Sub-grid scale variability of cloud and rain:

Implications for microphysical parameterization

Matt Lebsock
Jet Propulsion Laboratory
California Institute of Technology

Sub-grid variability of microphysics

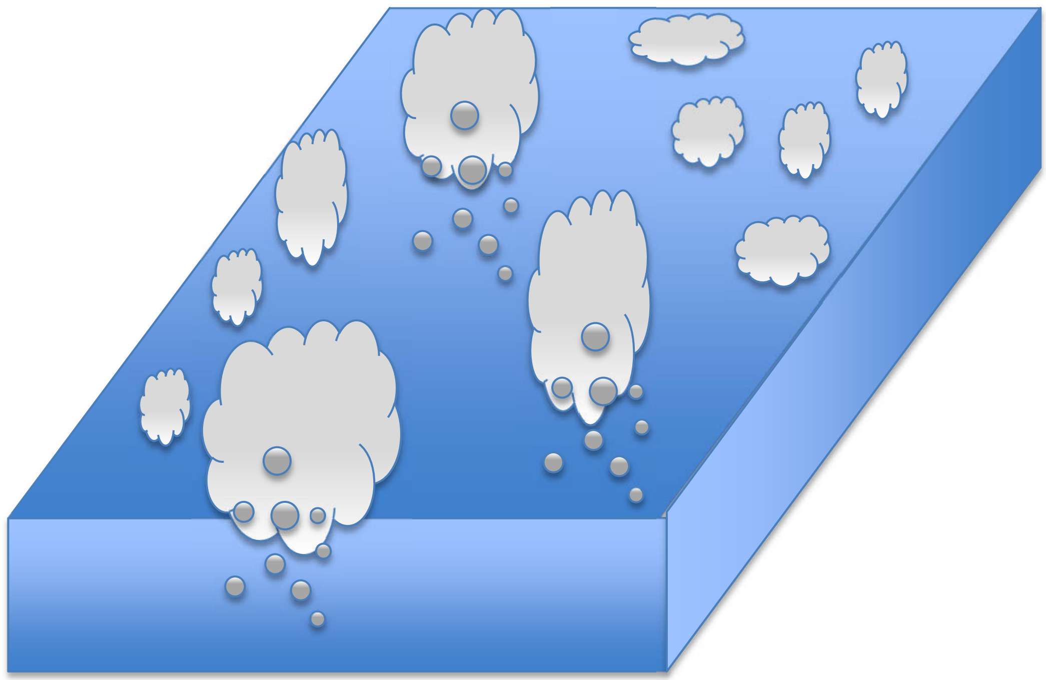
- The model provides grid mean:
  - q_c, N_c, q_r, N_r
- Microphysical processes are non-linear and occur at local scales [*Pincus and Klein, 2000; Rotstayn et al., 2000; Larson et al., 2001*]
  - Autoconversion: Direct conversion of cloud water to rain water

$$M'_{auto} = a\frac{q_c'^{b_1}}{N_c'^{b_2}}$$

  - Accretion: Collection of cloud water by falling rain

$$M'_{acc} = a\left(q_r' q_c'\right)^b$$

- Traditionally the coefficients are derived from LES and tuned when applied to the GCM



Morrison-Gettleman microphysics sub-grid variability

- MG microphysics prescribes sub-grid variability in cloud condensate as a gamma distribution with $\nu = 1$.

$$P(q_c') = \left(\frac{\nu}{q_c}\right)^{\nu} \frac{q_c'^{\nu-1}}{\Gamma[\nu]} e^{-\nu \frac{q_c'}{q_c}}$$

- Convenience of the gamma distribution PDF approach.

$$M' = a q_c'^{b}$$

Local

$$M = \int P(q') a q_c'^{b} \, dq' = E[\nu, b] a q_c^{b}$$

Grid-Mean

- The grid mean process rate can be calculated using the <u>original</u> microphysical coefficients modified by an enhancement factor *E[ν,β]* related to the sub-grid variability

Sub-grid variability effect on accretion

$$E[\nu, b]$$

	Inverse relative variance (ν)		
	0.5	1	8
Process rate	Enhancement factor (E)		
Autoconversion	6.08	3.22	1.23
Immersion freezing	3.00	2.00	1.13
Accretion by rain	1.13	1.07	1.01

Morrison and Gettleman, 2008

- Without including cloud/rain covariance the enhancement factor is small for accretion

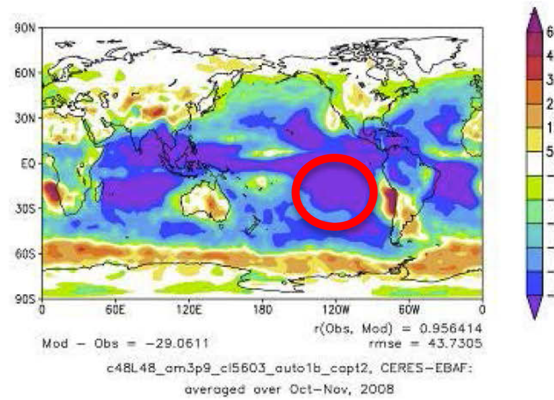
Global Simulations

Results courtesy of Huan Gou (GFDL)

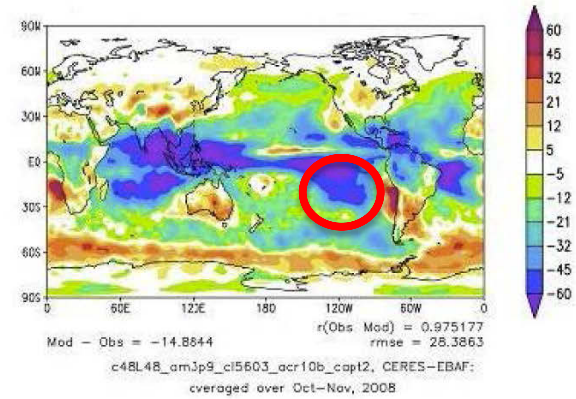
- Motivation: Climate Process Team
  - Replace four parameterizations [PBL, Shallow, Large scale cloud, microphysics] with a unified [CLUBB-MG] parameterization
  - Problems with too much cloud in shallow cumulus regimes. Why?
- Increasing accretion causes
  - Decreased cloudiness
  - Increased solar absorption
  - Better agreement with observations

CAPT simulations: SWABS

AM-CLUBB-MG

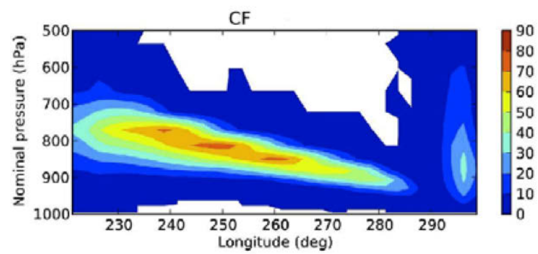


AM-CLUBB-MG: 10XAccretion

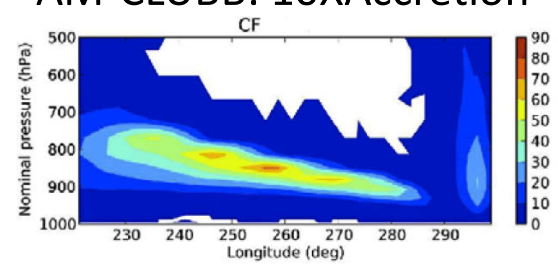


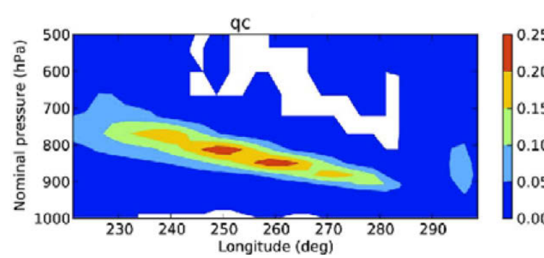
CAPT: cross section along 20S

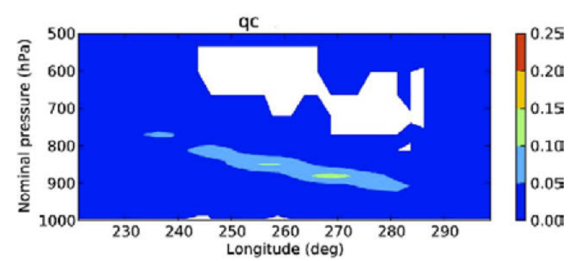
AM-CLUBB



AM-CLUBB: 10XAccretion







Including cloud/rain covariance

- MG scheme does not consider covariance between q_c' and q_r'

$$M'_{acc} = a\left(q'_r q'_c\right)^b$$

local

- Consider cloud/rain covariance of the form

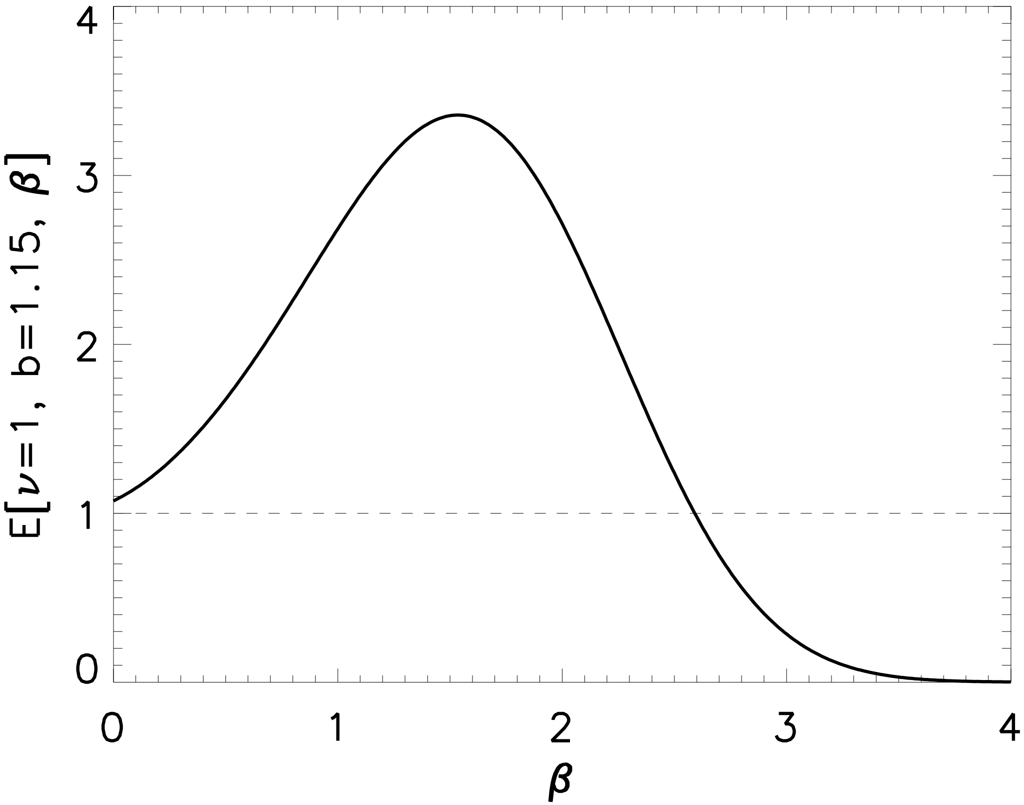
$$q'_r = \alpha q'^{\beta}_c$$

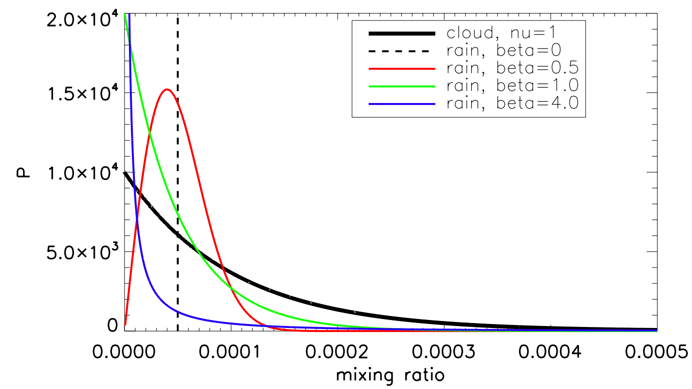
- Then the grid mean accretion rate

$$M_{accreation} = E^*\left[\nu, \beta, b\right] a\left(q_c q_r\right)^b$$

Grid-Mean

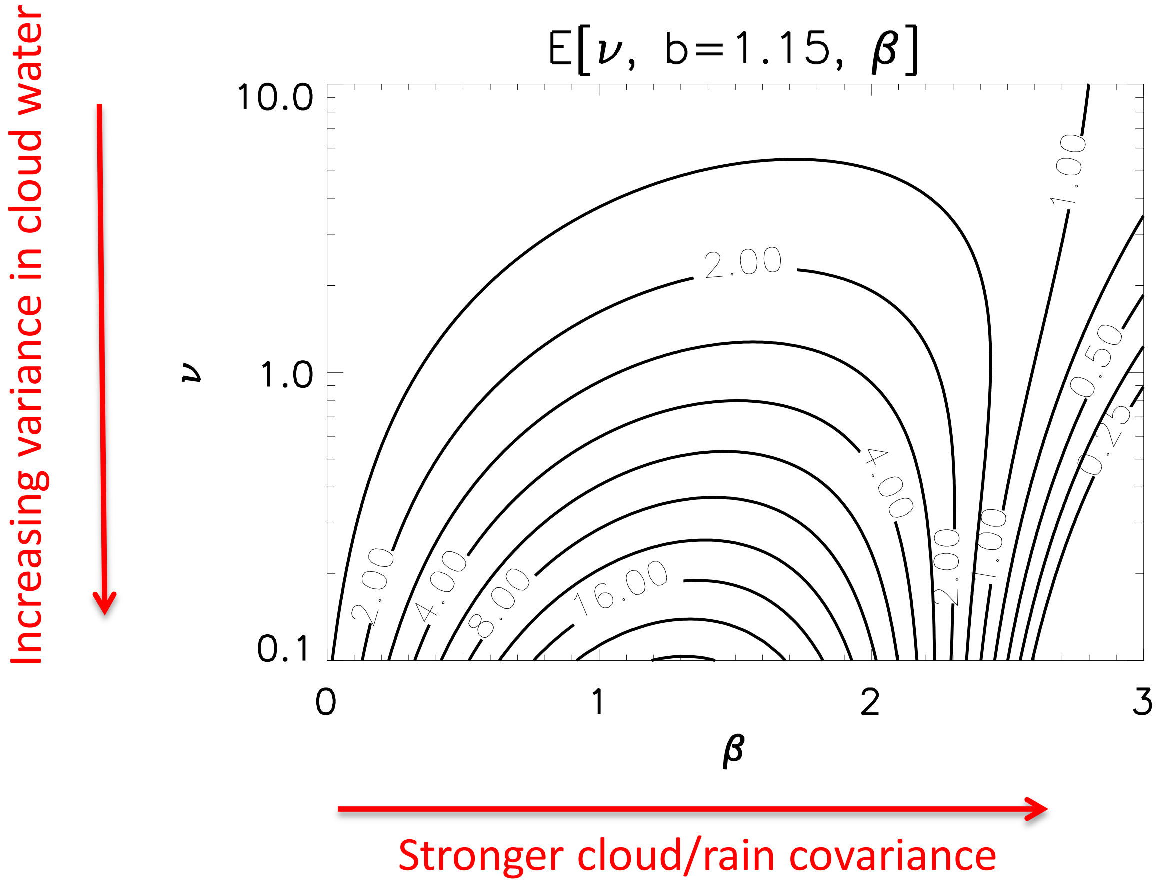
How does E vary with β?*





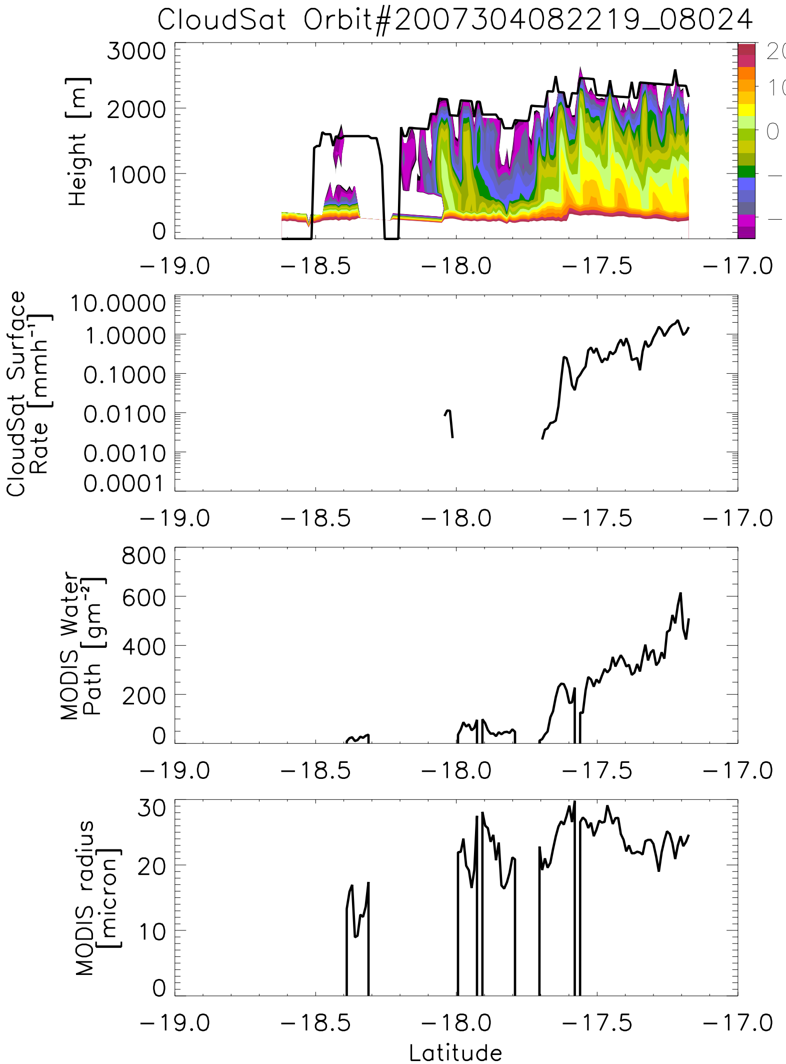
- Enhancement maximized for moderate values of β.

E^* variation with β and ν

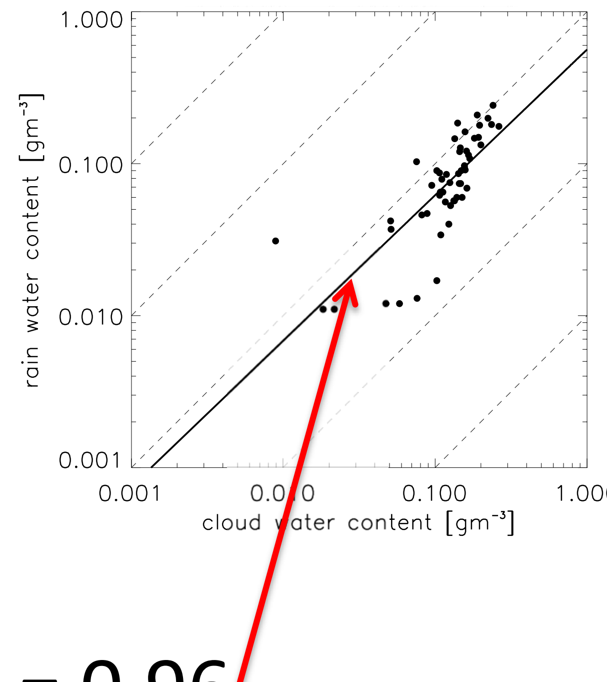


- Depending on sub-grid covariability of q_c' and q_r' E^* can be substantially greater than 1.

Estimating β from CloudSat & MODIS

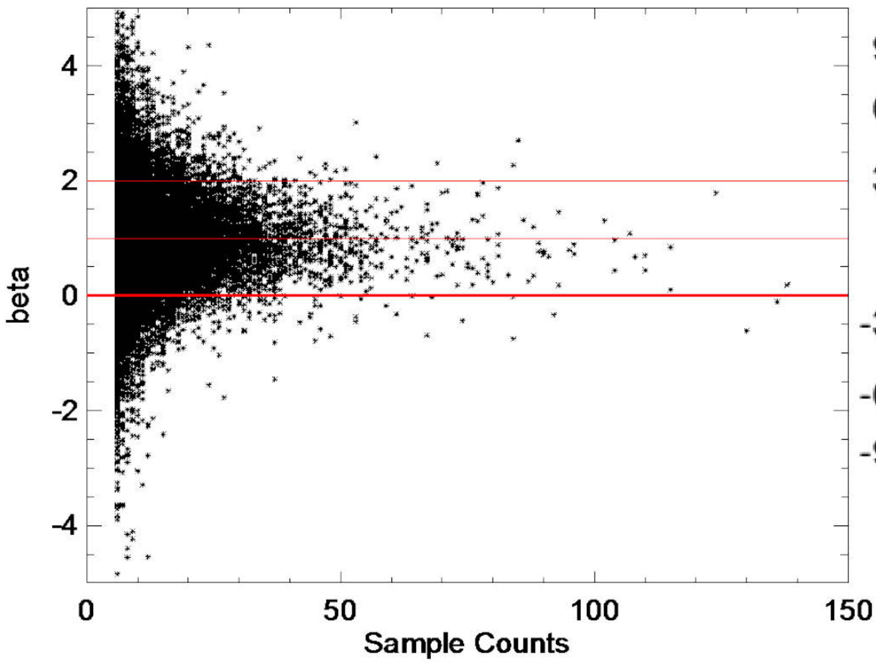


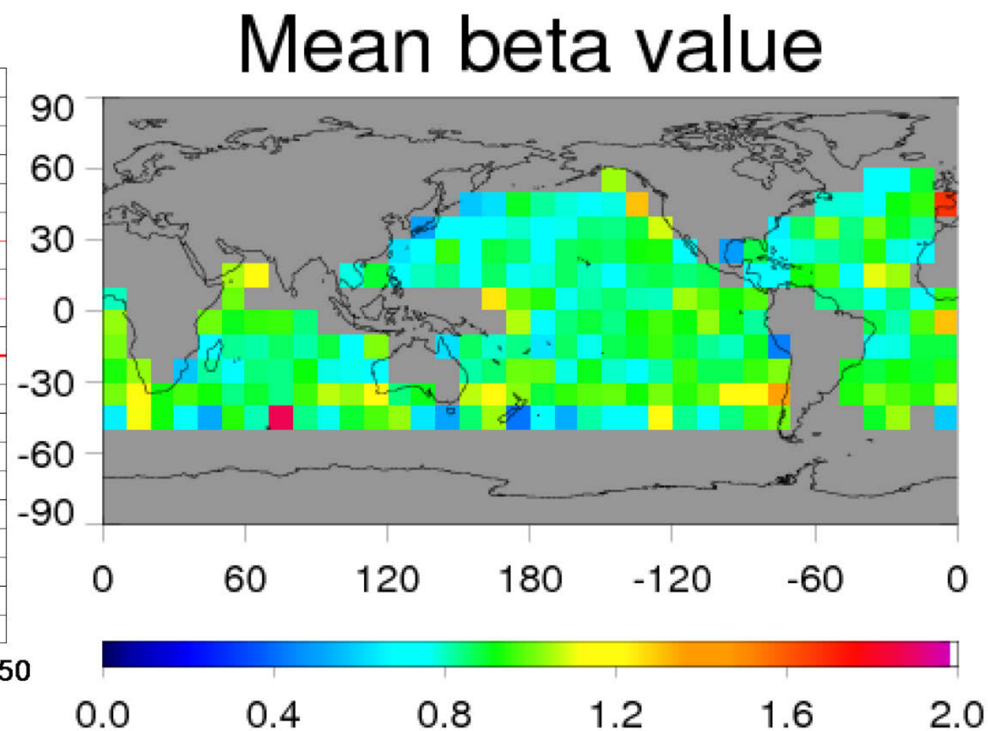
$$q'_r = \alpha q'^{\beta}_c$$



- *β* = 0.96
- correlation = 0.76

Estimating β from CloudSat & MODIS

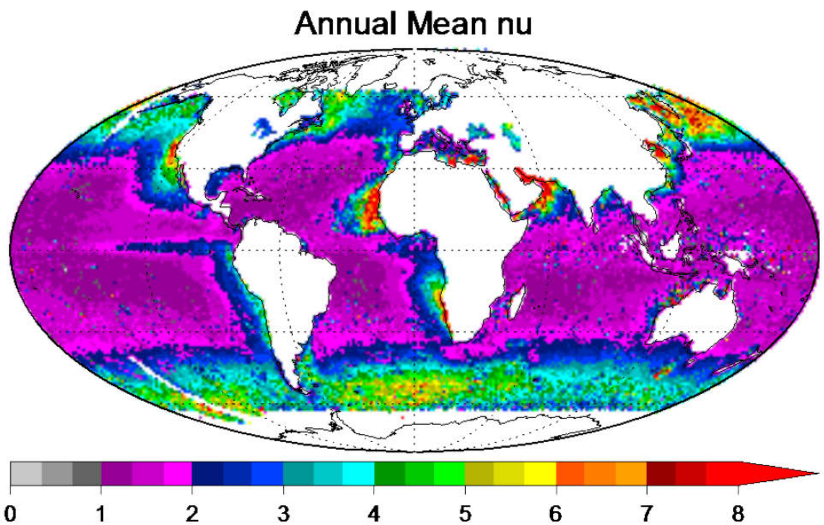


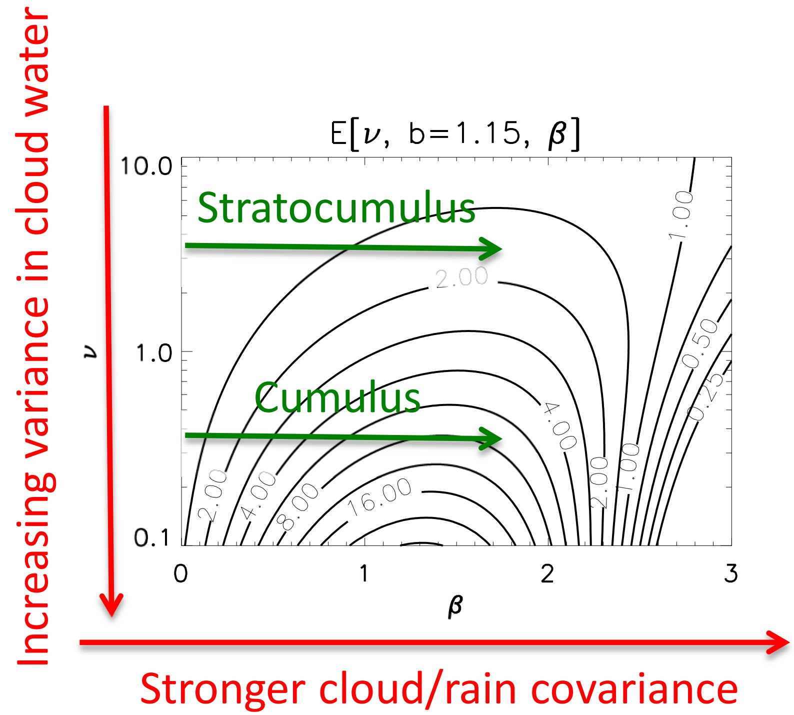


- $\beta = 0.88 \pm 0.87$
- β shows little regional variation

Regional pattern of cloud water variance

- Variability in cloud water shows a much more clear regional variability than does the covariance parameter *β.*
- Recall that the sensitivity of accretion to *β* increases with decreasing *ν.*

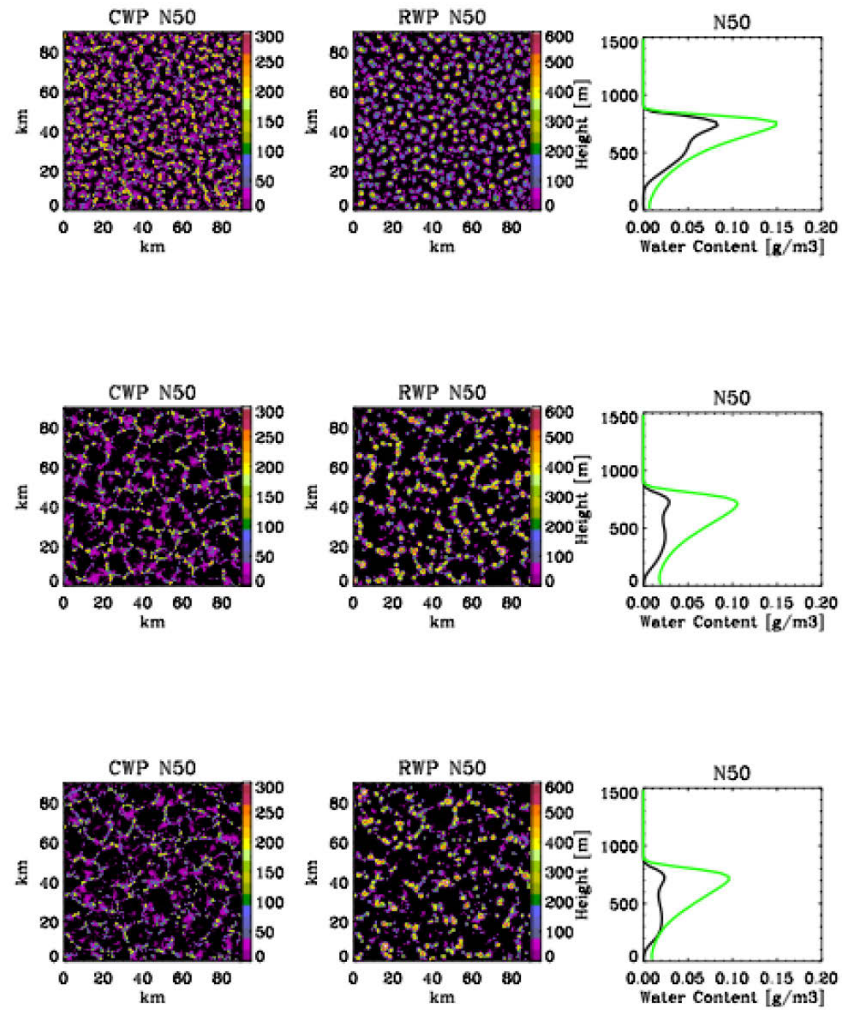




Estimates from a cloud model

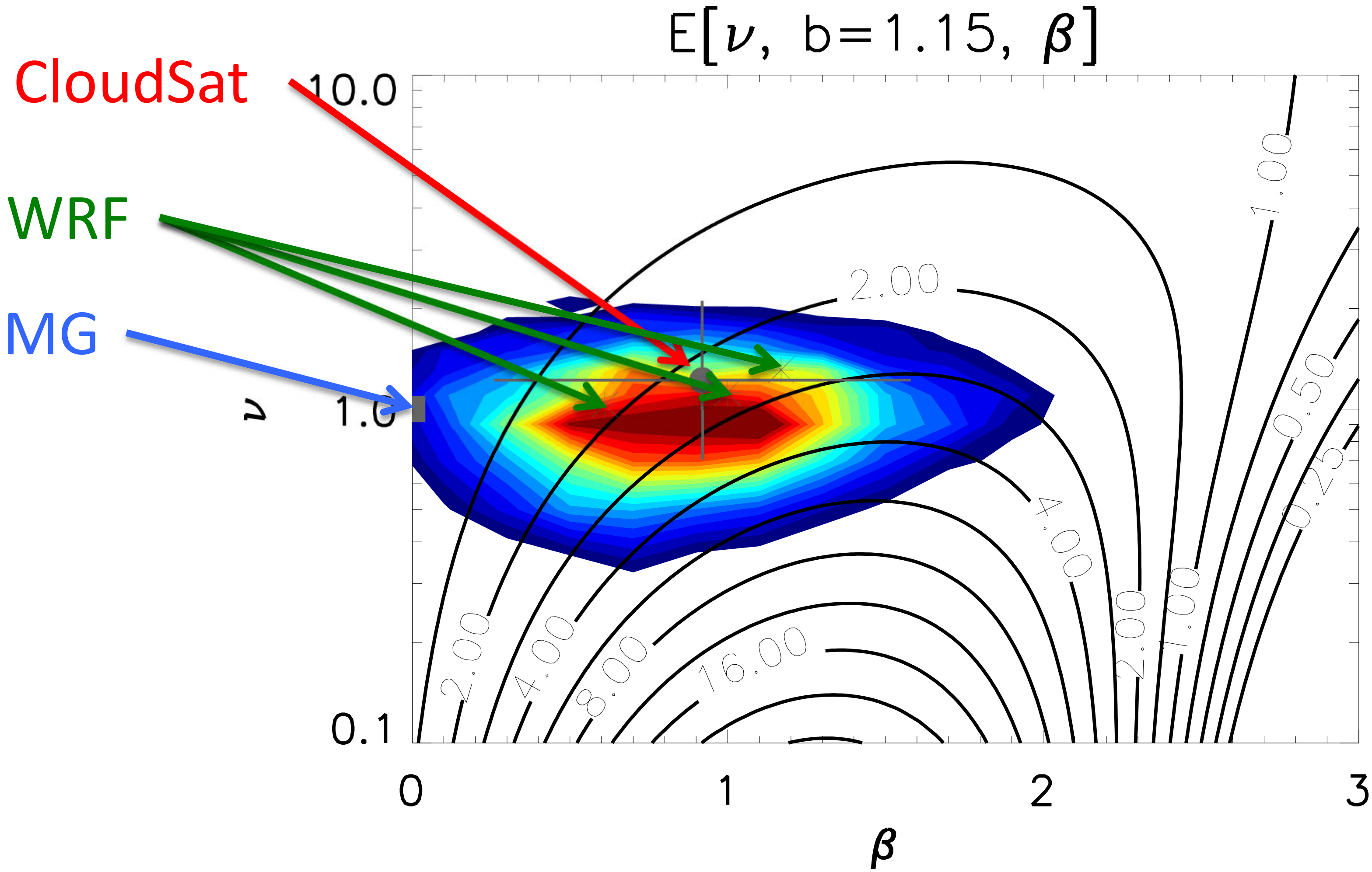
- Dycoms-II RF02 simulations
- WRF model
- 90x90x1.5 km domain
- 300x300X30 m grid spacing
- Two-moment microphysics in each species

	Scene 1	Scene 2	Scene 3
β	0.61	1.00	1.17
ν	1.03	1.12	1.31



Wang and Feingold, 2009

*Comparing observations to E**



- <u>Note</u>: Sampling bias towards stratocumulus regime.

Concluding thoughts

- Sub-grid covariance of cloud and rain can have a large effect on microphysical process rates.
  - *B* and *v* represents a computationally efficient way to implement the first order effects in MG and can be bounded by observations

- Analogous covariance analysis can probably be applied to N_c & q_c to inform autoconversion enhancement factor
  - Cloud model output
  - Some combination of MODIS/POLDER/Calipso (Need for a dedicated mission)

- Much bigger picture: sub-grid variability and covariance should be unified across parameterizations (*i.e.* radiation and microphysics)