of cloud parameter in isolation making them a very useful tool to quantify biases and to develop future parameterizations

With the use of SITCOM we have proved that:

- The IPA approach gives good results only in overcast situations.
- In broken clouds if the geometrical scale of organisation is chiefly organised below 2 km the unresolved geometrical arrangement of cloud is likely to be a primary source of

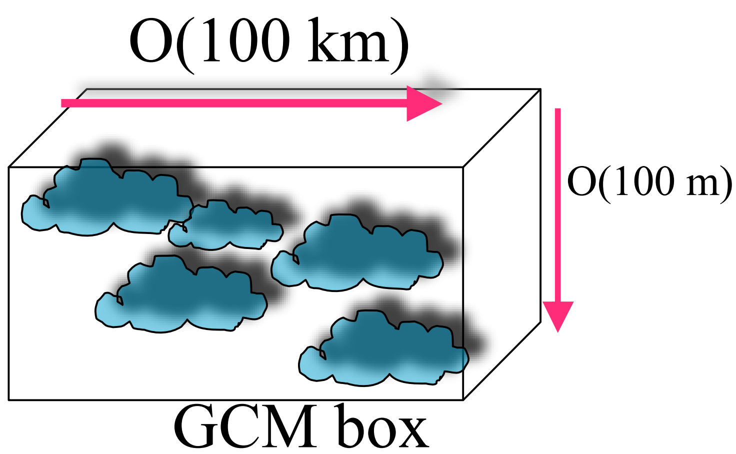
Conclusions

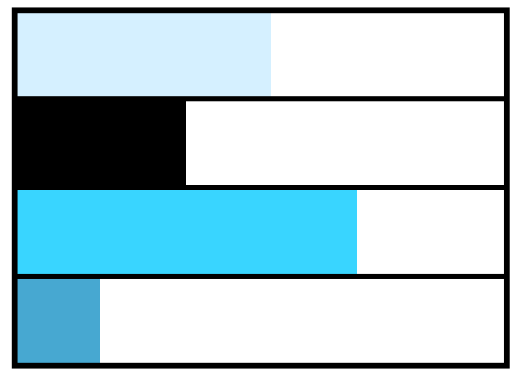
- It is very important to include the vertical cloud structure in a thermodynamic consistent way in the cloud generation techniques since the estimation of the bias can be Model dependent.

With the use of SITCOM we have proved that:

  - The neglect of vertical variability could have led to an overestimation of the PP bias
  - The IPA bias can be more important than previously thought

Cloud representation in GCMs



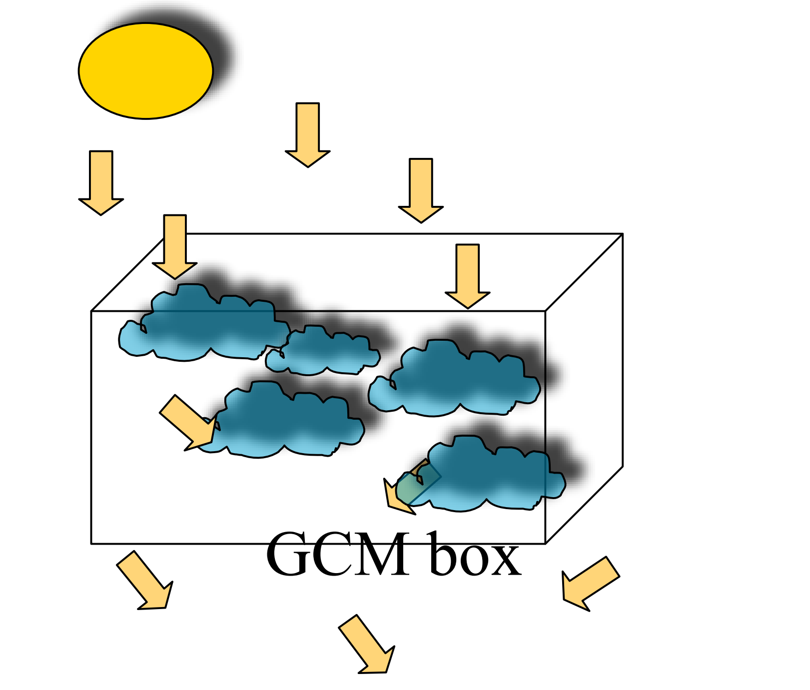


Cloud are not resolved by Large Scale atmospheric models.

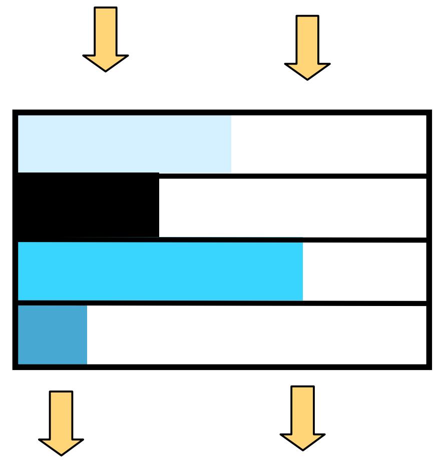
Simple geometrical representation;

1. No vertical cloud fraction
2. No horizontal variability, except cloud fraction
3. Simple overlap rules

Radiative issue



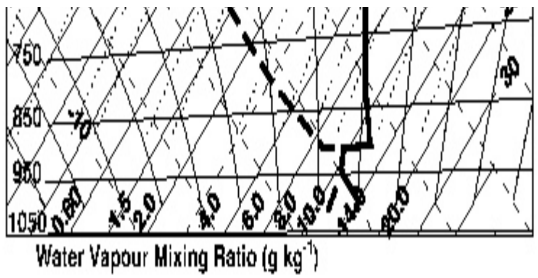
Exact solution via 3D RT



GCM interpretation

The SITCOM four ingredients

- Define the mean state of the atm through the definition of the vertical profile of qt and T.
  - qt=const
  - temperature inversion



- Define a qt 'perturbation' function in the frequ

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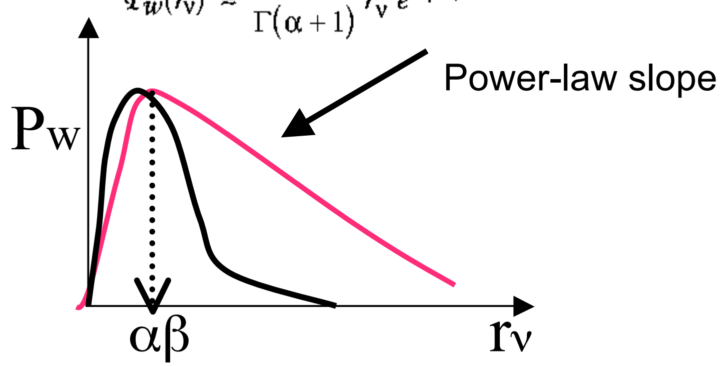

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Derived from the mean atmospheric state by solving a Turbulent transport equation

$$-2\overline{w'q_t'}\frac{\partial \overline{q_t}}{\partial z} - \frac{\partial \overline{w'\sigma^2_{q_t}}}{\partial z} - \epsilon = 0.$$

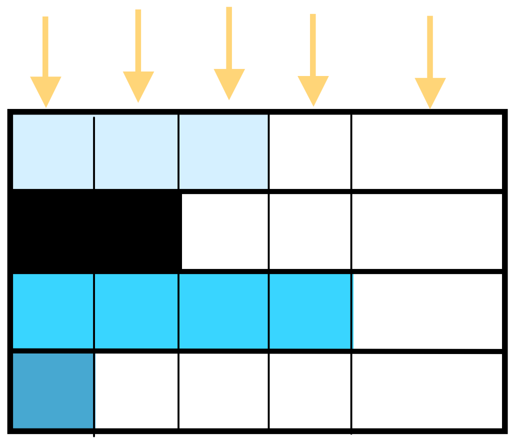
$$\overline{w'q_t'} = -K\frac{\partial \overline{q_t}}{\partial z}$$

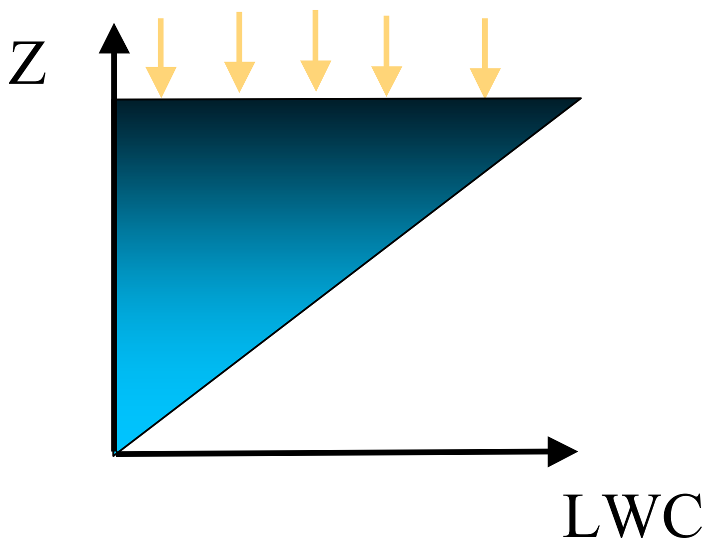
$$\overline{w'\sigma^2_{q_t}} = -K\frac{\partial \overline{\sigma^2_{q_t}}}{\partial z}$$

- Define the vertical overlap

Maximum Overlap

PP bias Mechanisms - Schematic



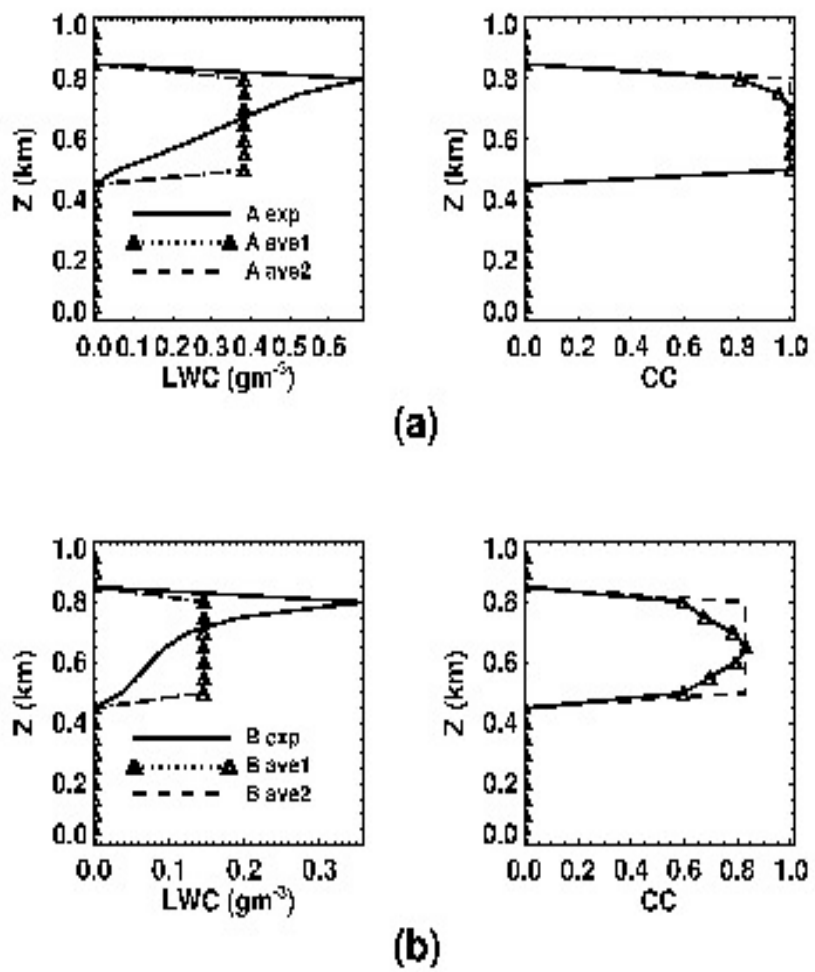


- 1 GCMs with sufficient vertical resolution perform a multi-column calculation

(the effect of the horizontal averaging between columns is negligible)

- 2 The adiabatic liquid water profile Effectively increases the optical depth of the cloud layer

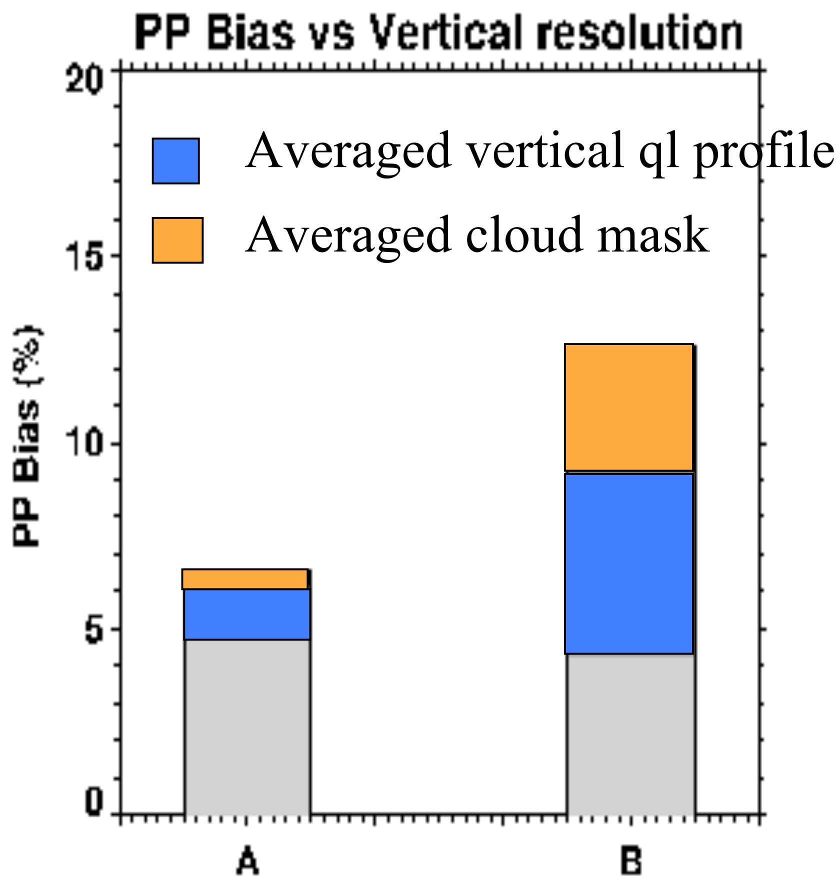
2 More experiments



- EXP ‘ave1’: cloud mask untouched adiabatic profile removed
- EXP ‘ave2’: cloud mask averaged out adiabatic profile removed

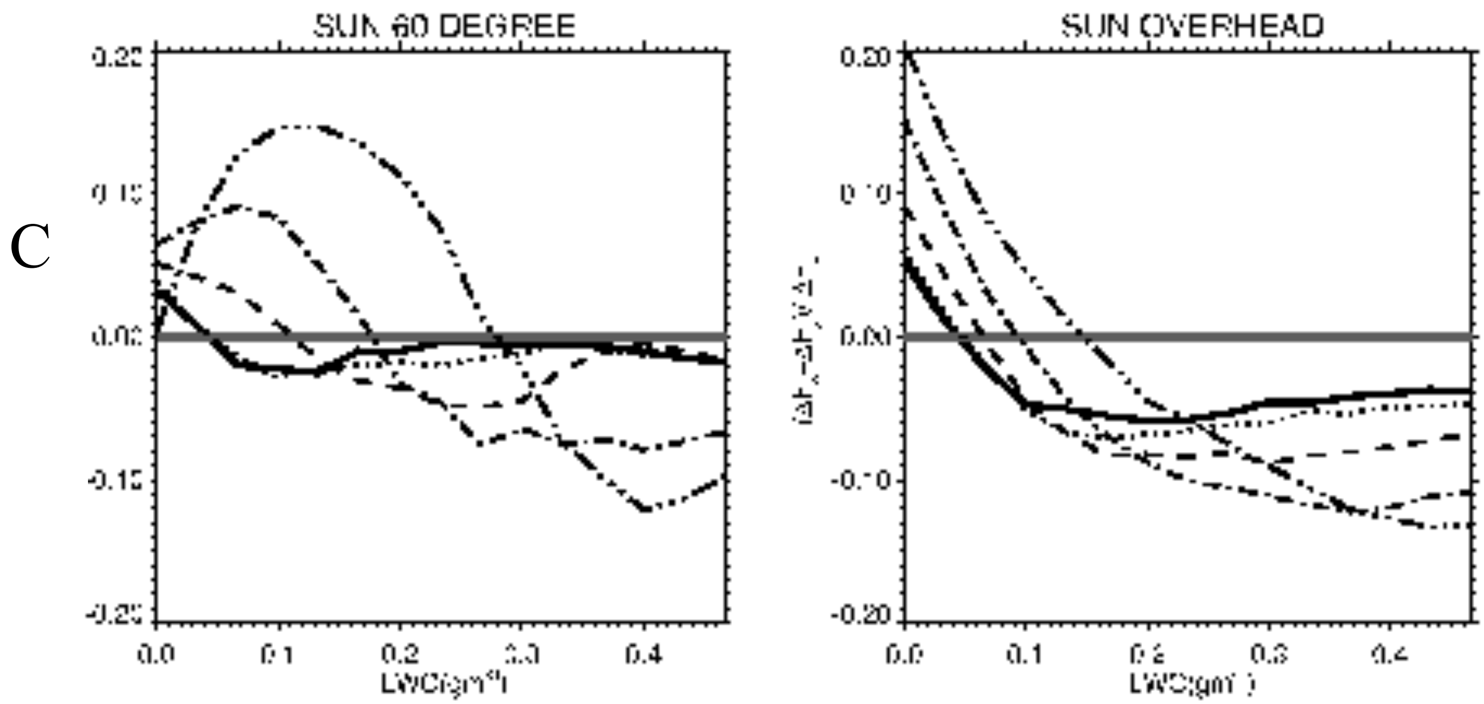
EXP ‘ave2’ is equivalent to a cascade model

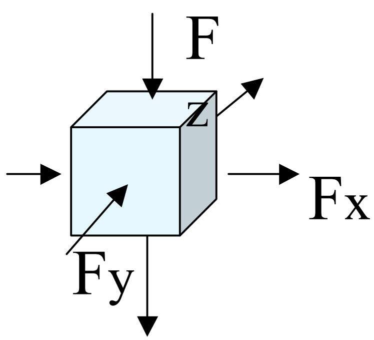
Result



- The contribution to the PP bias due to the neglect of the adiabatic liquid water is the most important factor.
- In broken cloud the vertical-overlap rule 'help' to reduce the PP bias

IPA bias





C= (ΔFx+ΔFy)/ΔFz

C>0 → convergence

C<0 → divergence

Note that C= 0 in the IPA