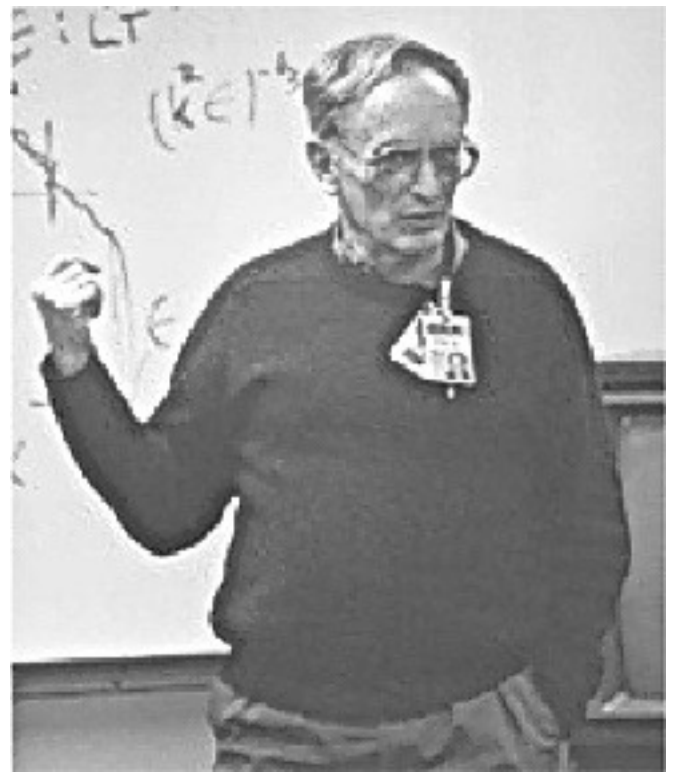
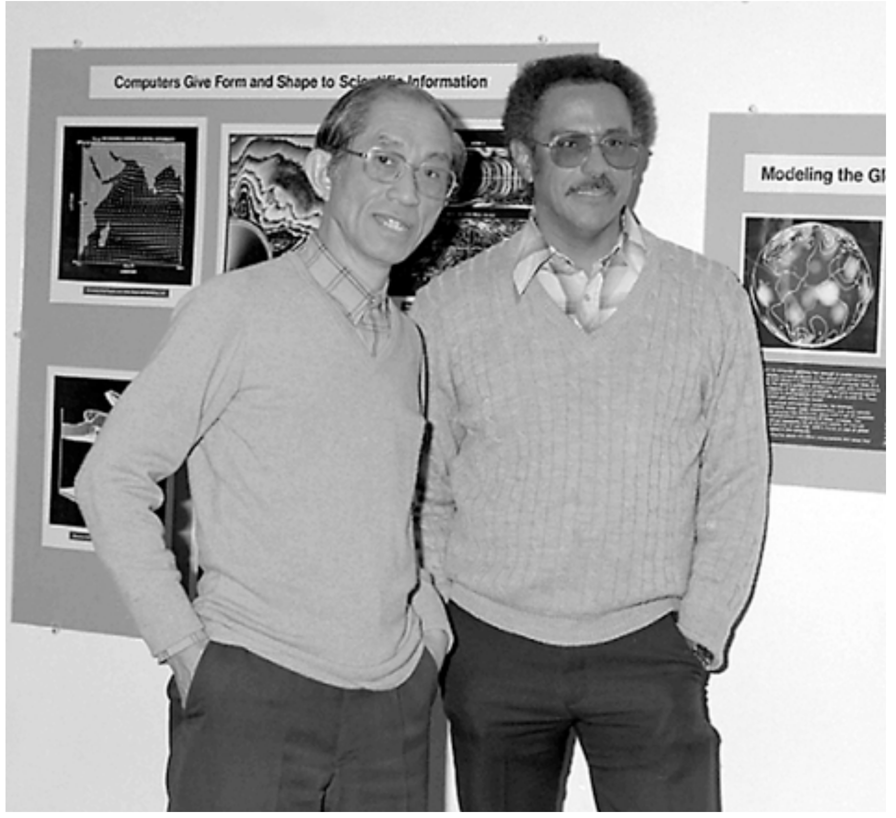
Earth System Skunkworks

We modelers are tool builders.

“Tool builder” is a pejorative, dismissive term in some quarters.

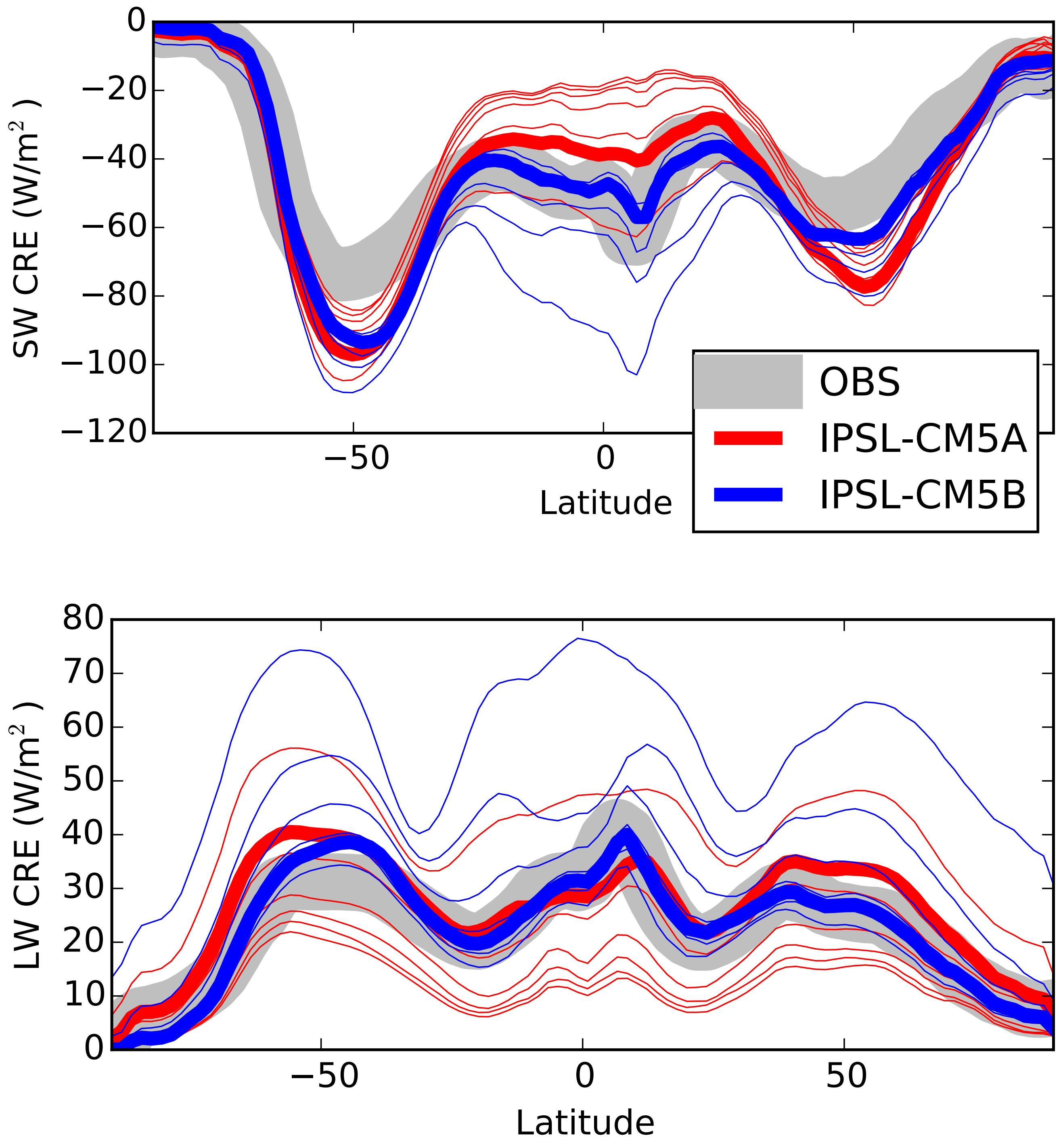
Early tool builders



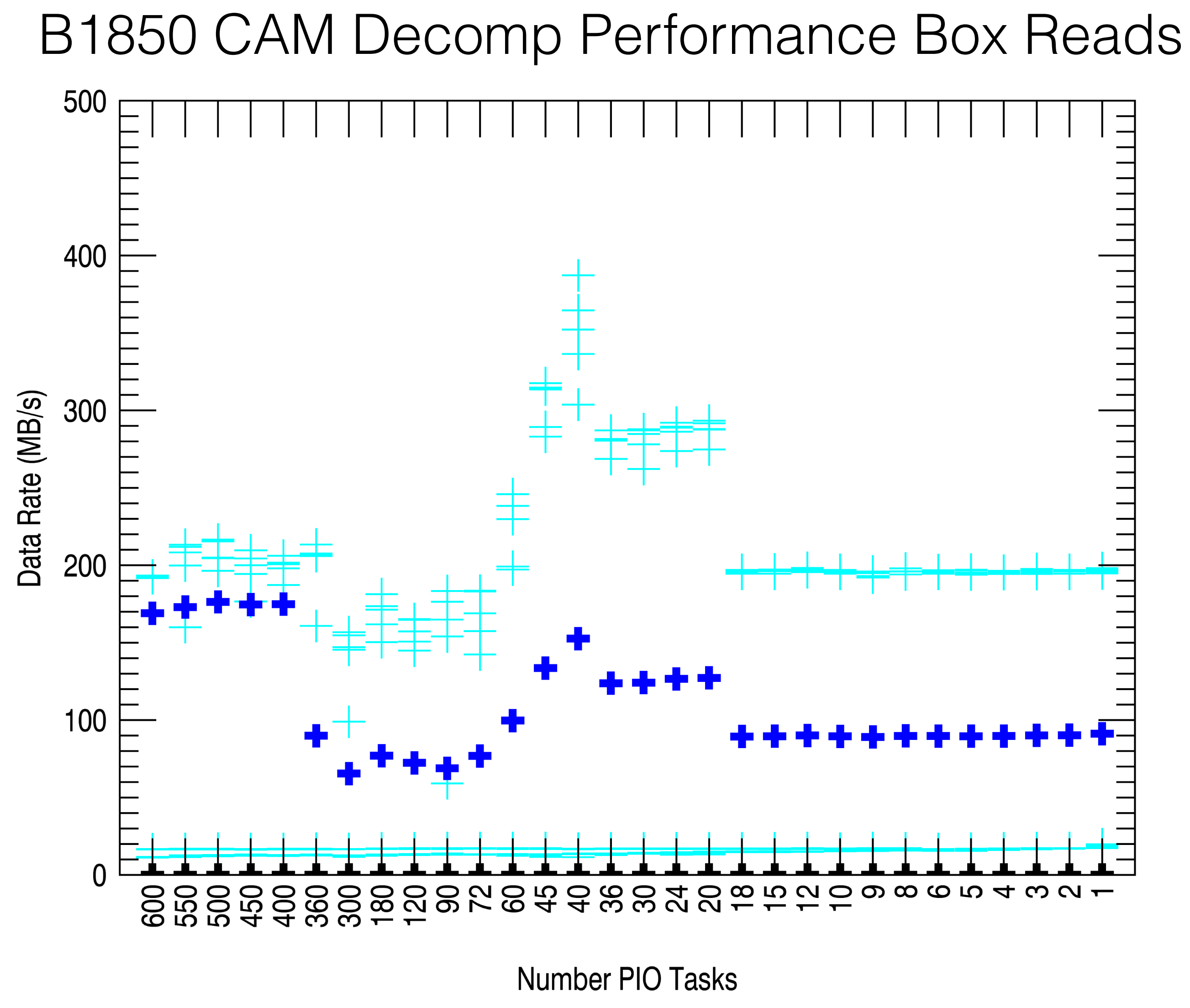


Then	Now
Troposphere	Troposphere & stratosphere, ocean with sea ice, land surface, lots of biology and chemistry, terrestrial ice sheets
Curiosity-driven academic research, mostly aimed at climate simulation	Applications: NWP, climate-change simulations. Academic research disguised to fit with agency FOAs.
All models were developed in the USA. All model builders were men.	World-wide modeling community. More diverse participation.
Model as a tool to achieve understanding	Model as a tool for performing simulations
Model users = Model builders	Model users >> Model builders
Small, informally organized modeling groups	Corporatized modeling
Mostly closed modeling shops	Mostly open modeling shops, with lots of international intercomparison projects

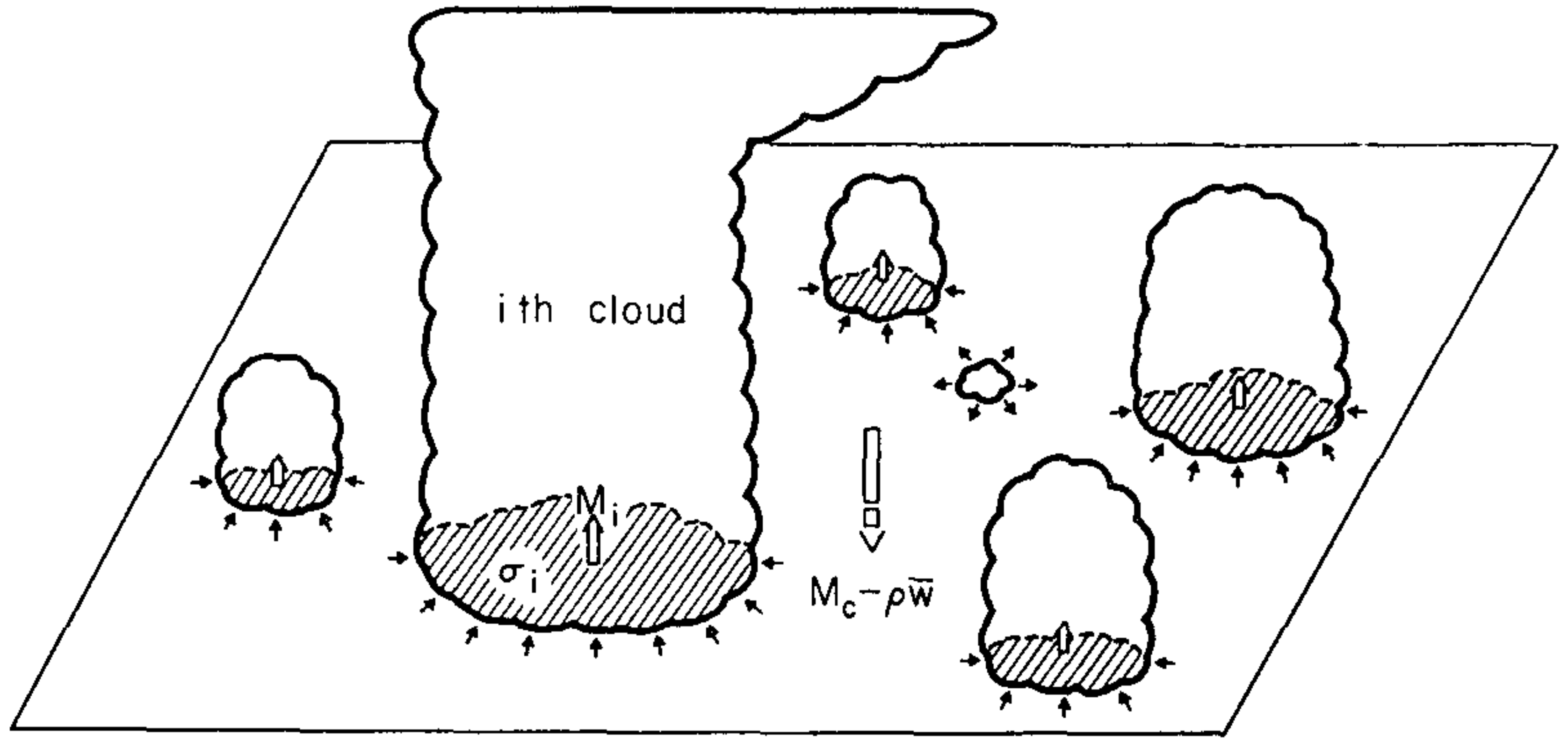
Model development involves both science and engineering.



Hourdin et al. (2017)



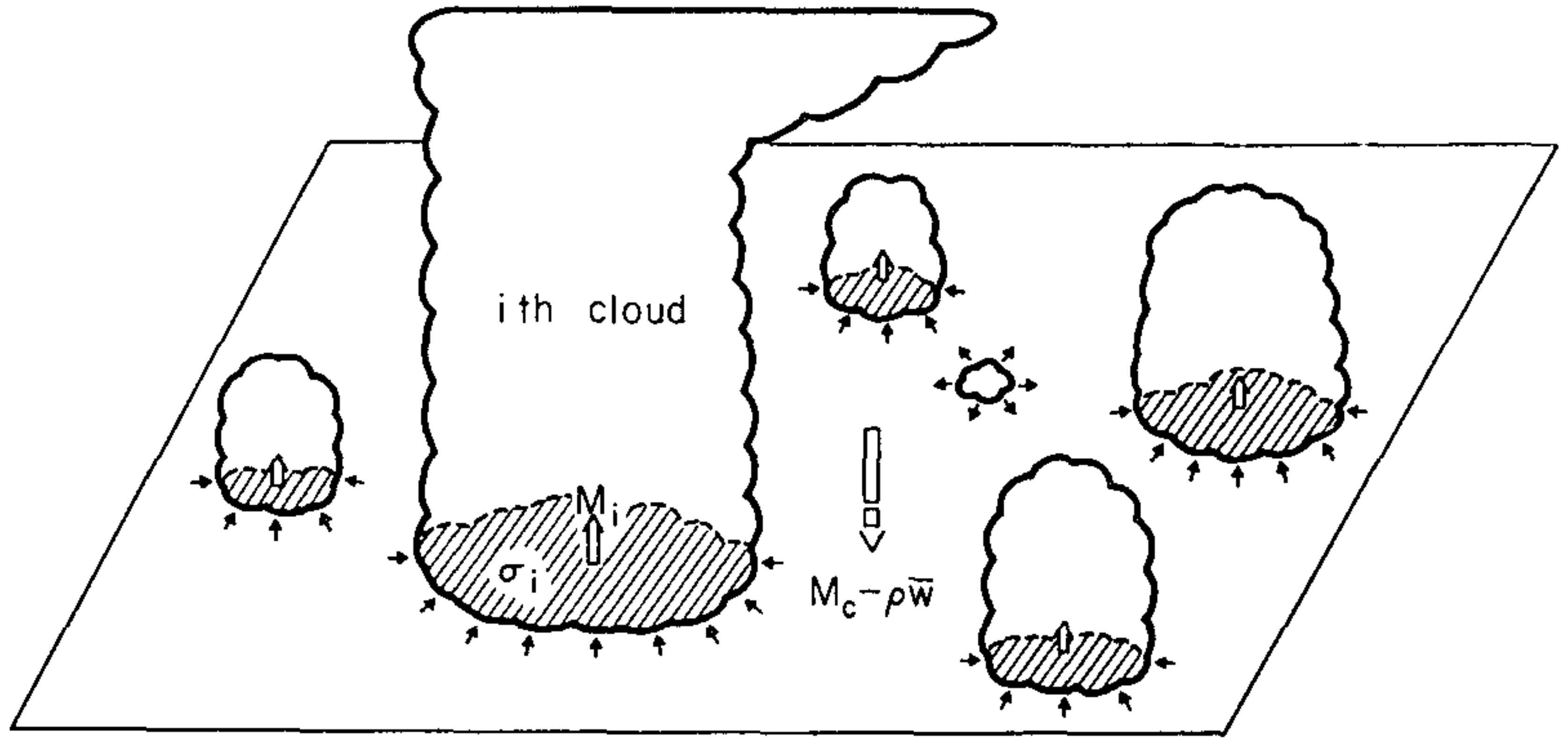
Thayer-Calder & Edwards (2016)



$$\left|\frac{dA(\lambda)}{dt}\right| \ll \left|\left[\frac{dA(\lambda)}{dt}\right]_c\right|$$

Arakawa & Schubert (1974)

The scientific side of model development gives us a better understanding of the real world.



$$\left|\frac{dA(\lambda)}{dt}\right| \ll \left|\left[\frac{dA(\lambda)}{dt}\right]_C\right|$$

Arakawa & Schubert (1974)

That's why it's more than just tool building.

Aspiration

Create a well funded university-based model-development project that pursues risky new approaches and offers the successful ones for possible adoption by the climate and NWP communities.

Tool Building in the Universities

University scientists have valuable ideas that are not easily injected into corporate modeling centers.

A university-based effort can can pursue promising but risky new directions that would be difficult to justify in a laboratory environment.

University-based tool builders can train future, more highly evolved generations of tool builders.

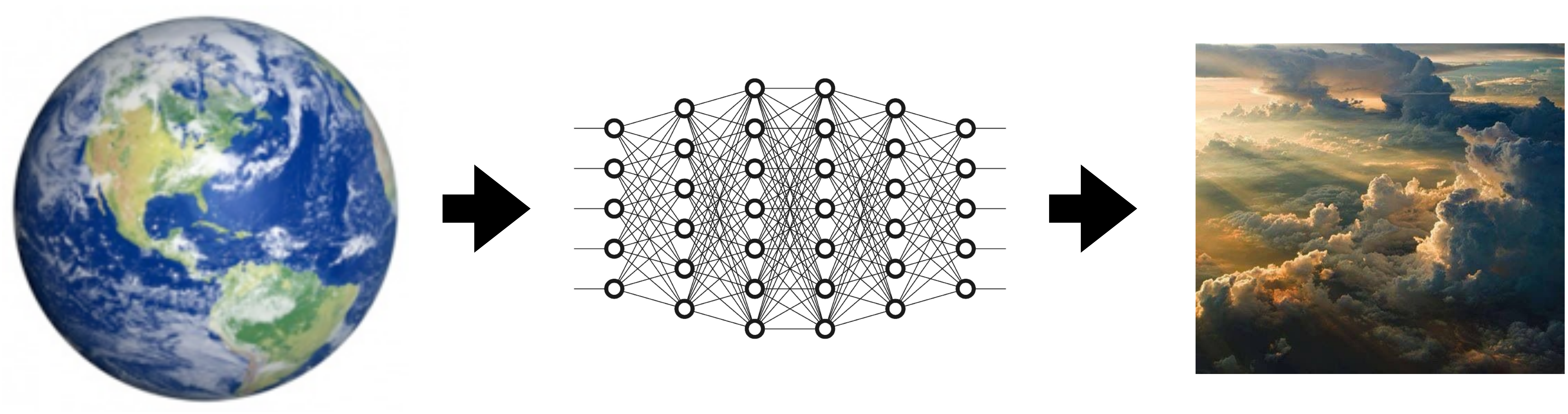
A Precedent

CMMAP was all about model development.

CPTs have been limited to "shovel-ready" projects. In contrast, CMMAP's model development work started from basic concepts, took big risks, and needed a long time to produce results.

CMMAP demonstrated that a university-based model-development project can complement and add value to laboratory-based modeling centers.

Machine-Assisted Development
(MAD)



Thoughts about strategy

- Start from an "exact" set of equations that have gaps to be filled by machine learning.
- Notwithstanding the gaps, the equations should guarantee important principles like conservation of energy, water, and momentum.
- Yes, don't forget momentum.
- If the parameterizations are to be stochastic, then they need to include some memory.

Higher-order closure

$$\frac{\partial}{\partial t}\left(\rho_0\overline{\theta}\right)+\frac{\partial}{\partial x_j}\left(\rho_0\overline{u}_j\overline{\theta}+\rho_0\overline{u_j'\theta'}+\overline{H}_j\right)=\frac{\theta_0}{c_pT_0}\overline{Q}$$

A first moment equation

$$\frac{\partial}{\partial t}\left(\rho_0\overline{u_i'\theta'}\right)+\frac{\partial}{\partial x_j}\left(\overline{u}_j\rho_0\overline{u_i'\theta'}+\overline{u_j'\rho_0u_i'\theta'}\right)$$

$$=-\rho_0\overline{u_i'u_j'}\frac{\partial\overline{\theta}}{\partial x_j}-\rho_0\overline{u_j'\theta'}\frac{\partial\overline{u}_i}{\partial x_j}+2\varepsilon_{i,j,k}\rho_0\overline{u_j'\theta'}\Omega_k$$

$$-\overline{\rho_0\theta'\frac{\partial}{\partial x_i}\left(\frac{\delta p'}{\rho_0}\right)}+\rho_0\frac{\overline{\left(\theta'\right)^2}}{\theta_0}g_i+\overline{\theta'\frac{\partial\mathfrak{I}_{i,j}'}{\partial x_j}}+\frac{\theta_0}{T_0}\frac{\overline{u_i'Q'}}{c_p}-\overline{u_i'\frac{\partial H_j'}{\partial x_j}}$$

A second moment equation

$$\frac{\partial}{\partial t}\overline{\theta'\theta'\theta'}+\overline{u}_j\frac{\partial}{\partial x_j}\overline{\theta'\theta'\theta'}+3\overline{\theta'\theta'u_j'}\frac{\partial\overline{\theta}}{\partial x_j}+\frac{1}{\rho_0}\frac{\partial}{\partial x_j}\left(\rho_0\overline{u_j'\theta'\theta'\theta'}\right)=\frac{3}{\rho_0}\overline{\theta'\theta'\frac{\partial H_{3,j}'}{\partial x_j}}-\frac{3\overline{\theta'\theta'}}{\rho_0}\frac{\partial}{\partial x_j}\left(\rho_0\overline{\theta'u_j'}\right)$$

A third moment equation

These are “exact.”

Closures Needed

1) Closures for higher moments that are not predicted, e.g., the fourth moments in a third-moment equation.

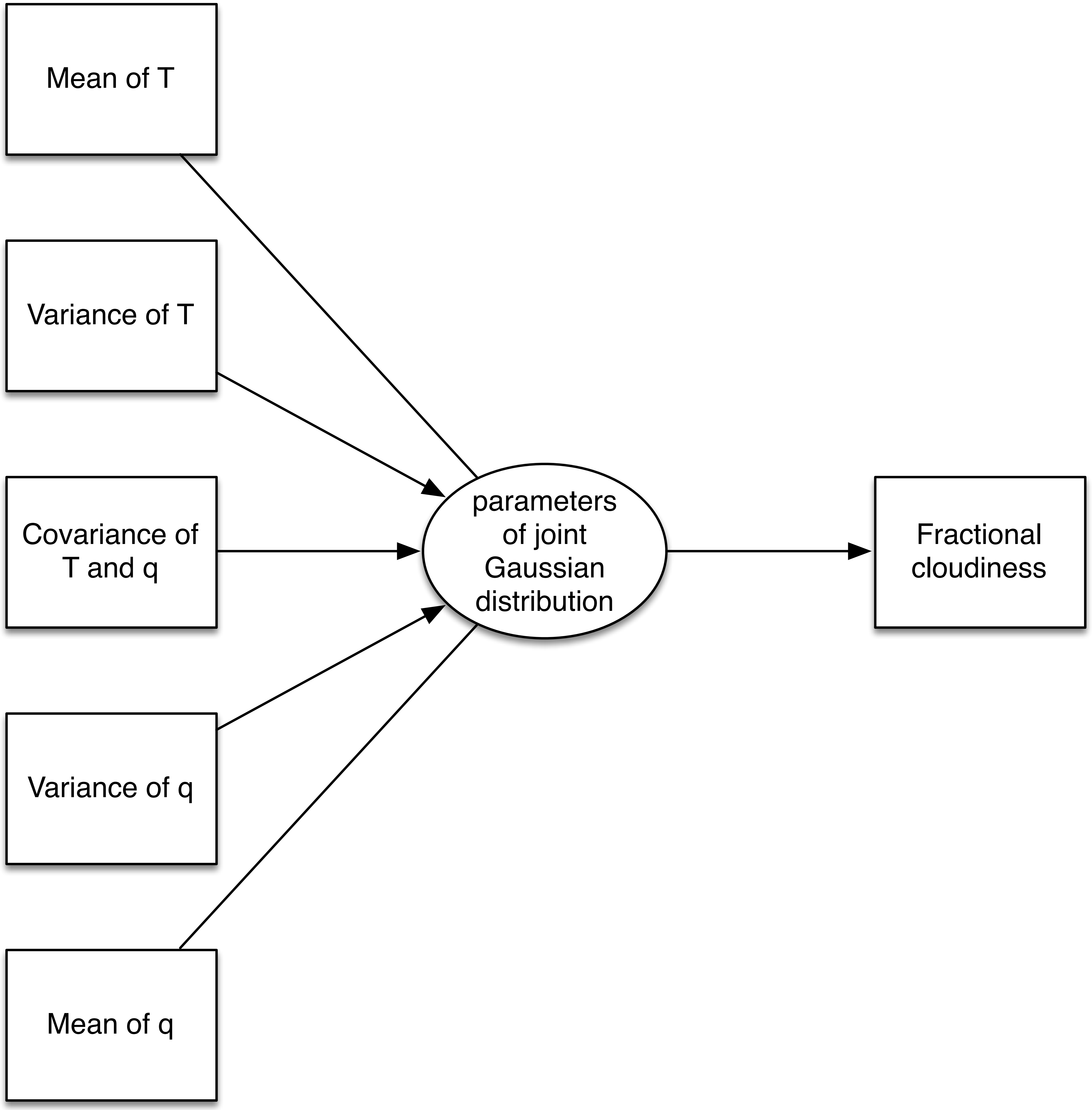
2) Closures for moments involving the pressure, which occur whenever a velocity component is involved.

3) Closures for dissipation rates, which are especially important in the equations governing variances.

4) Closures to determine moments involving SGS phase changes and other microphysical processes, as well as radiative heating and cooling.

ADHOC

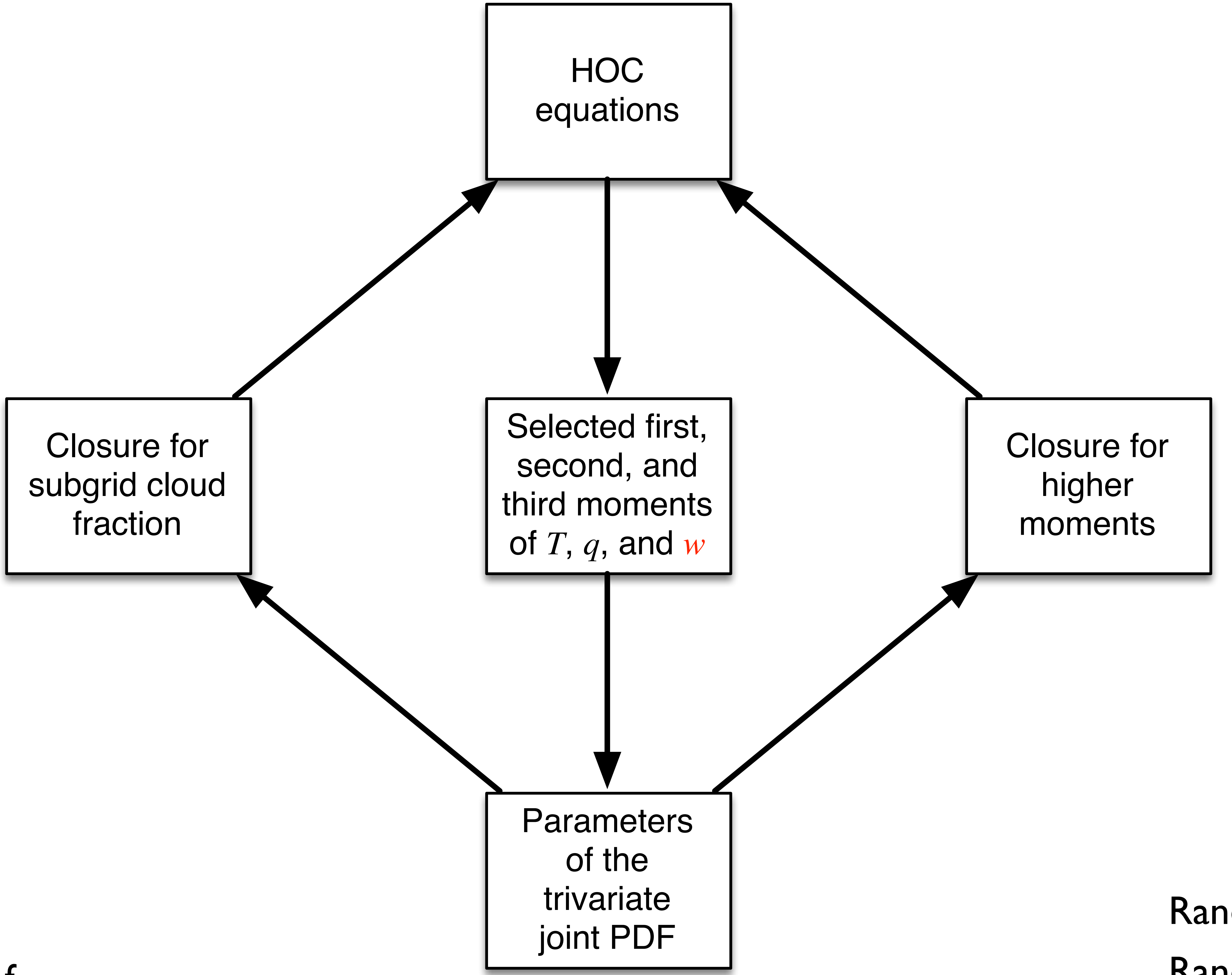
(Assumed Distributions with Higher-Order Closure)



Sommeria and Deardorff used an *assumed joint distribution* of temperature and moisture.

They needed 2 first moments and 3 second moments to determine the parameters of the joint distribution.

Let's include w in the joint distribution.



This is a generalization of
what Sommeria and Deardorff did.

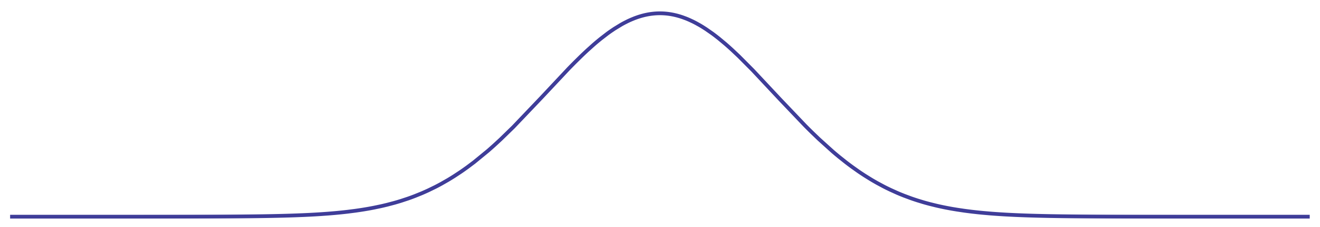
Randall JAS 1987

Randall, Shao, and Moeng, JAS 1992

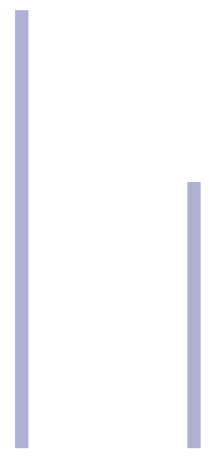
Lappen and Randall, JAS 2001

Which assumed PDF?

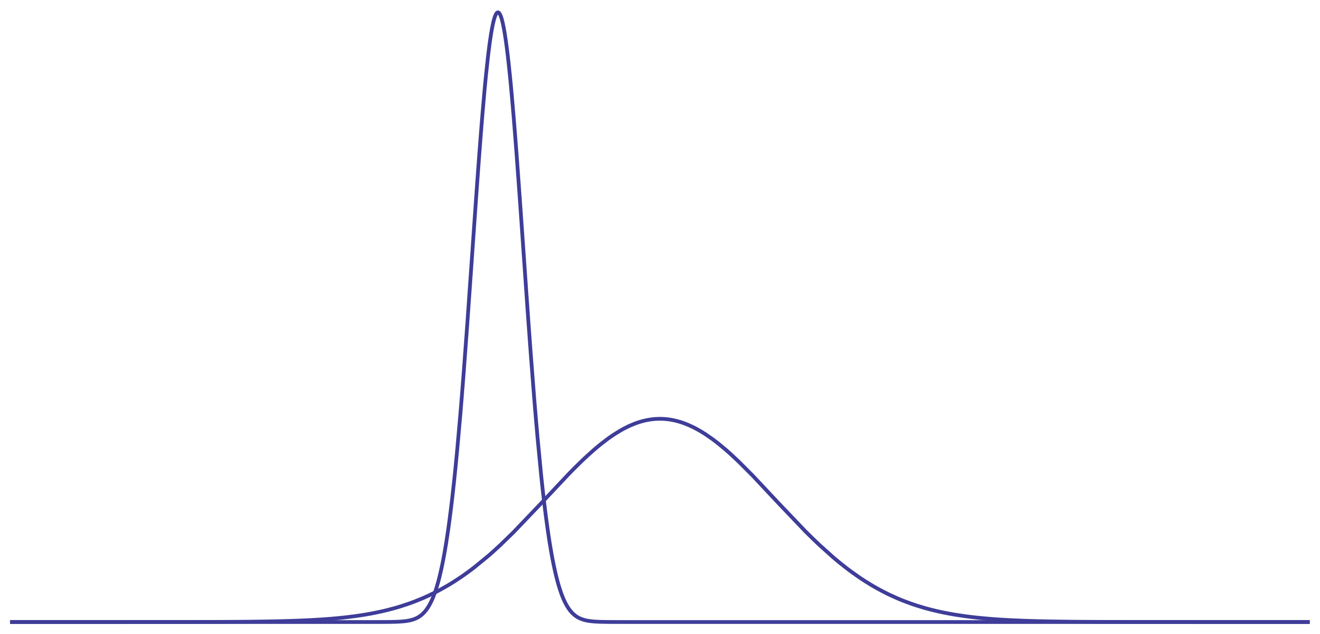
- Gaussian?
  No third moments.

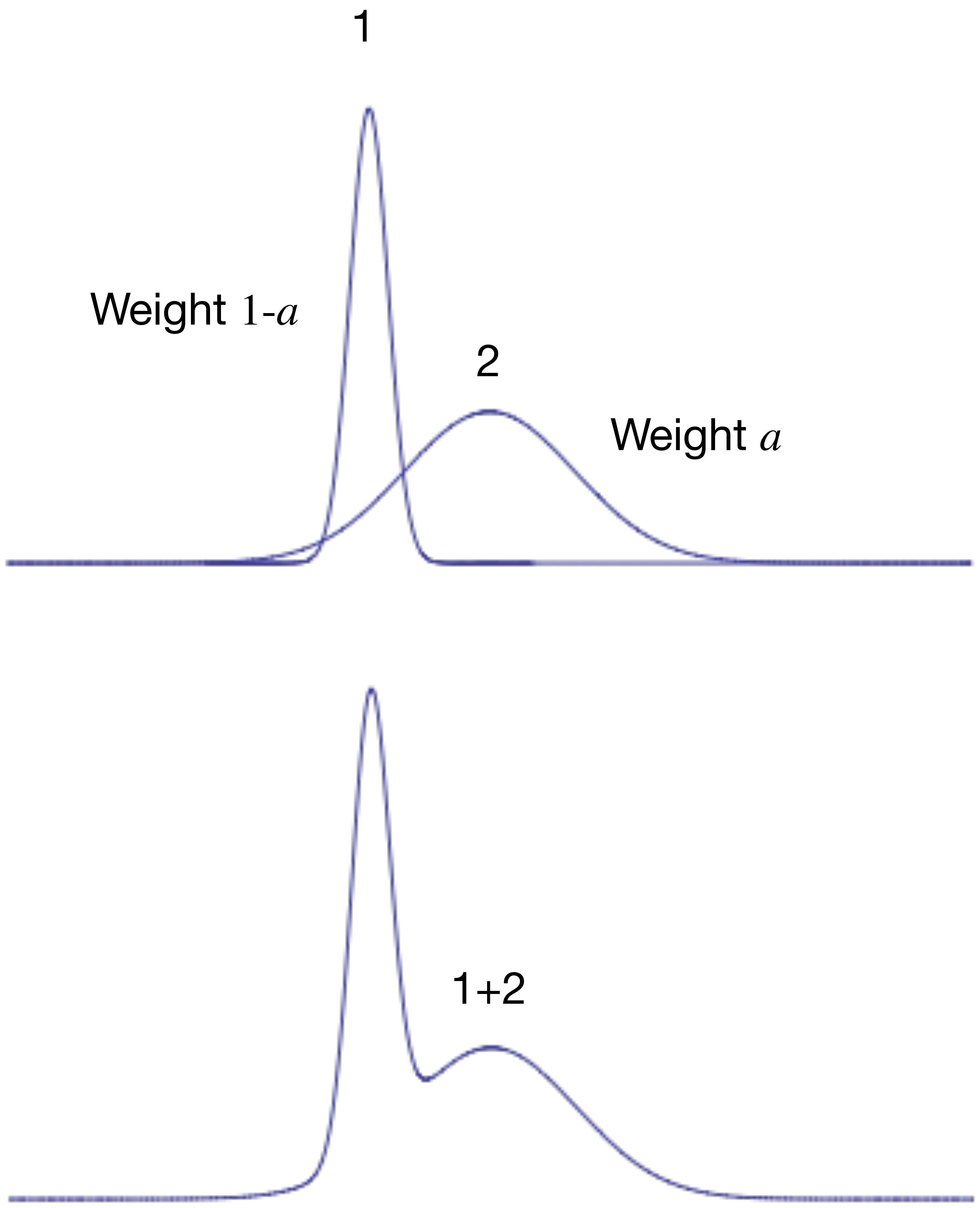


- Two delta functions?
  Not realistic enough.



- Two Gaussians?
  Good initial compromise, suggested by Lewellen and Yoh (1993) and adopted by Golaz et al. (2002).





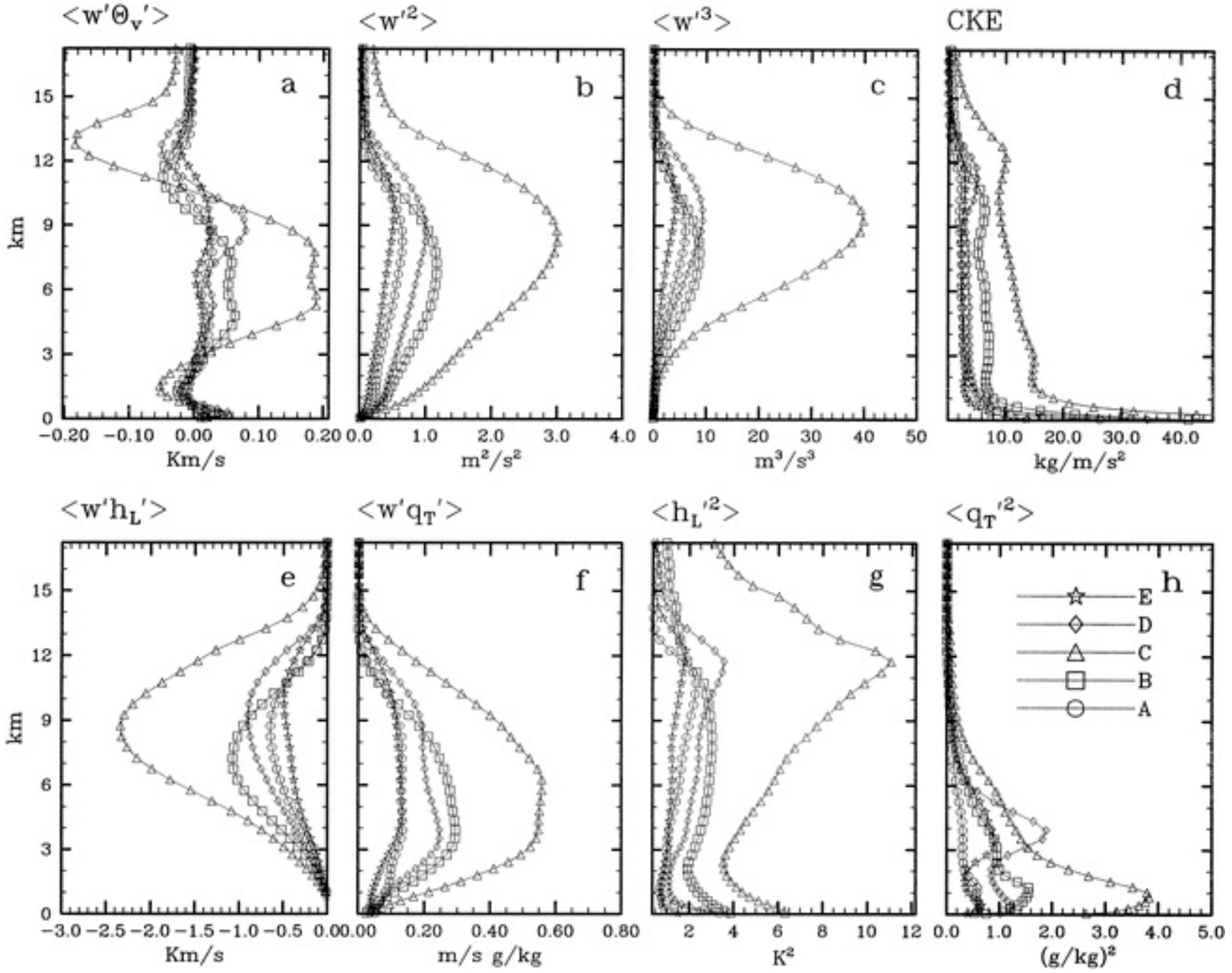
The third moments measure the "distance" between the Gaussians.

Phenomenology

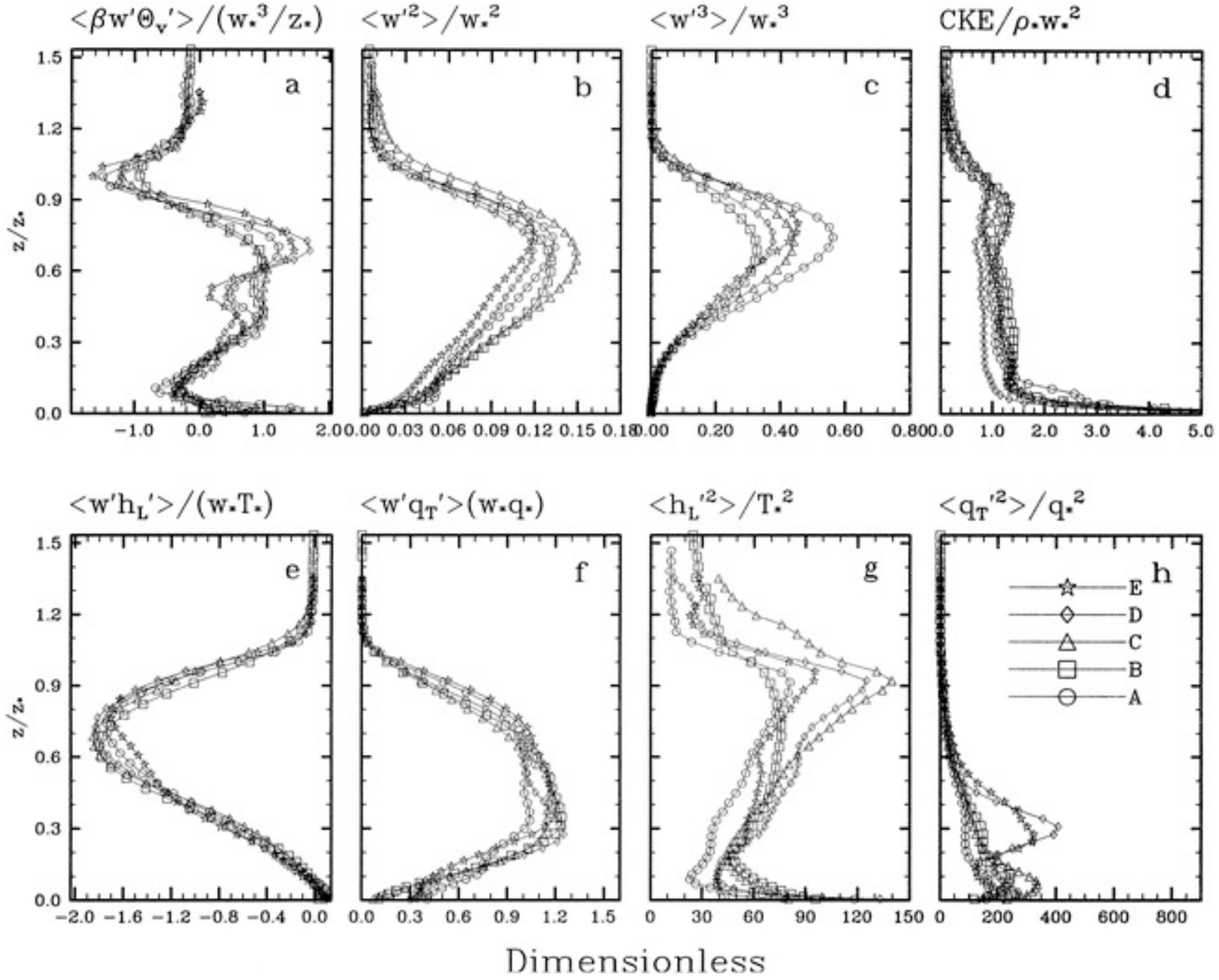
One Gaussian represents the clouds, and the other represents the environment.

Using the equations to diagnose deep convection

2nd & 3rd moments

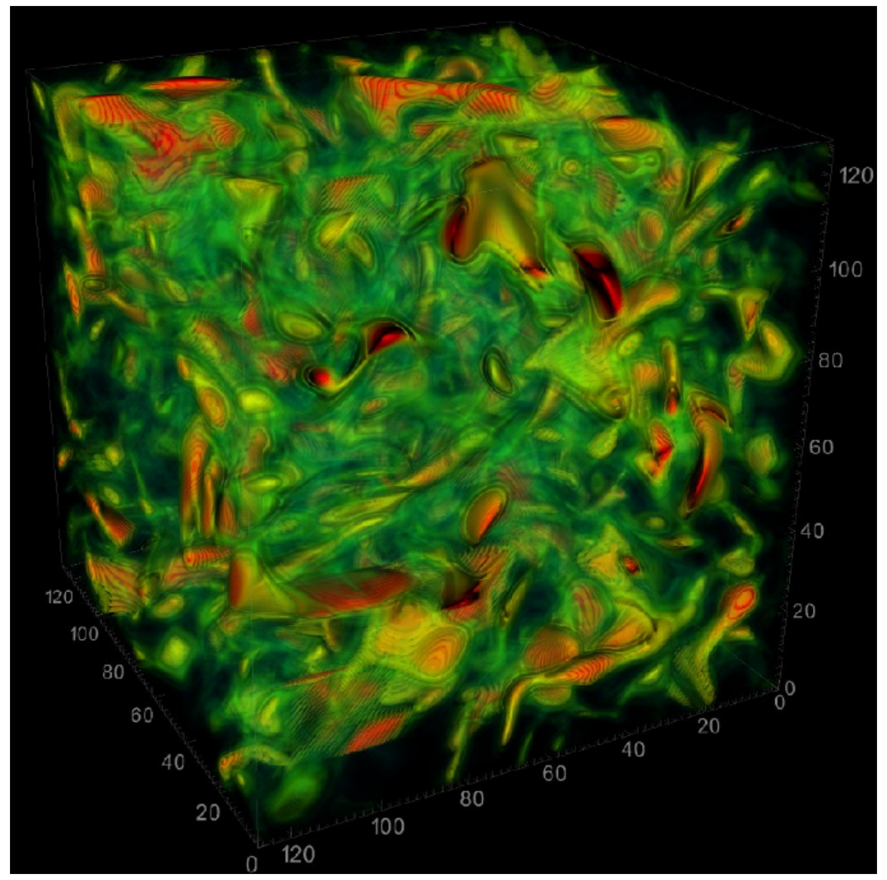


Similarity

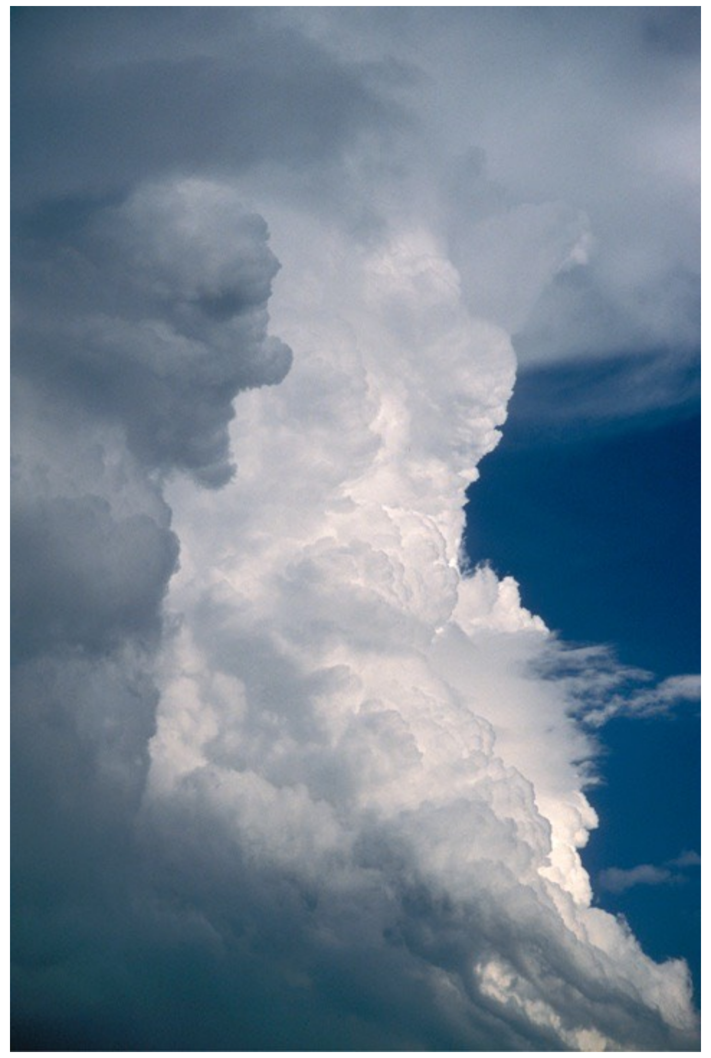


Khairoutdinov & Randall, 2002

Is HOC a "theory of everything?"



Turbulence



Deep convection

Gravity waves

To represent all of these things, very general closures would be needed.

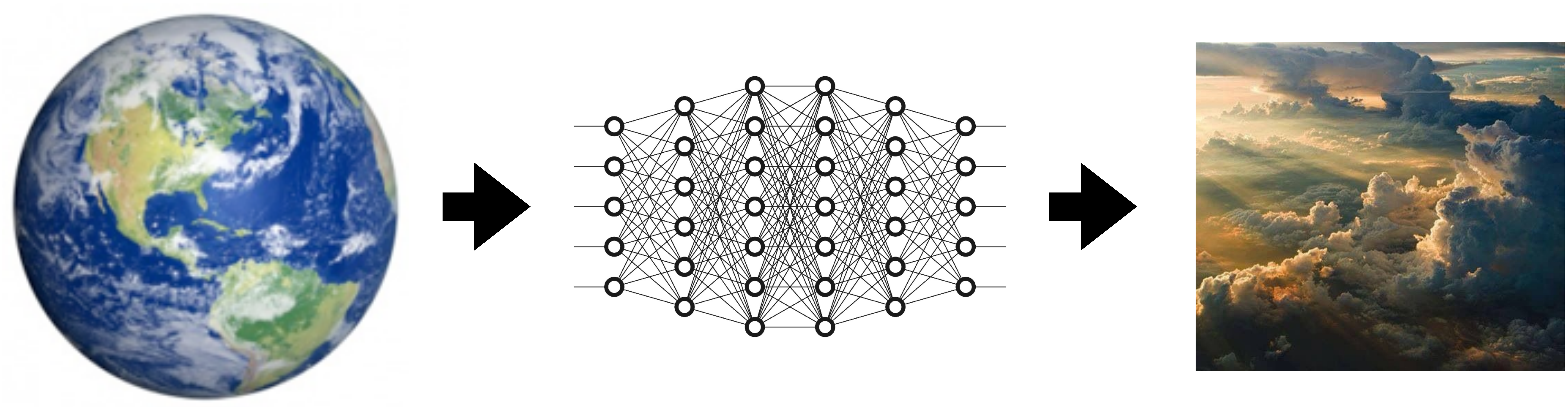
Maybe a neural net can find them.

This will involve more than just assigning values to parameters.

For the atmosphere, microphysics is the problem that will never die.


And then there’s Biology.

Maybe MAD will give us better simulations.



What is the strategy for *increasing understanding* with this approach?