

Cloud Effect on Snowball Earth Deglaciation

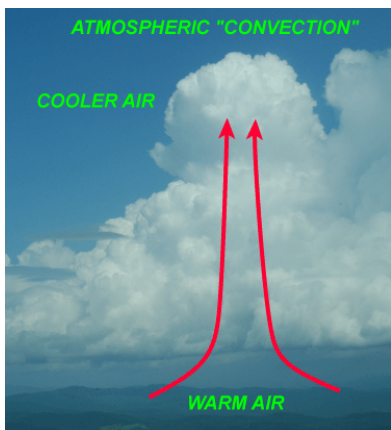
Dorian S. Abbot



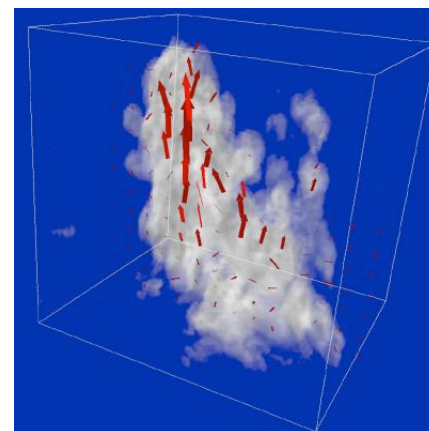
Snowball



Convection still active



Super-parameterized code



Aiko Voigt



MAX-PLANCK-GESELLSCHAFT

Mark Branson



Raymond T. Pierrehumbert



David Pollard



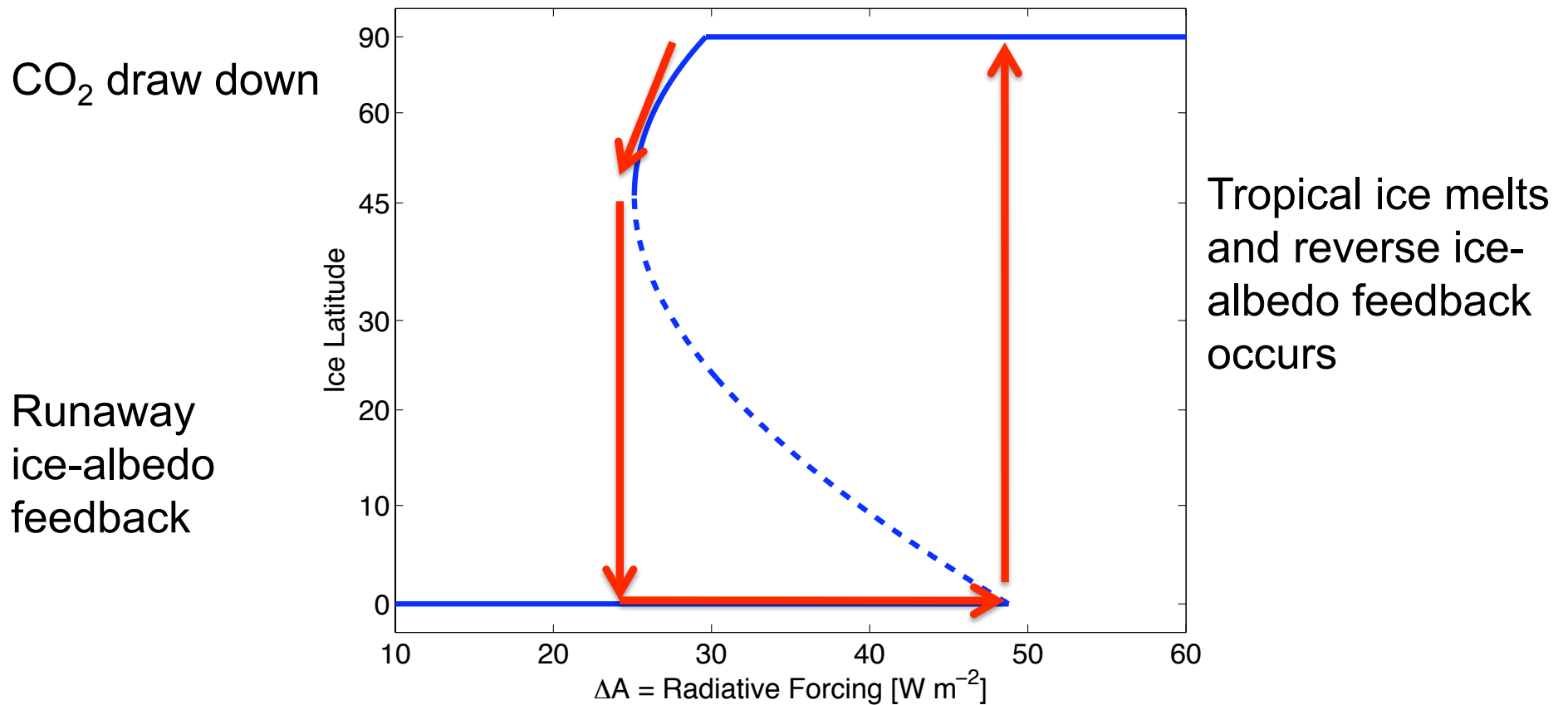
Guillaume Le Hir



Daniel Koll



The Budyko-Sellers climate picture and silicate weathering feedback are combined in the **Snowball Earth hypothesis**.

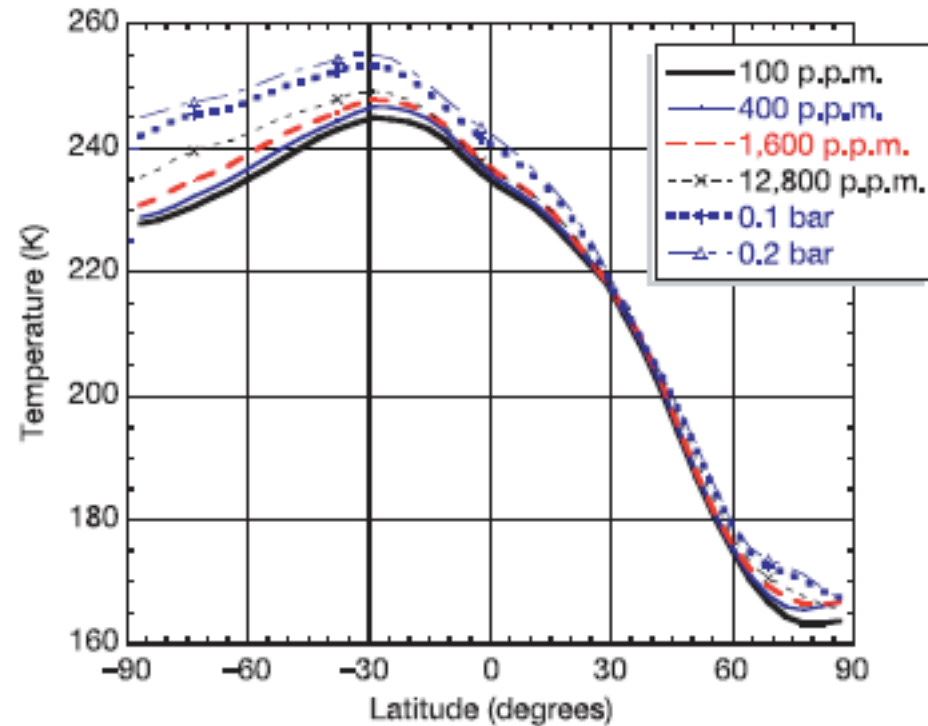


Very low weathering allows CO₂ to build up to ~10% of atmosphere over 1-10 million years

[Budyko, 1969; Sellers, 1969; Walker et al., 81; Kirschvink, 92; Hoffman et al., 98]

Early FOAM results indicated that a huge amount of CO₂ might be needed to deglaciate a Snowball.

January Surface Air Temperature



[Pierrehumbert, 2004]

Two simulations are performed in a variety of models:
 $\text{CO}_2=10^{-4}$ and $\text{CO}_2=0.1$.

Participating Models:

FOAM

GENESIS

ECHAM

LMDz

CAM

SP-CAM

Model Specifications:

Solar Constant 94% of modern

Obliquity= 23.5°

Eccentricity= 0°

Uniform surface albedo of 0.6

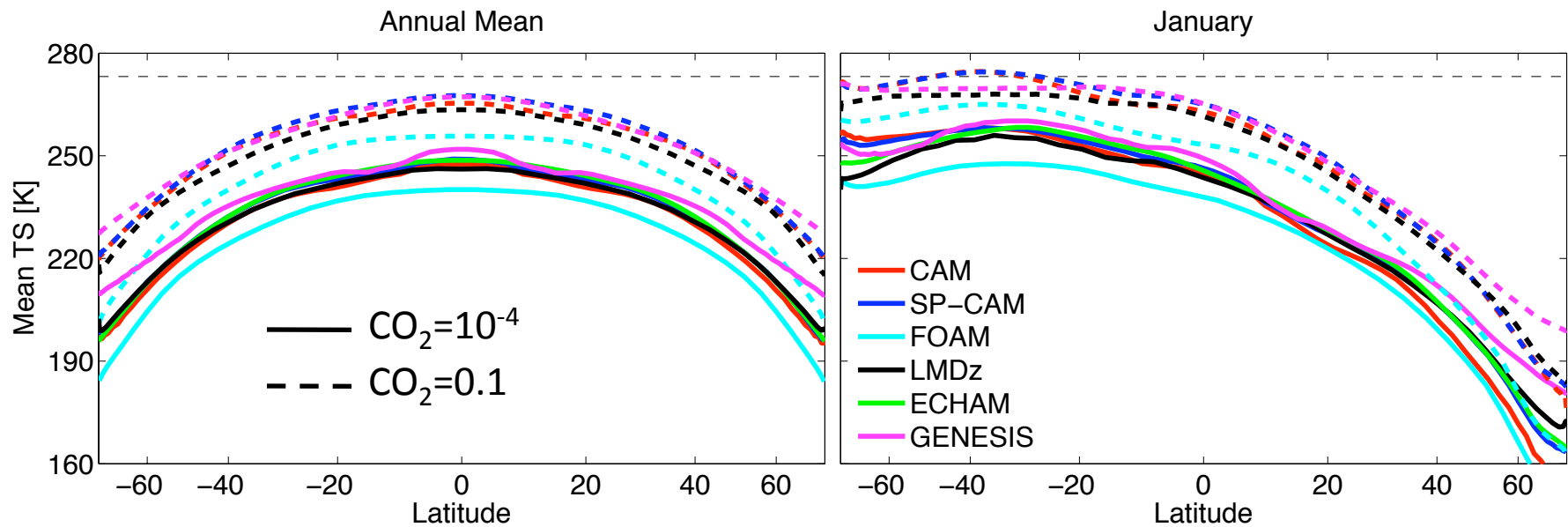
Zero aerosol

Zero ozone

Zero non- CO_2 GHG

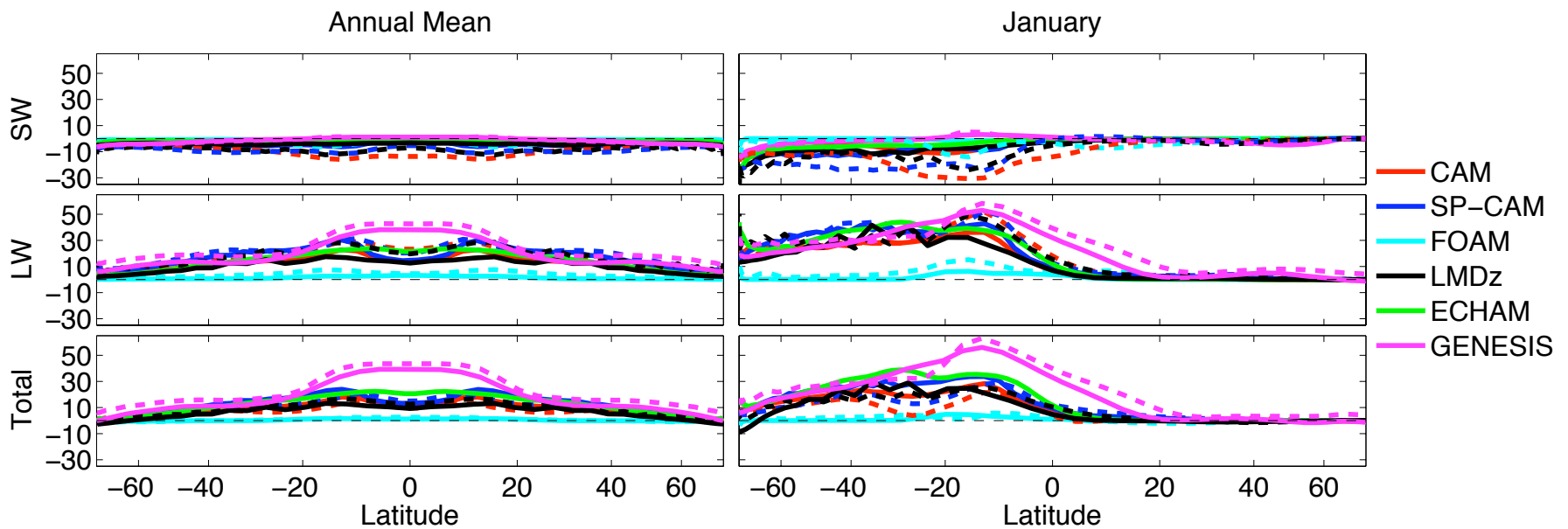
FOAM is 8-12 K colder than the other models, which is equivalent to an **order of magnitude change in CO₂**.

Surface Temperature



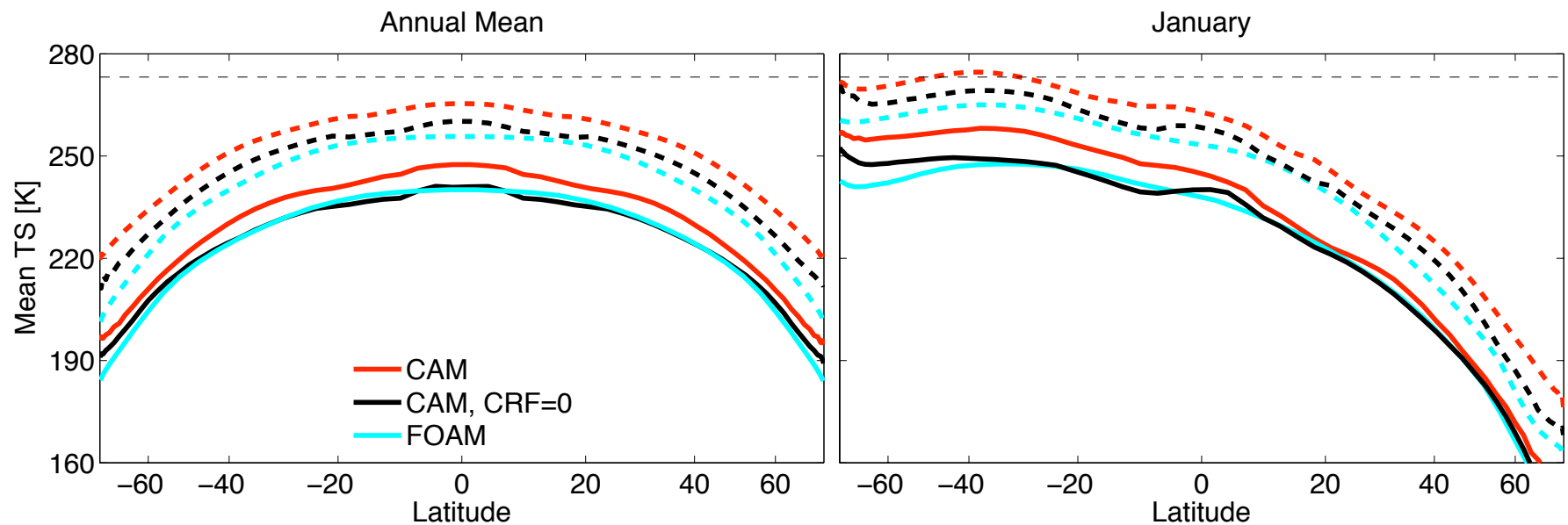
FOAM produces near zero CRF; GENESIS produces roughly double the CRF of the other models.

Cloud Radiative Forcing

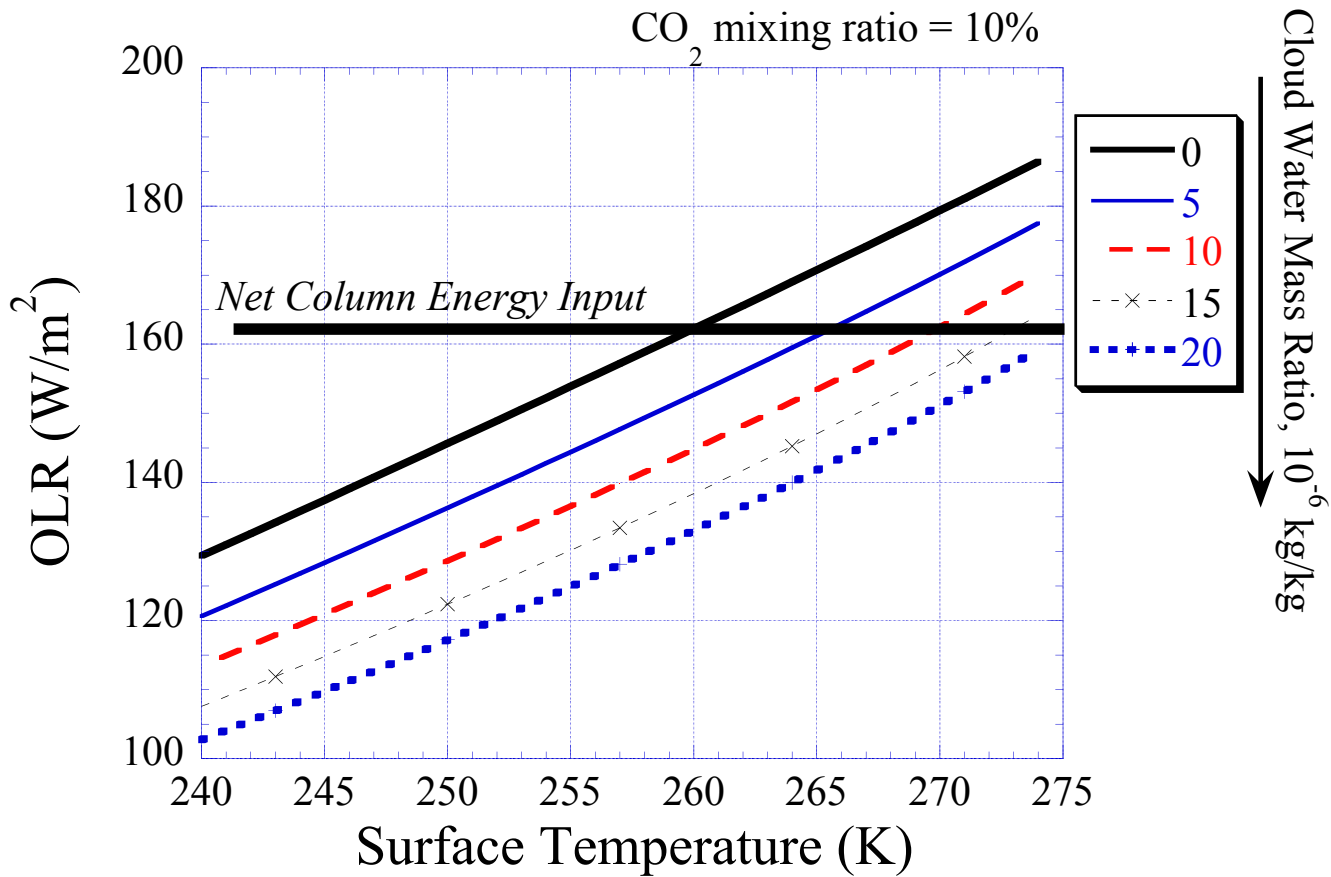


The surface temperature in CAM with CRF set to zero is similar to that in FOAM.

Surface Temperature

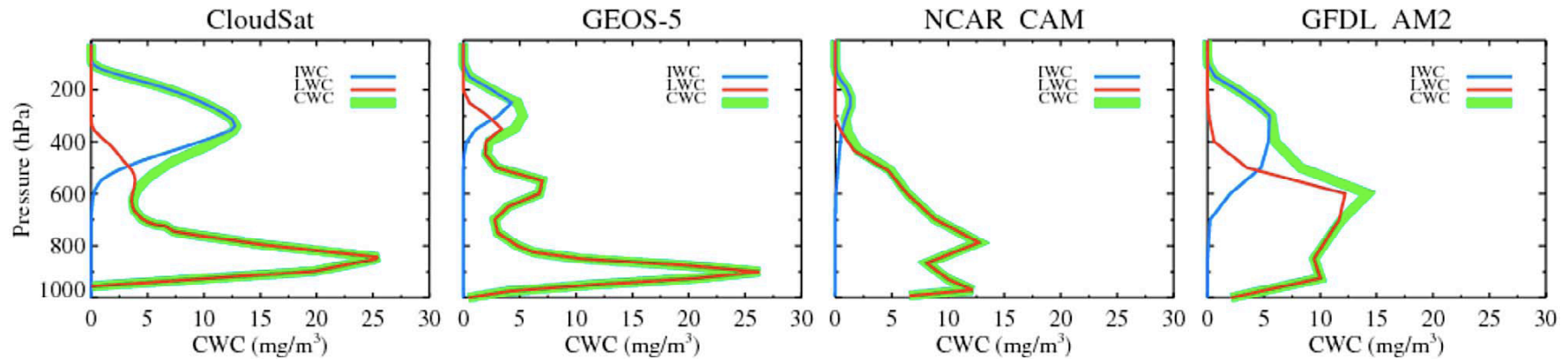


$10 \times 10^{-6} \text{ kg kg}^{-1}$ cloud condensate can cause about 10 K surface warming in the Snowball.



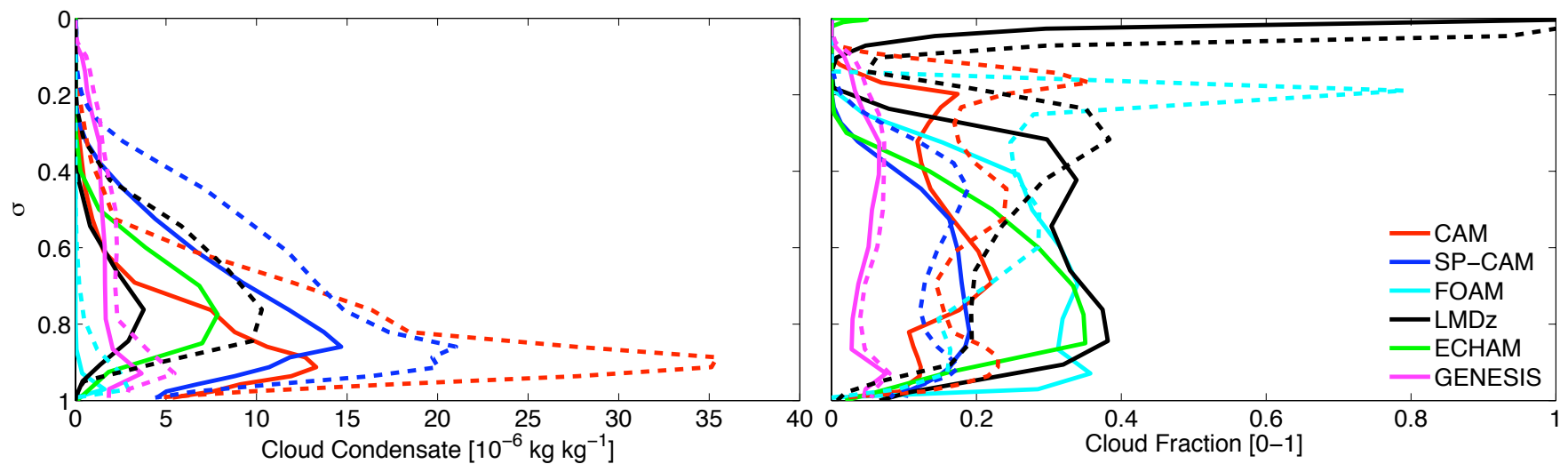
Most models produce Snowball tropical cloud condensate commensurate with modern observations.

Modern



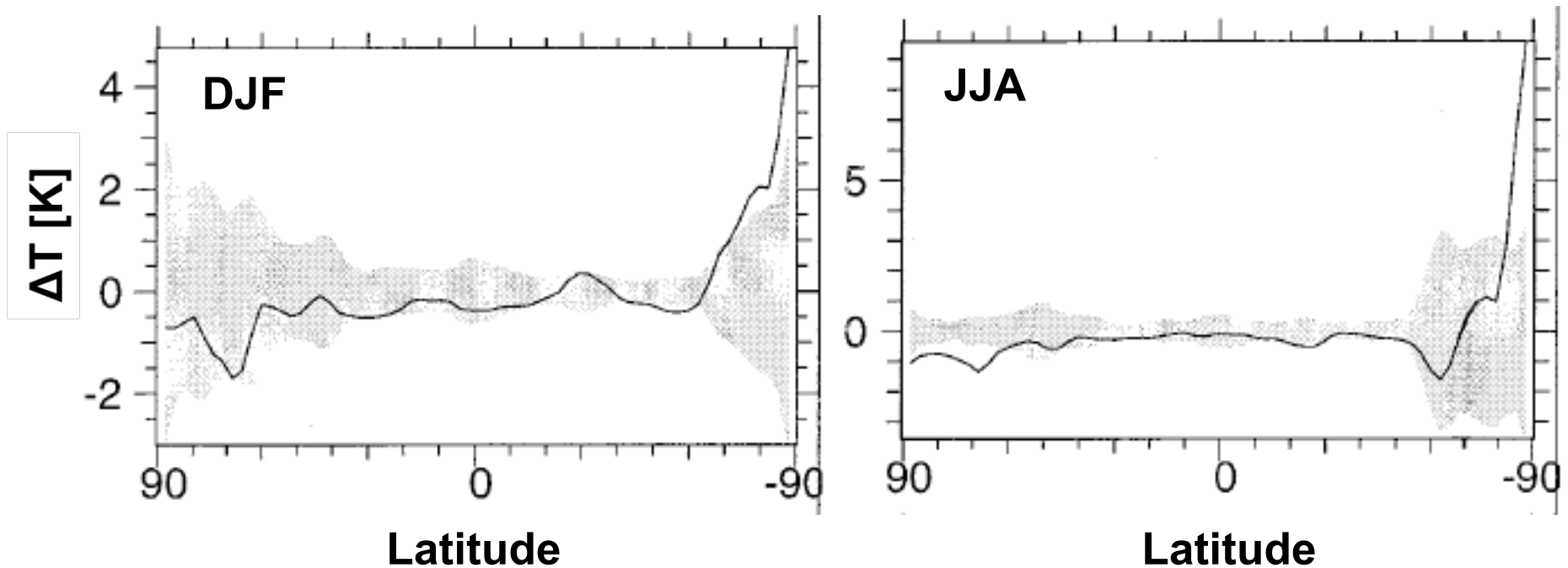
[Su et al., 2011]

Snowball



A prognostic cloud condensate scheme warms Antarctica by 2-8 K relative to the FOAM scheme in modern climate.

Surface temperature difference between new and old scheme



[Rasch and Kristjansson, 1998]

Main conclusion: Snowball deglaciation may be significantly easier than previously thought.

- (1) As a result of an archaic cloud condensate parameterization, FOAM acts as a “no-cloud” model in Snowball conditions and is dramatically colder than other models.
- (2) FOAM’s cloud scheme leads to a cold bias in present-day Antarctica.
- (3) In contrast with FOAM, a super-parameterized cloud resolving model and three GCMs with modern cloud schemes produce moderate positive cloud radiative forcing, causing roughly 10 K higher surface temperatures.