CLUBB: How it works

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18 Feb 2015, AMWG

Outline

- Our parameterization’s equation set
- Our parameterization’s closure assumptions
- Our parameterization’s scientific possibilities

CLUBB denotes
"Cloud Layers Unified By Binormals"

CLUBB parameterizes clouds and turbulence.

CLUBB is based on higher-order closure methods.

Golaz et al. (2002b)

In the candidate model version, CLUBB unifies the representation of boundary layer clouds and turbulence

- Boundary Layer
- Shallow Convection
- Cloud Macrophysics
- Deep Convection
- Microphysics (Morrison-Gettelman)
- Radiation
- Aerosols

CLUBB is used for all 3

The parameterization problem[1]

A cloud and turbulence parameterization needs to supply subgrid-scale fluxes of heat, moisture, and momentum (and PDFs of cloud fraction and liquid water for microphysics and radiation):

Moisture

$$\frac{\partial \bar{r}_t}{\partial t} = -\bar{w}\frac{\partial \bar{r}_t}{\partial z} - \frac{\partial}{\partial z}\overline{w'r_t'} + \overline{\text{Microphys}}$$

Heat

$$\frac{\partial \bar{\theta}_l}{\partial t} = -\bar{w}\frac{\partial \bar{\theta}_l}{\partial z} - \frac{\partial}{\partial z}\overline{w'\theta_l'} + \overline{\text{Radiation}} + \overline{\text{Microphys}}$$

Momentum

$$\frac{\partial \bar{u}}{\partial t} = -\bar{w}\frac{\partial \bar{u}}{\partial z} - f(v_g - \bar{v}) - \frac{\partial}{\partial z}\overline{u'w'}$$

$$\frac{\partial \bar{v}}{\partial t} = -\bar{w}\frac{\partial \bar{v}}{\partial z} + f(u_g - \bar{u}) - \frac{\partial}{\partial z}\overline{v'w'}$$

Red and Magenta = calculated by host model

Blue = calculated by parameterization

[1]Peter Stone of MIT.

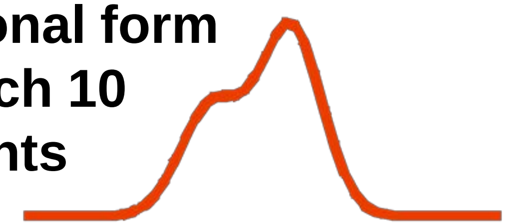
Overview of CLUBB's solution procedure

Advance 10 prognostic equations

$\overline{w},\ \overline{\theta_l},\ \overline{q_t},\ \overline{w'^2},\ \overline{w'^3},\ \overline{q_t'^2},\ \overline{\theta_l'^2},\ \overline{q_t'\theta_l'},\ \overline{w'q_t'},\ \overline{w'\theta_l'}$

Close dissipation terms

Select PDF from given functional form to match 10 moments



Diagnose cloud fraction, liquid water from PDF

Δt

Use PDF to close higher-order moments, buoyancy terms

$\overline{w'q_t'^2},\ \overline{w'\theta_l'^2},\ \overline{w'q_t'\theta_l'},\ \overline{w'^2q_t'},\ \overline{w'^2\theta_l'},\ \overline{w'^4},$
$\overline{q_t'\theta_v'},\ \overline{\theta_l'\theta_v'},\ \overline{w'\theta_v'},\ w'^2\theta_v'$

Golaz et al. (2002a)

The prognostic higher-order equations can be thought of as an extension to the dynamical core

$$\text{Means}: \quad \frac{\partial \overline{u}}{\partial t} = \ldots \quad \frac{\partial \overline{v}}{\partial t} = \ldots \quad \frac{\partial \overline{r_t}}{\partial t} = \ldots \quad \frac{\partial \overline{\theta_l}}{\partial t} = \ldots$$

$$\text{2nd}-\text{order}: \quad \frac{\partial \overline{w' r_t'}}{\partial t} = \ldots \quad \frac{\partial \overline{w' \theta_l'}}{\partial t} = \ldots \quad \frac{\partial \overline{w'^2}}{\partial t} = \ldots$$

$$\frac{\partial \overline{r_t'^2}}{\partial t} = \ldots \quad \frac{\partial \overline{\theta_l'^2}}{\partial t} = \ldots \quad \frac{\partial \overline{r_t' \theta_l'}}{\partial t} = \ldots$$

$$\text{3rd}-\text{order}: \quad \frac{\partial \overline{w'^3}}{\partial t} = \ldots$$

$w =$ vertical velocity $\quad r_t =$ total water mixing ratio

$\theta_l =$ liquid water potential temperature

Higher-order equations contain lots of physics

Higher-order closure is not merely an arid "statistical" method.

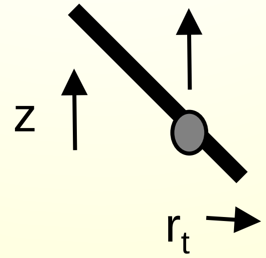
Example of physical interpretation: $r_t'^2$ evolves like a drop of ink injected in a fluid. The only difference is the addition of some unusual source and sink terms related to turbulence.

The higher-order equations can be interpreted in a physically satisfying way

$\overline{r_t'^2}$ = Variance of total water (vapor+liquid) mixing ratio.

The $\overline{r_t'^2}$ equation is derived by Reynolds averaging the advection-diffusion equation:

$$\frac{\partial \overline{r_t'^2}}{\partial t} = \underbrace{-\bar{w}\frac{\partial \overline{r_t'^2}}{\partial z}}_{\text{Mean Adv}} \underbrace{-\frac{\partial \overline{w' r_t'^2}}{\partial z}}_{\text{Turb Transport}} \underbrace{-2\overline{w' r_t'}\frac{\partial \bar{r}_t}{\partial z}}_{\text{Turb Prod}} \underbrace{-2\kappa \overline{\vec{\nabla} r_t' \cdot \vec{\nabla} r_t'}}_{\text{Dissipation}} + \underbrace{\frac{\partial}{\partial z}\left(K \frac{\partial}{\partial z}\overline{r_t'^2}\right)}_{\text{Background Dissip}}$$



The dissipation term also has a simple interpretation

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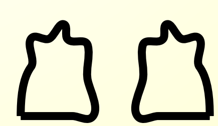


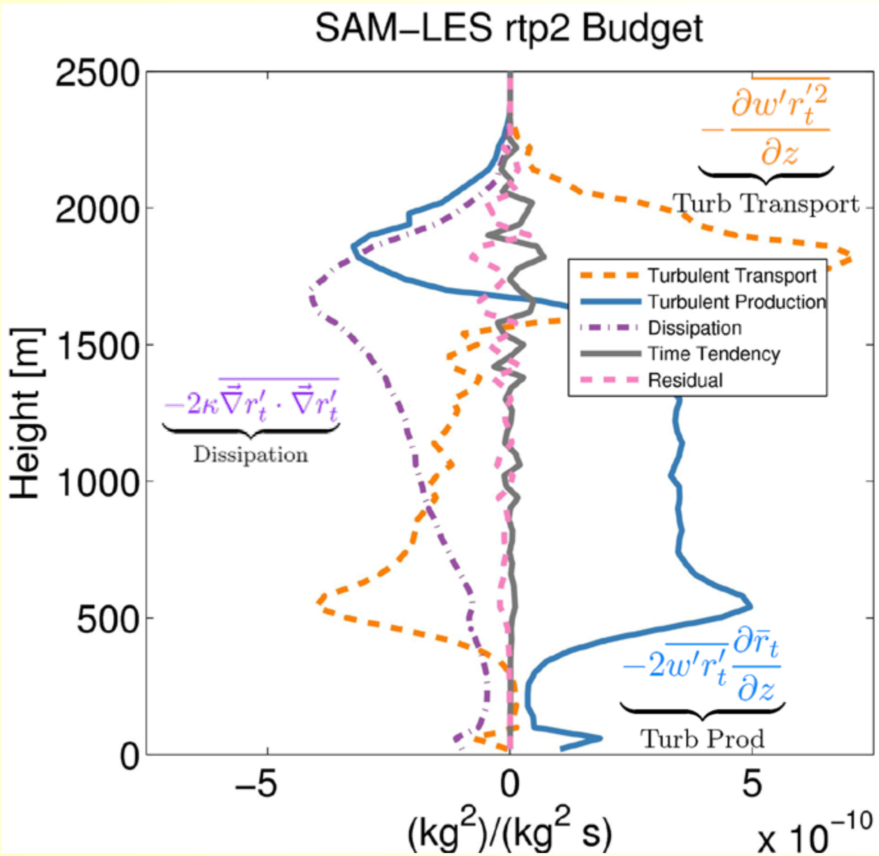
CLUBB sets up a mathematical framework first and *then* makes modeling assumptions

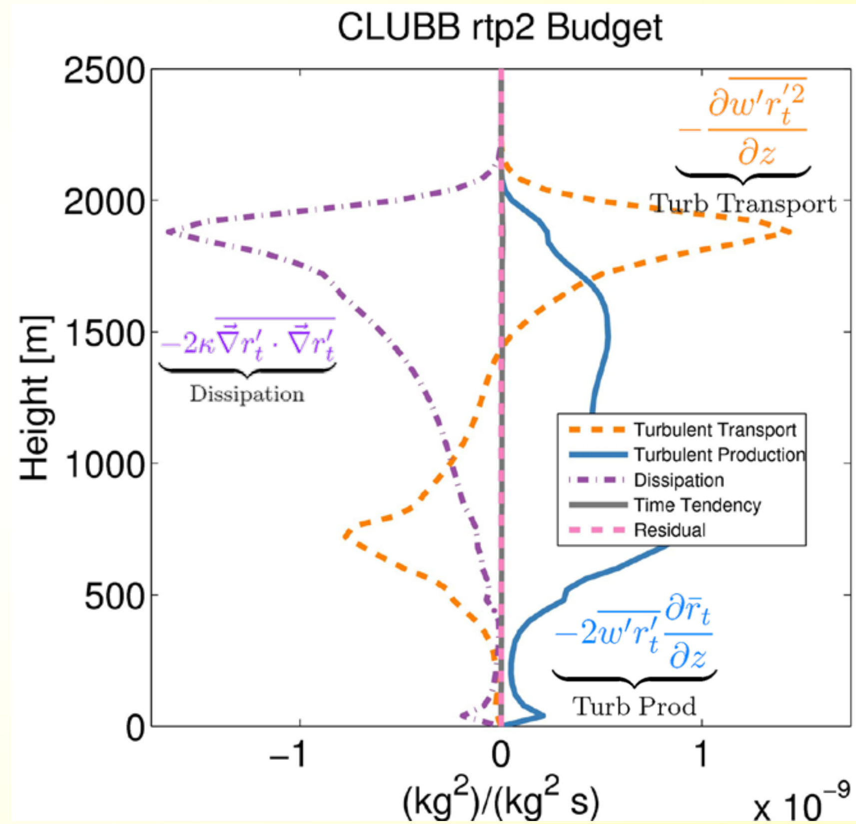
That is, CLUBB first *analyzes* the governing equations. *Only later* does it parameterize terms in the resulting equations

Doing analysis first is better than building assumptions into the foundation of a parameterization.

CLUBB models the higher-order equations term by term

BOMEX shallow cumulus case





Figs courtesy Justin Weber

The dissipation and pressure terms are closed by standard turbulence closures

For instance, the dissipation term is closed by the use of a turbulent time scale, tau:

$$\epsilon_{r_t} \equiv 2\kappa \overline{\vec{\nabla} r_t' \cdot \vec{\nabla} r_t'} \approx -\frac{C_2}{\tau} \overline{r_t'^2}$$

An advantage: turbulent dissipation is better defined than concepts such as entrainment (e.g. Romps 2010).

What about other terms? We close some of them by integrating them over the PDF of subgrid variability

For instance, the turbulent transport term, $w'r_t'^2$, is closed by integration over the PDF:

$$\overline{f(x)} = \int P(x) f(x) dx$$

This ensures a consistent closure for all terms closed using the PDF.

CLUBB assumes the shape of the subgrid PDF

Unfortunately, predicting the PDF directly is too expensive.

Instead we use the *Assumed* PDF Method. We *assume* a *functional form* of the PDFs, and determine a *particular instance* of this functional form for each grid box and time step. (The form we assume is a double Gaussian PDF.)

Therefore, the PDF varies in space and evolves in time.

E.g., Manton and Cotton (1977)

The Double Gaussian PDF Functional Form

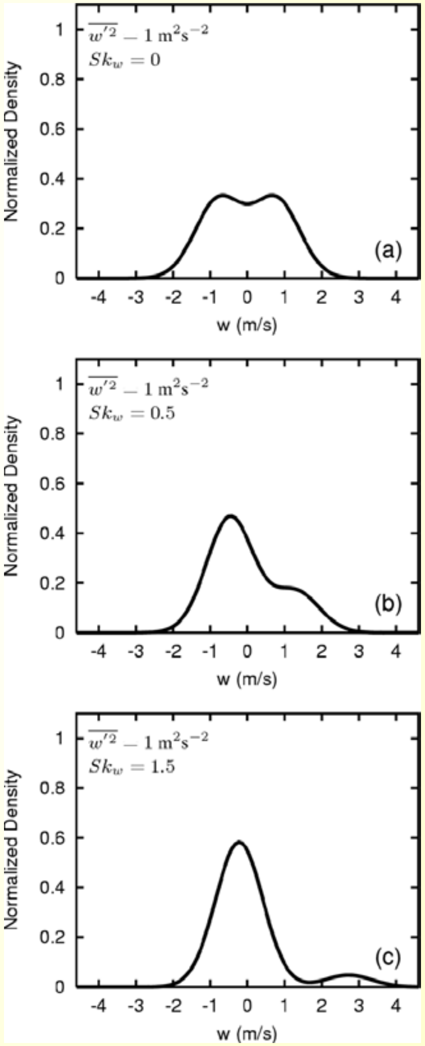
A double Gaussian PDF is the sum of two Gaussians. It satisfies *three important properties*:

(1) It allows both negative and positive skewness.

(2) It has reasonable-looking tails.

(3) It can be multi-variate.

We do not use a completely general double Gaussian, but instead restrict the family in order to simplify and reduce the number of parameters.



The subgrid PDF includes several variables

We use a three-dimensional PDF of vertical velocity, total water mixing ratio, and liquid water potential temperature:

$$P = P(w, q_t, \theta_l)$$

CLUBB's PDF is multivariate.

The PDF oozes

The subgrid PDF evolves with time and space as the meteorological conditions (i.e. higher-order moments) change.

It is not a prescribed, climatological PDF.

Is CLUBB complex?

CLUBB does contain a lot of terms. But those processes exist in nature.

To the extent that it unifies parameterizations, CLUBB avoids the complexity of interactions between separate schemes.

And the fundamental idea behind CLUBB is simple.

Does CLUBB have too many tunable parameters?

CLUBB contains one tunable pre-factor per each dissipation or pressure term. But some of these terms are small; hence their prefactors are less important.

We have added tunable parameters to CLUBB in recent years. Sensitivity studies show that some of these parameters are unimportant. Probably they could be removed.

CLUBB is a platform that can be built upon

CLUBB's wealth of subgrid information can be used to inform parameterizations of other processes, such as radiation and aerosols.

Many extensions can be envisaged.

What new science is enabled by CLUBB?

CLUBB allows the same microphysics parameterization to be used in stratocumulus and shallow cumulus clouds.

Thereby, CLUBB extends the parameterization of aerosol indirect effects to shallow cumulus clouds.

Conclusions

- CLUBB's formulation is tied closely the governing equations.

- CLUBB is not merely a statistical model; it contains a lot of physics.

- CLUBB is an extensible platform upon which the community can build. It enables new science.

Thanks for your time!

Broad philosophy: CLUBB tries to emulate aspects of what a LES model does, but using horizontal averaged eqns

CLUBB attempts to be a LES emulator.

Like Large-Eddy Simulation (LES), CLUBB starts with the governing equations and spatially filters them.

Unlike LES, CLUBB's equations are averaged to form a 1D (single-column) model.

Like LES, CLUBB has memory, but only of prior timestep.

Unlike LES, CLUBB has no representation of horizontal spatial structure of clouds (e.g. clumping in space).

Can a parameterization of turbulent fluxes handle “non-local” transport?

Like LES, CLUBB contains vertical derivatives (d/dz), more so than vertical integrals.

Like LES, CLUBB can represent “non-local” processes, such as cumulus transport.

In nature and LES, “non-local” transport is composed of a series of local transport events. Whether we deem it non-local depends on model time step. However, moments evolve more slowly than updrafts.

CLUBB has a single, multivariate PDF for each grid level

CLUBB does *not* have a set of separate *univariate* PDFs for each grid level.

Rather the PDF contains information about covariances.