Linear responses of two convective parameterization schemes

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Cumulus parameterizations

- Express theory or interpretation of observed atmospheric phenomena.
- Mean states often agree.
- Tropics and short-term responses are troublesome.
A comparison

- 3D Cloud System Resolving Model (CSRM)
- Two 1D single-column models (convective parameterization schemes)
Explicit scheme model (CSRM)

- System for Atmospheric Modeling* (SAM)
- horizontal resolution: 2 km
- vertical resolution: 100 m - 1 km
- domain: 128 km x 128 km x 32 km

*(Khairoutdinov and Randall, 2003)
Single-column models

- MIT Single-Column Model\(^1\) (MSCM)
  - CONVECT parameterization scheme
  - vertical resolution: 250 m
  - column height: 20 km

- Diabat3 toy cumulus parameterization\(^2\) (D3)
  - (same resolution and height)

\(^1\)(Emanuel, 1991; Emanuel and Živković, 1999)
\(^2\)(Raymond, 1994; Raymond, 2007)
Identical forcing schemes in all 3 models

Constant radiative cooling

Bulk surface fluxes

- \( FT_{surf} \propto C_D V (SST - T_0) \)
- \( Fq_{surf} \propto C_D V (q_{s0} - q_0) \)
- \( C_D = 1 \times 10^{-3} \)
- \( V_{surf} = 5 \text{ m s}^{-1} \)
- \( SST = 28 \, ^\circ\text{C} \)
Each model $\approx$ linear transformation matrix

$$\frac{dx}{dt} = Mx,* \quad x = (T, q)$$

How to generate matrix columns:

1) Obtain an RCE state

2) Apply unique $\dot{T}, \dot{q}$ → new equilibrium

3) $\Delta$equilibrium → anomalies $T', q'$

*(Kuang, 2010)*
Assemble the matrix

\[ \frac{dX}{dt} = \begin{bmatrix} \dot{T}_{0,0} & \ldots & \dot{T}_{0,n} \\ \vdots & \ddots & \vdots \\ \dot{T}_{m,0} & \ldots & \dot{T}_{m,n} \\ \dot{q}_{0,0} & \ldots & \dot{q}_{0,n} \\ \vdots & \ddots & \vdots \\ \dot{q}_{m,0} & \ldots & \dot{q}_{m,n} \end{bmatrix}, \quad X = \begin{bmatrix} T_{0,0} & \ldots & T_{0,n} \\ \vdots & \ddots & \vdots \\ T_{m,0} & \ldots & T_{m,n} \\ q_{0,0} & \ldots & q_{n,0} \\ \vdots & \ddots & \vdots \\ q_{m,0} & \ldots & q_{m,n} \end{bmatrix} \]

\[ M = \left( \frac{dX}{dt} \right) X^{-1} \]

\[ \frac{dx}{dt} = Mx(t) \quad \leftarrow \text{2 h avg.} \]
Convective responses to temperature anomalies
$\dot{T}, \dot{q} \leftarrow$ warm anomaly (800 hPa)

**SAM**: cools anomalous layer and aloft, moistens below

**D3**: similar behavior, except drying aloft

**MSCM**: warming and drying aloft, negligible moistening below
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\( \dot{T}, \dot{q} \leftarrow \) warm anomaly (650 hPa)

**SAM**
- Cools anomalous layer and aloft
- Moistens below

**D3**
- Highly localized cooling and moistening

**MSCM**
- Heating inflection point, drying below
- Anomaly (neither convection scheme has cooling aloft)
\( \dot{T}, \dot{q} \leftarrow \text{warm anomaly (650 hPa)} \)

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Convective responses to moisture anomalies
\( \dot{T}, \dot{q} \leftarrow \text{moist anomaly (800 hPa)} \)

**SAM**
- Strong localized drying, warming at and above anomaly

**D3**
- Cooling and moistening aloft,
  \( \Delta q \approx 2.5 \)

**MSCM**
- No mid-level warming, significant drying aloft
\( \dot{T}, \dot{q} \leftarrow \text{moist anomaly (800 hPa)} \)

- **SAM**: strong localized drying, warming at and above anomaly

- **D3**: cooling and moistening aloft, \( \Delta q \approx \Delta T \approx 2.5 \)

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\( \dot{T}, \dot{q} \leftarrow \text{moist anomaly (800 hPa)} \)

- **SAM**: strong localized drying, warming at and above anomaly
- **D3**: cooling and moistening aloft, \( \Delta q : \Delta T \approx 2 : 5 \)
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- **D3**: cooling and moistening aloft, \( \Delta q : \Delta T \approx 2 : 5 \)
- **MSCM**: no mid-level warming, significant drying aloft
$\dot{T}, \dot{q} \leftarrow$ moist anomaly (650 hPa)

SAM D3 MSCM

SAM: strong localized drying, warming at and above anomaly
D3: (both convection schemes show cooling aloft)
MSCM: moistening aloft
\( \dot{T}, \dot{q} \leftarrow \text{moist anomaly (650 hPa)} \)

- **SAM**: strong localized drying, warming at and above anomaly

- **D3**: (both convection schemes show cooling aloft)

- **MSCM**: moistening aloft
\( \dot{T}, \dot{q} \leftarrow \text{moist anomaly (650 hPa)} \)

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Conclusions

- The linear transformation matrix is a useful medium for comparison.
- D3 and MSCM manifest highly localized convective responses.
- D3 expresses phase changes where advection may be more important.
- MSCM and D3 show sign errors in $\dot{T}$ and $\dot{q}$, which may disrupt/prevent certain dynamic phenomena (e.g. convectively-coupled waves).
Extras
Stratospheric relaxation

$T$ and $q$ are relaxed near tropopause over $1/2$ day
2:5 ratio $\implies$ only phase change occurs

\[
MSE = c_p T + gz + L_v q
\]

If a pseudoadiabatic process (rain) occurs at some level...

\[
\Delta MSE \bigg|_{z=z_0} = c_p \Delta T + L_v \Delta q = 0
\]

\[
\frac{\Delta T}{\Delta q} = -\frac{L_v}{c_p} \approx -2/5
\]