Cumulus-Stratocumulus-Stratus Clouds in Climate Models: What Matters?

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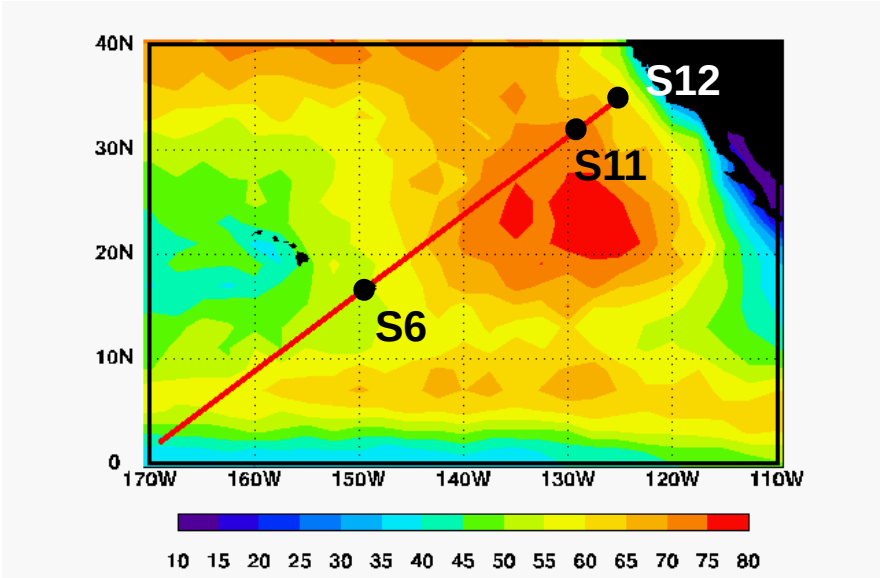
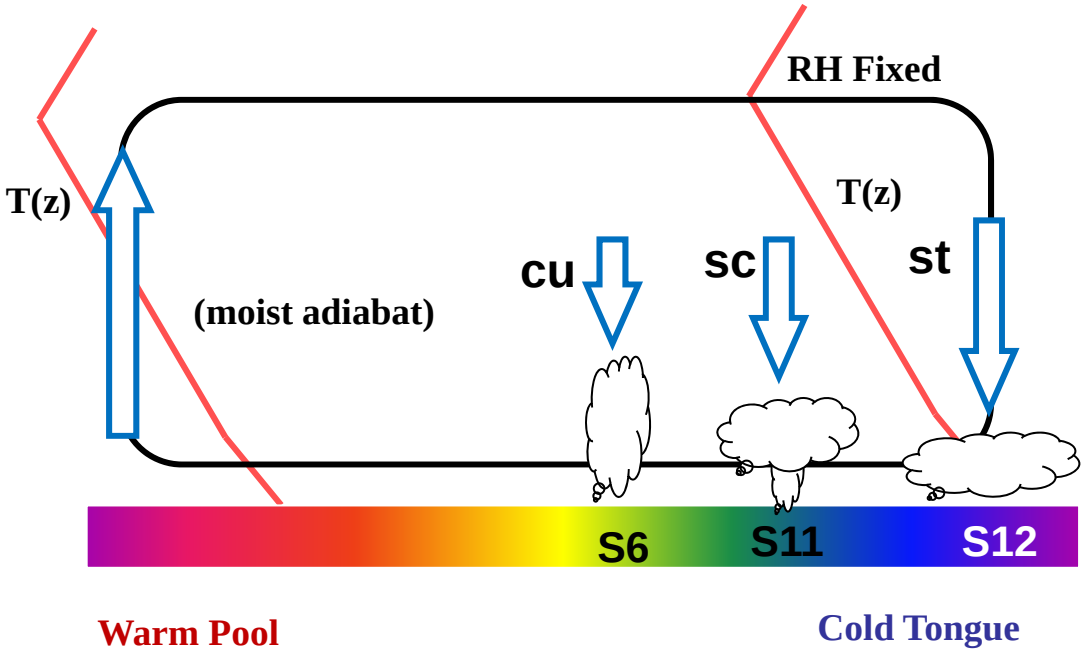
Why Do Models Differ?



CGILS Locations – ARM MAGIC AMF

Large-Scale Condition (SST, Subsidence, Advections) for shallow cu, sc, st



CGILS Locations – ARM MAGIC AMF

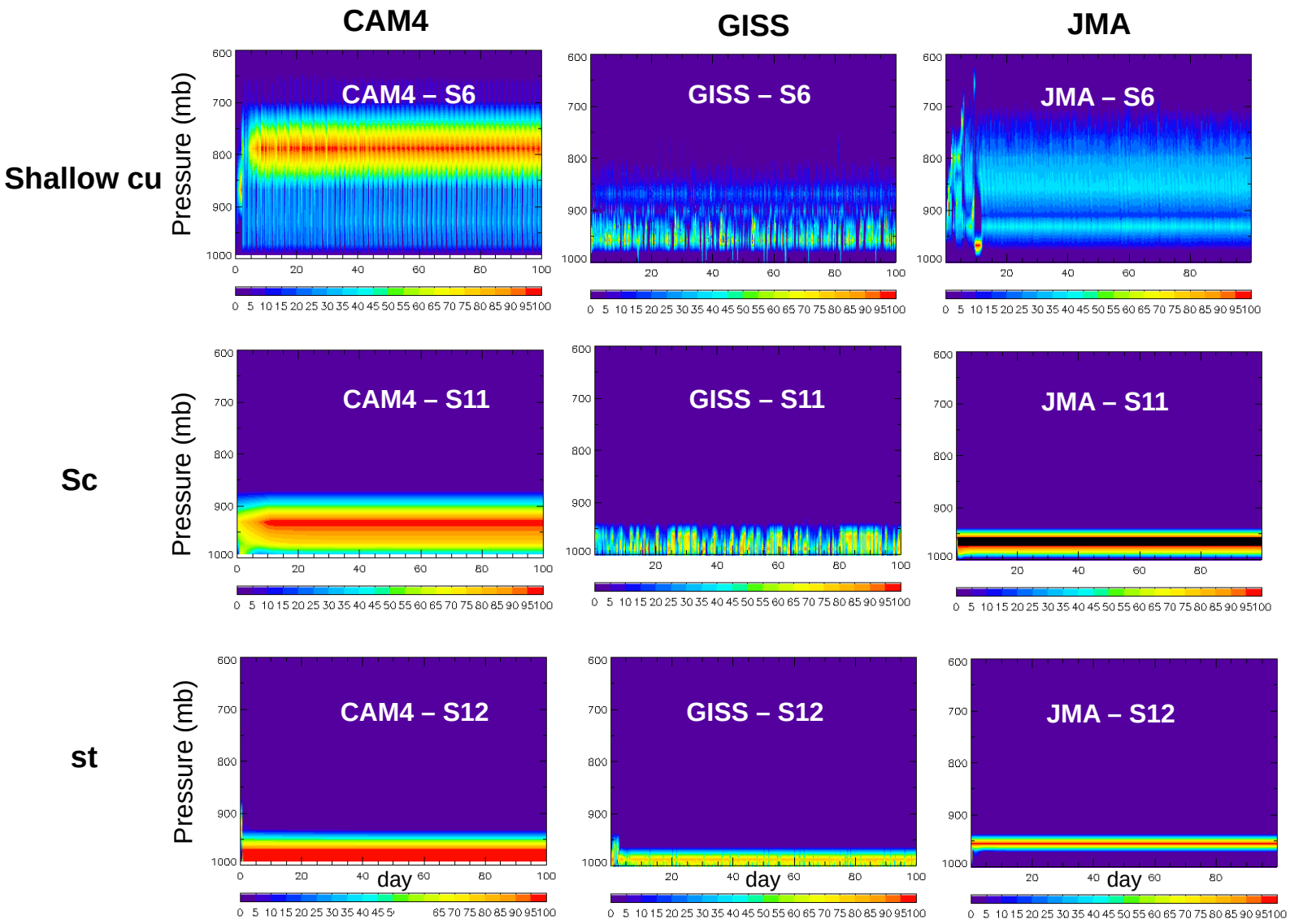
Participating Models

SCM (15)

CAM4 (Hannay, Zhang)
CAM5 (Hannay, Zhang)
CCC (Austin)
CSIRO (Franklin)
ECHAM-ETH (Siegenthaler-LeDrian, Isotta)
ECHAM-MPI (Kumar, Stevens)
ECMWF (Koehler)
GFDL (Golaz, Zhao)
GISS (Wolf, Del Genio)
GSFC (Molod, Bacmeister, Suarez)
JMA (Kawai)
IPSL/LMD (Brient, Bony, Jean-Louis)
RACMO (Neggers)
UKMO (Webb, Lock)
UWM (Larson, Senkbeil)

LES (6)

DALES (de Roode, Siebesma)
SAM (Blossey, Bretherton, Khairdinov)
UCLA (Sandu, Stevens, Heus)
LaRC (Cheng, Xu)
UKMO (Lock)
WRF-BNL (Endo, Liu)

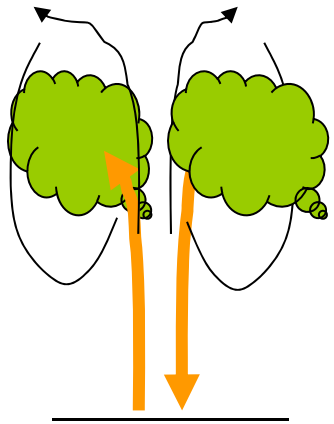

CAM4
GISS
JMA
Shallow cu
Sc
st
Pressure (mb)
CAM4 – S6
GISS – S6
JMA – S6
CAM4 – S11
GISS – S11
JMA – S11
CAM4 – S12
GISS – S12
JMA – S12
day

In Climate Models:

$$\frac{\partial q_m}{\partial t} = -\left(\frac{\partial \overline{w'q'}}{\rho \partial z}\right)_{turb} - \left[\frac{\partial \overline{w'q'}}{\rho \partial z} + c - e\right]_{conv} - c_{stra} - \left[(\vec{V} \cdot \nabla q)_{LS} + \omega_{LS} \frac{\partial q_m}{\partial p}\right]$$

Turbulence | Convection | Stratiform | Large-Scale Forcing

$$\frac{\partial q_l}{\partial t} \sim c_{stra} - P, \qquad P \sim q_l, \qquad c_{stra} \sim q_l$$



Moisture Tendencies:

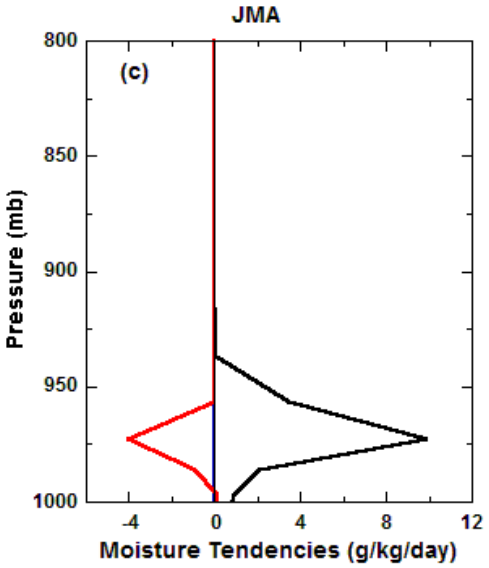
Turbulence

Convection

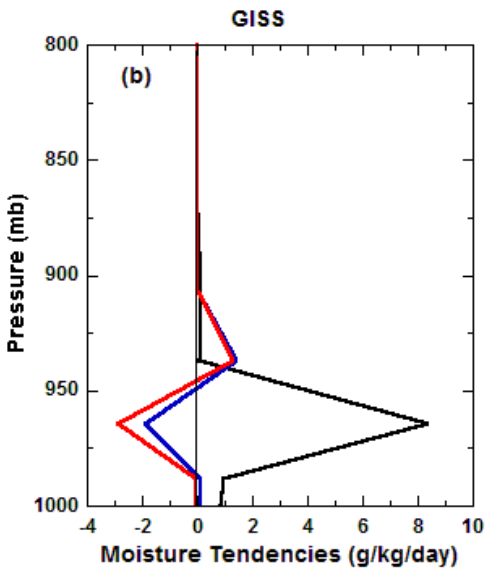
Stratiform

S11 Stratocumulus

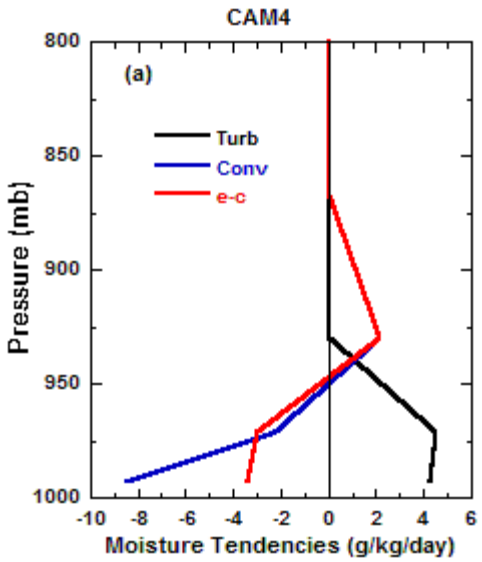
JMA

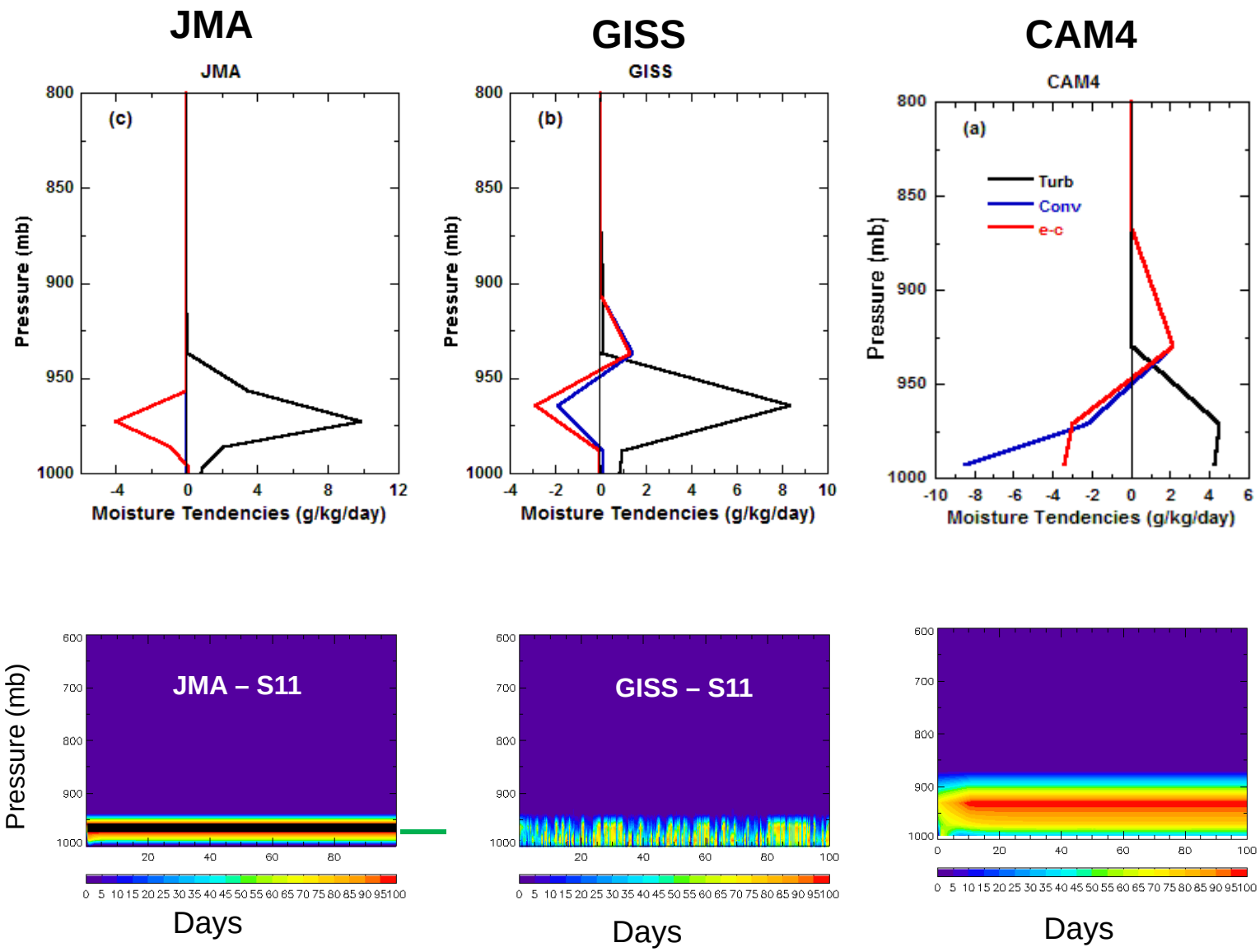


GISS



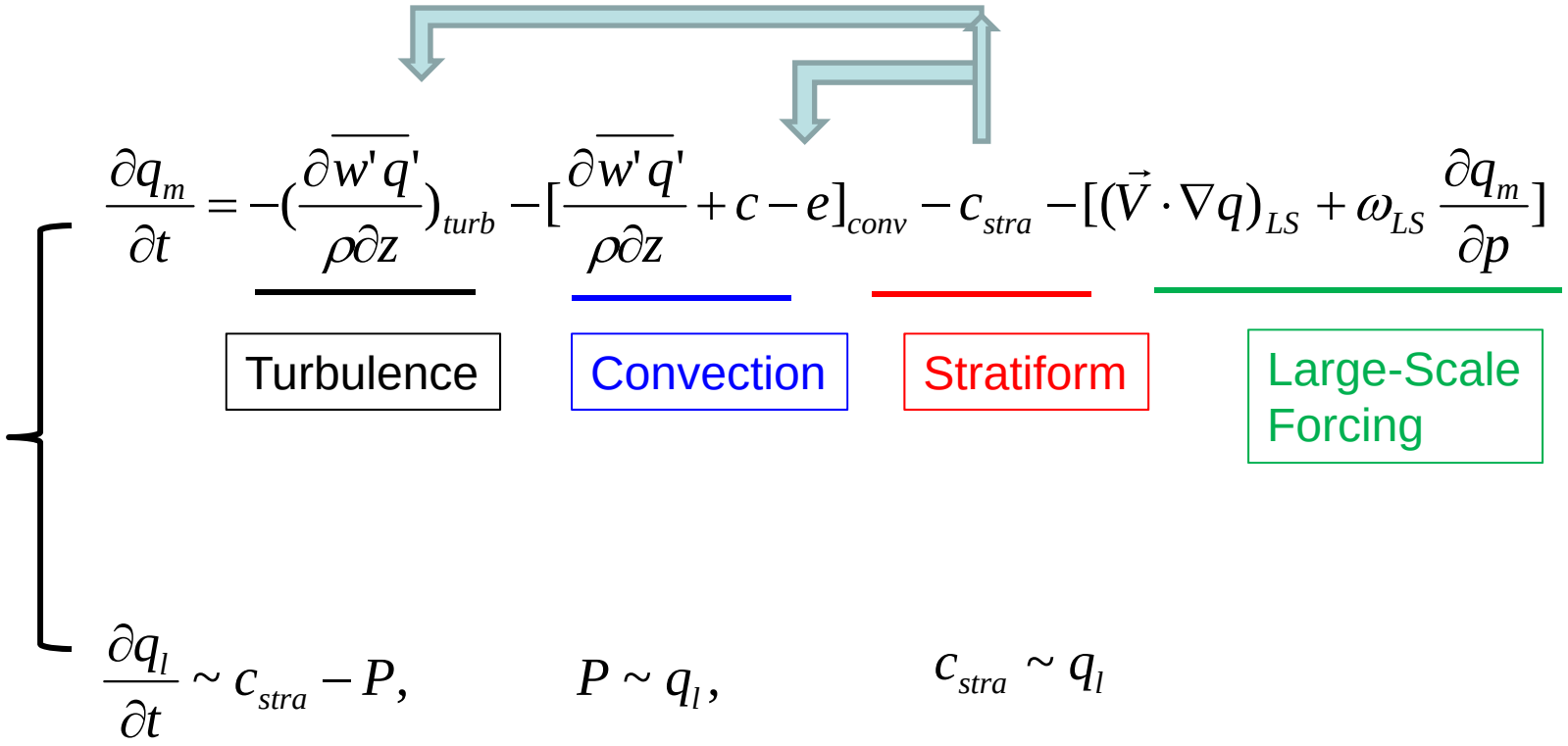
CAM4




JMA
GISS
CAM4
JMA
GISS
CAM4
(c)
(b)
(a)
Turb
Conv
e-c
Pressure (mb)
Moisture Tendencies (g/kg/day)
JMA – S11
GISS – S11
Days

The different balance of the terms produces different types of clouds

In Climate Models:



Moisture Tendencies:

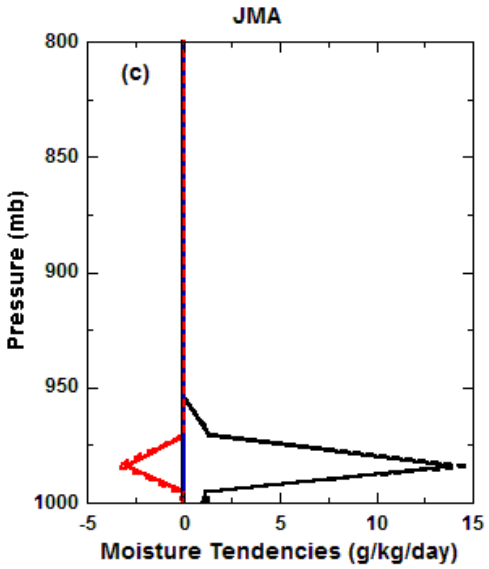
Turbulence

Convection

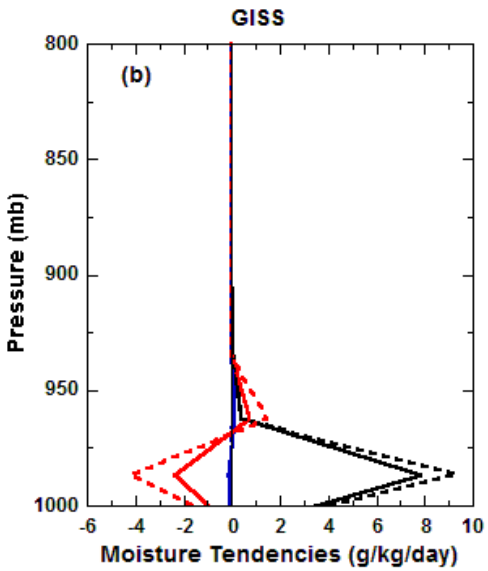
Stratiform

S12 Stratus

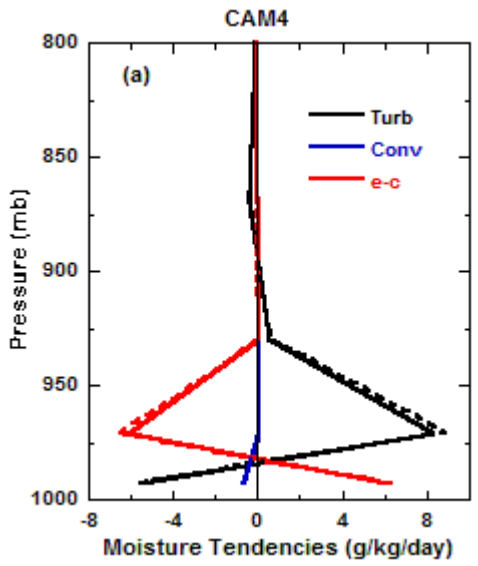
JMA



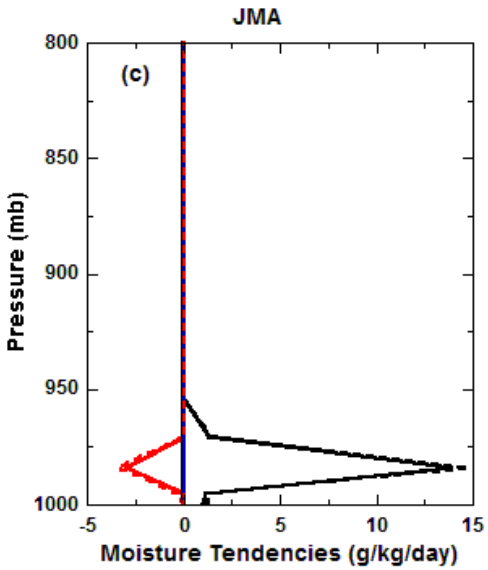
GISS



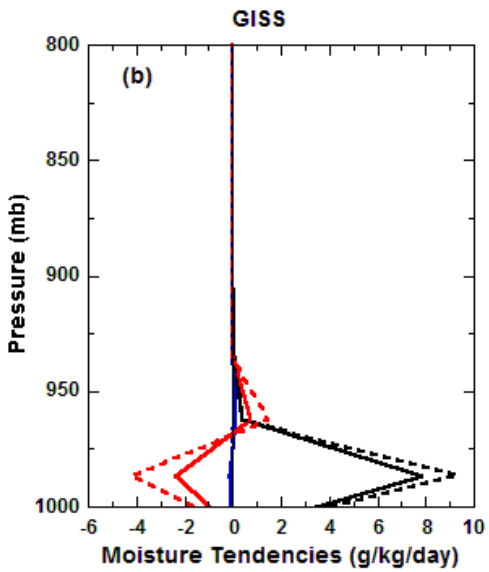
CAM4



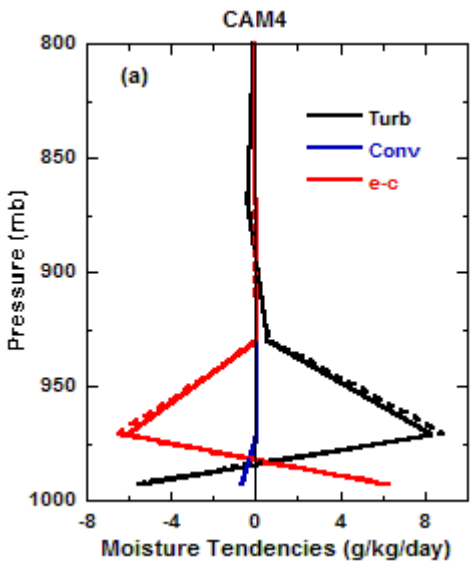
JMA



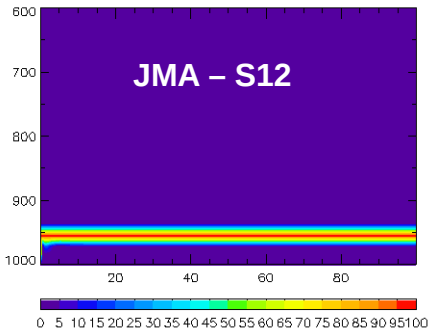
GISS



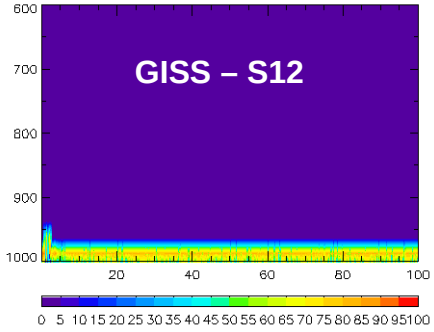
CAM4



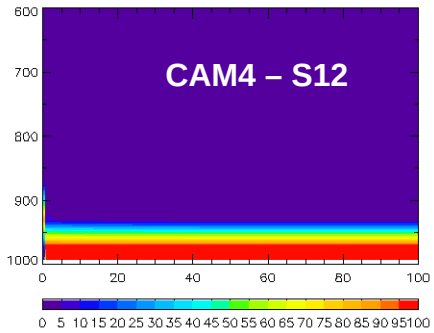
Pressure (mb)



Days



Days



Days

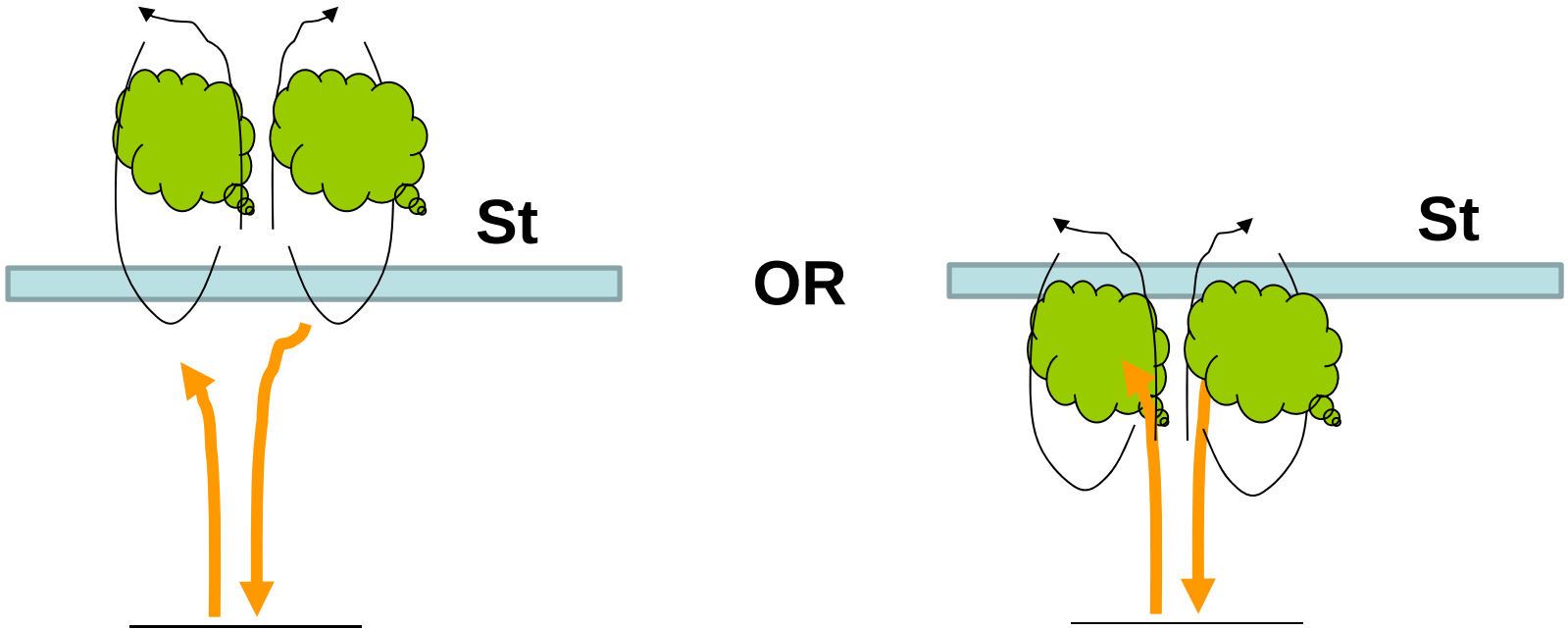
Parameterization of the flux profiles differ among the models

Issues in Models

1. Shallow convection

Acts as entrainment process, drawing dry and warm air down, ventilates the PBL

Different models use different assumptions on the vertical extent, the entrainment and detrainment rates, and mass flux profiles.



2. PBL Parameterization

Height and flux profiles, cloud-top entrainment

$$-\left(\frac{\partial \overline{w'q'}}{\rho \partial z}\right)_{turb},$$

$$\overline{w'q'} = -K\frac{\partial \overline{q}}{\partial z} + \Gamma, \qquad K = ?, \Gamma = ?$$

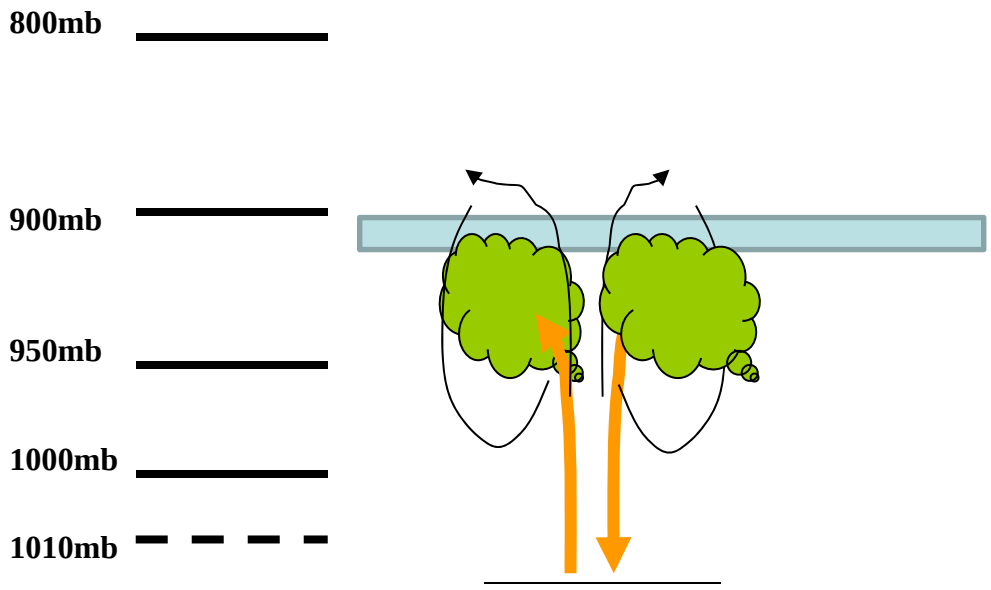
$$\overline{w'q'} = w_e \Delta q, \qquad w_e = ?,$$

3. Cloud and precipitation microphysics

Feedback to radiation, thermodynamics, and turbulence

4. Vertical Resolution

Can the turbulent mixing be parameterized by coarse resolution?



ARM Measurements

Thermodynamic profiles

Vertical and horizontal extend of clouds

Cloud microphysical properties

Surface fluxes

These might constrain the mixing of air from shallow convection and turbulence in the models.

Need large-scale dynamical conditions as well.

ARM and ASR are in a good position to build a database of case studies and statistics to systematically calibrate model parameterizations and to verify the models.