UNIFIED PARAMETERIZATION – AN UPDATE

Akio Arakawa

University of California, Los Angeles, California

Chien-Ming Wu

National Taiwan University, Taipei, Taiwan

- Better justification
- More complete description
- Inclusion of uncertainty
- Vertical structure
- Physical sources and sinks

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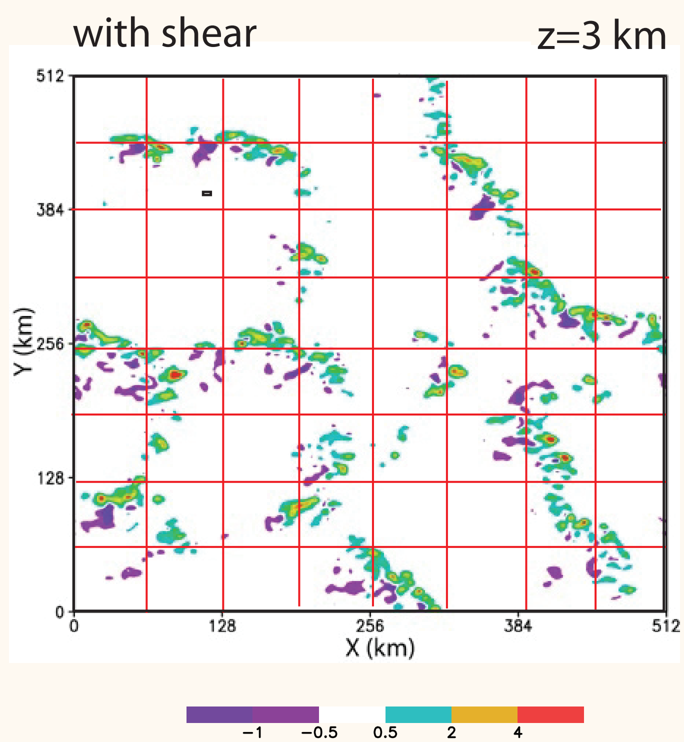
CRM SIMULATIONS USED

Horizontal domain size : 512 km   Horizontal grid size : 2km

Steady forcing based on - Q1/Q2 typically observed during the GATE Phase III

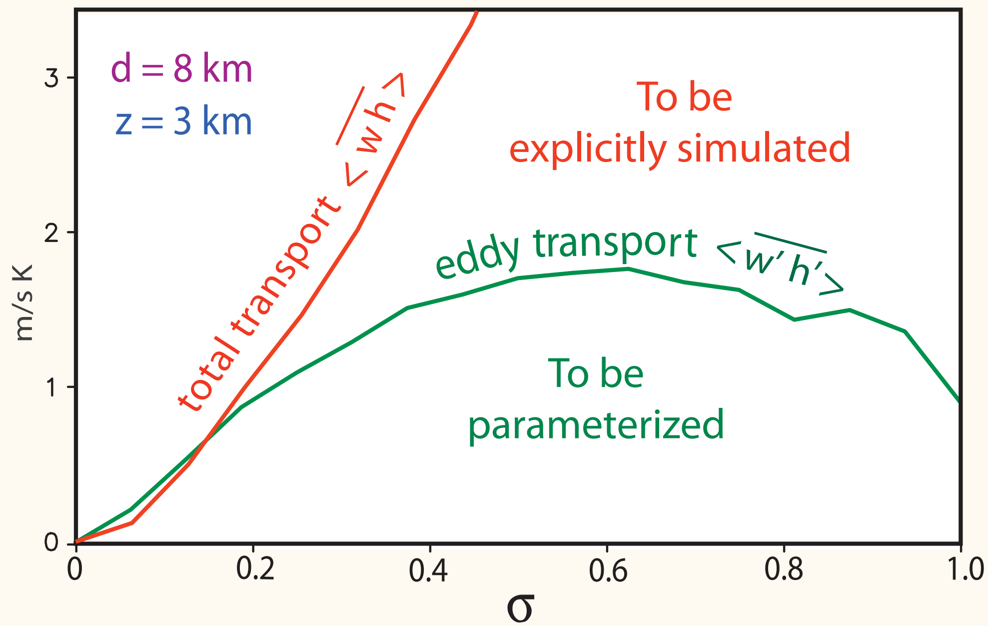
With and without background vertical shear

A snapshot of w with an example of subdomains



] d : Subdomain size representing GCM grid size

DIAGNOSED VERTICAL TRANSPORT OF MOIST STATIC ENERGY



Fractional area covered by updrafts

– a measure of cloud population in the grid cell –

h : Deviation of moist static energy from a reference state

$\overline{(\ )}$: Average over all CRM grid points in the sub-domain

$\langle\ \rangle$: Ensemble average over cloud-containing ($\sigma > 0$) sub-domains during the analysis period (12 hr)

$(\ )' : (\ ) - \overline{(\ )}$

Parameterization must not overdo its job

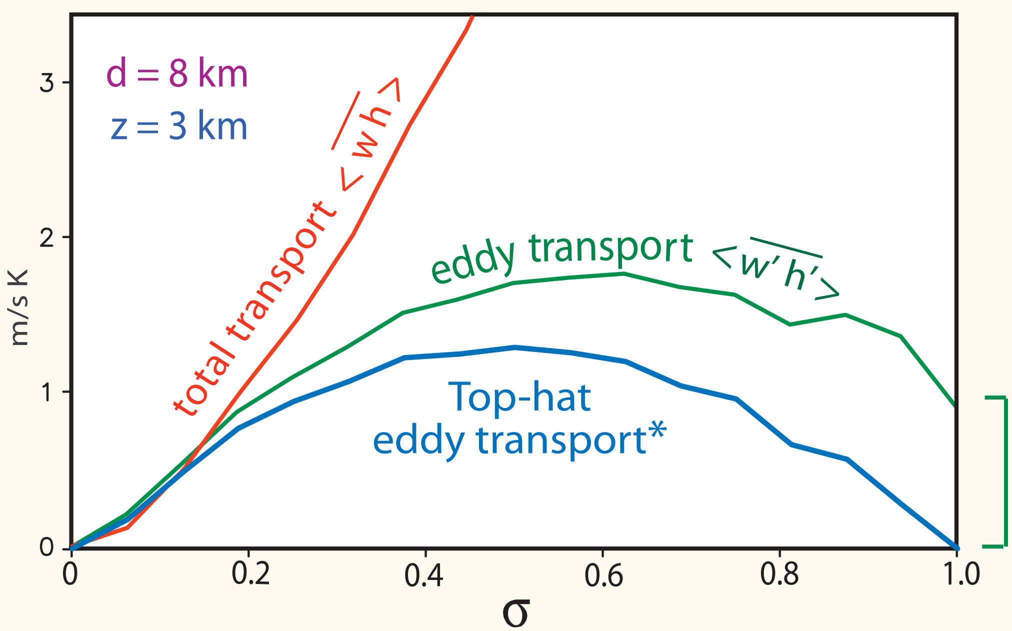
so that explicitly-simulated transport is not over-stabilized .

FIRST STEP TOWARD UNIFIED PARAMETERIZATION

Most conventional parameterizations assume that clouds and the environment are horizontally homogeneous.

–– "top-hat profile" ––

Continue to use this assumption to start.



* Diagnosed from the dataset modified to fit a top-hat profile

Transport due to the internal structure of clouds

EXPRESSIONS WITH A TOP–HAT PROFILE

$(\ )_c$: cloud value $\widetilde{(\ )}$: environment value $\Delta(\ ) \equiv (\ )_c - \widetilde{(\ )}$

$$\overline{(\ )} = \sigma(\ )_c + (1 - \sigma)\widetilde{(\ )}$$

$$\overline{w} = \widetilde{w} + \sigma\,\Delta w \qquad \overline{\psi} = \widetilde{\psi} + \sigma\,\Delta\psi$$

$$\overline{w'\psi'} = \sigma(1-\sigma)\Delta w\,\Delta\psi + (\sigma - \sigma)\,\widetilde{w}\,\Delta\psi$$

ψ : Temperature, water-vapor mixing ratio, or their combinations

Conventional parameterization

$$\sigma \to 0: \qquad \overline{\psi} \to \widetilde{\psi} \qquad \overline{w'\psi'} \to \underbrace{\sigma\,w_c}_{\text{cumulus massflux}}\,\Delta\psi$$

Unified parameterization

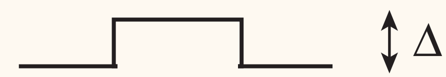
$$\sigma = \sigma: \quad \overline{\psi} = \widetilde{\psi} + \sigma\,\Delta\psi \qquad \overline{w'\psi'} = \sigma(1-\sigma)\Delta w\,\Delta\psi$$

CLOUD PROPERTIES RELATIVE TO THE ENVIRONMENT

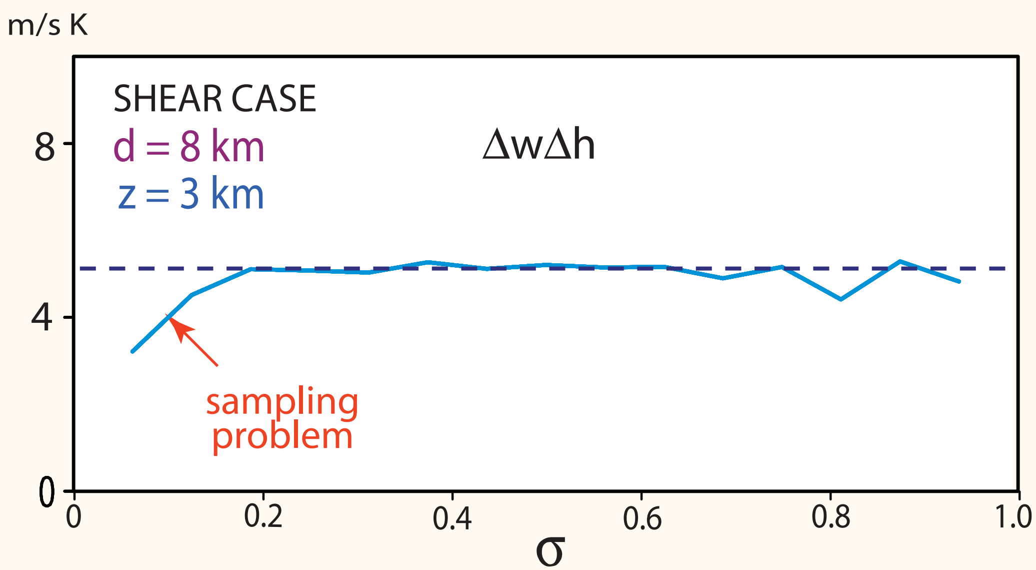
Recall

$$\Delta w \equiv w_c - \tilde{w}$$
$$\Delta \psi \equiv \psi_c - \tilde{\psi}$$

$\tilde{(\;)}$: environment value



Δw and $\Delta\psi$ should be virtually independent of σ, which is a measure of cloud population in the grid cell.



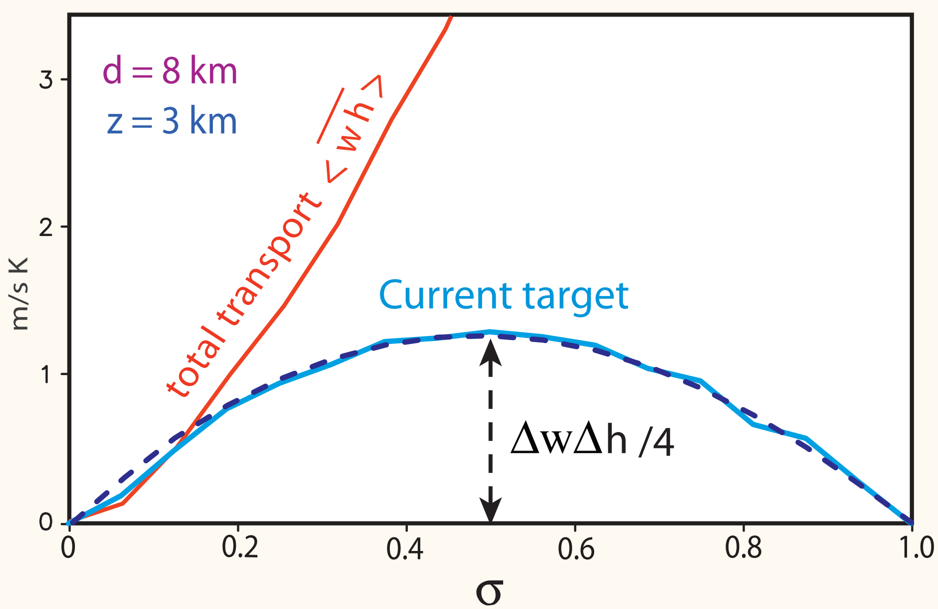
PARAMETERIZATION OF THE σ-DEPENDENCE

$$\overline{w'\psi'} = \sigma(1-\sigma)\,\Delta w\,\Delta\psi$$

If $\Delta w \Delta\psi$ is in fact independent of σ,

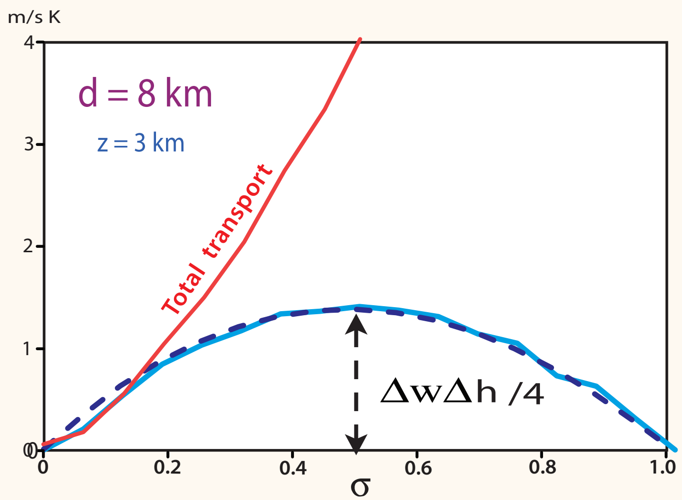
the eddy transport depends on σ through $\sigma(1-\sigma)$.

(Earlier, this dependency was introduced as the simplest *choice* for convergence.)

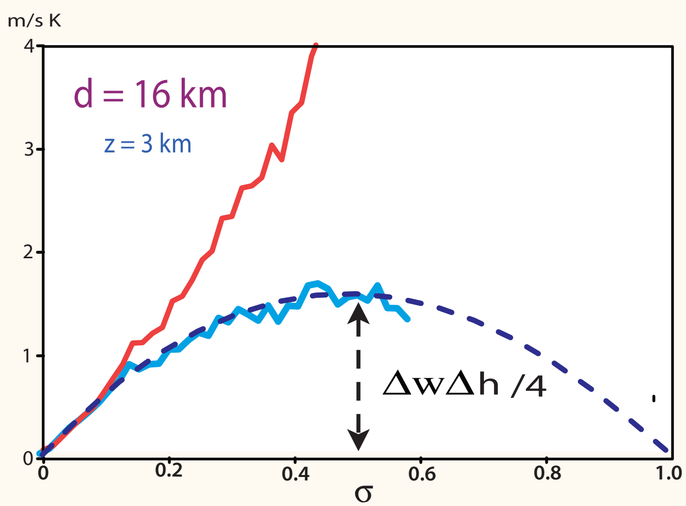


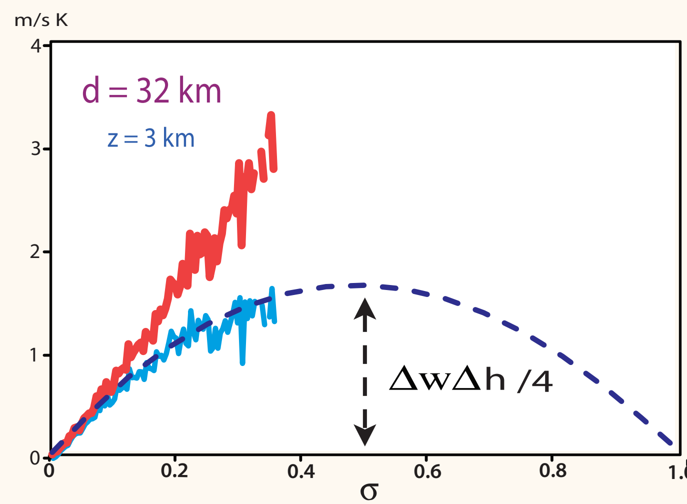
Curve $\sigma(1-\sigma)\,\Delta w\,\Delta h$
with the "best-fit"
constant $\Delta w \Delta\psi$

SIMILARITY BETWEEN DIFFERENT RESOLUTIONS



- The σ-dependence of the eddy transport is similar between different resolutions.
- The value of ΔwΔψ is also similar.





CLOSURE ASSUMPTION

$\left(\overline{w'h'}\right)_E$: Equilibrium eddy transport determined by the grid-scale destabilization

CONVENTIONAL PARAMETERIZATION

$$\overline{w'h'} < \left(\overline{w'h'}\right)_E$$

Arbitrarily relaxed adjustment

A priori assumption

$$\sigma << 1$$

$$\overline{w'\psi'} = \sigma\left(1-\not\sigma\right)\Delta w\,\Delta\psi$$

$$\sigma < \left(\overline{w'h'}\right)_E \Big/ \Delta w\,\Delta h$$

Can be inconsistent with $\sigma << 1$.

UNIFIED PARAMETERIZATION

$$\overline{w'h'} = \left(1-\sigma\right)^2 \left(\overline{w'h'}\right)_E$$

Relaxed adjustment based on σ.

$$\overline{w'h'} = \sigma\left(1-\sigma\right)\Delta w\,\Delta h$$

$$\sigma = \left(\overline{w'h'}\right)_E \Big/ \left[\Delta w\,\Delta h + \left(\overline{w'h'}\right)_E\right]$$

$0 \le \sigma \le 1$ is enforced.

DETERMINATION OF σ IN PRACTICAL APPLICATIONS, I

$\Delta\psi \equiv \psi_c - \tilde{\psi}$

environment value

not given

$\delta\psi \equiv \psi_c - \overline{\psi}$

grid-poit value

given

We have chosen

$$\sigma = \left(\overline{w'h'}\right)_E / \left[\Delta w\,\Delta h + \left(\overline{w'h'}\right)_E\right]$$

A plume model applied to grid-point values gives $\delta w\,\delta\psi$, not $\Delta w\,\Delta\psi$.

We can derive

$$\Delta w\,\Delta h = \delta w\,\delta h / (1-\sigma)^2$$

Define

$$\lambda \equiv \left(\overline{w'h'}\right)_E / \delta w\,\delta h$$

A measure of grid-scale destabilization normalized by eddy transport efficiency

$$\sigma = (\lambda - \lambda\sigma)(1-\sigma)^2$$

DETERMINATION OF σ IN PRACTICAL APPLICATIONS, II

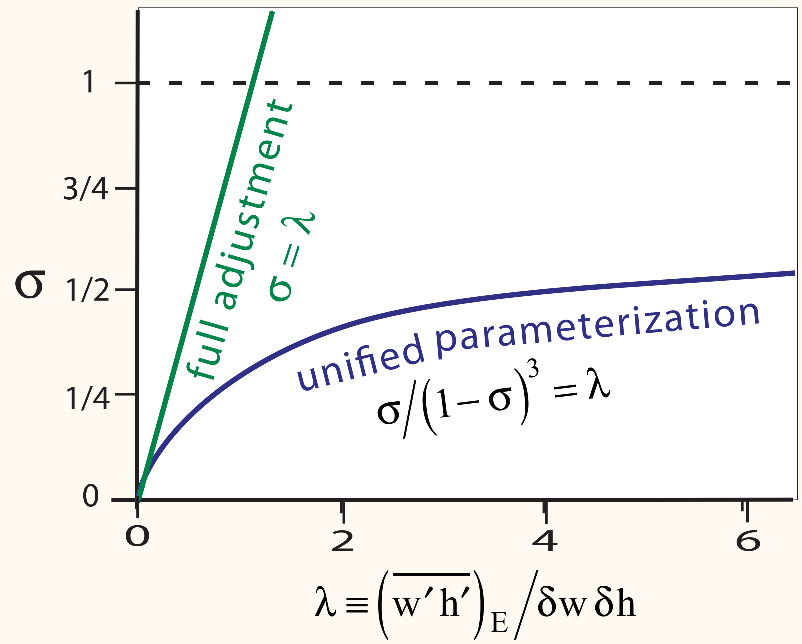
$$\sigma = (\lambda - \lambda\sigma)(1-\sigma)^2$$

Conventional $(\lambda \to 0,\ \sigma \to 0)$

$$\sigma \to \lambda$$

Unified $(\lambda = \lambda,\ \sigma = \sigma)$

$$\sigma/(1-\sigma)^3 = \lambda$$



destabilization

weaker ⟷ stronger

(toward Cu) (toward MCC)

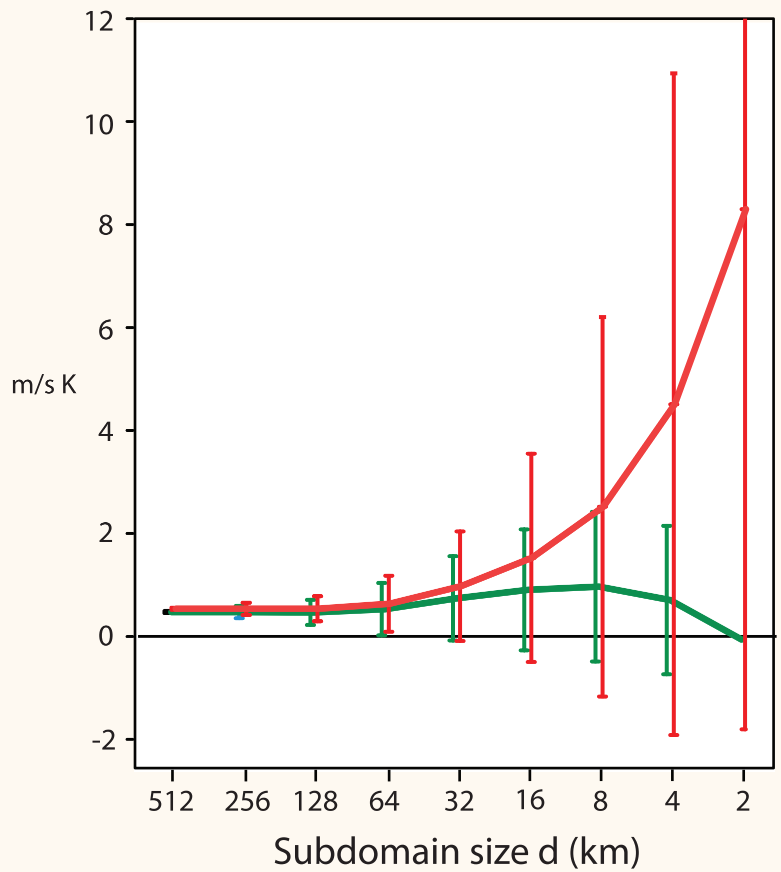
eddy transport efficiency

higher ⟷ lower

(toward Cb) (toward Sc)

PARAMETERIZATION OF UNCERTAINTY

Resolution dependency of the vertical transport of h



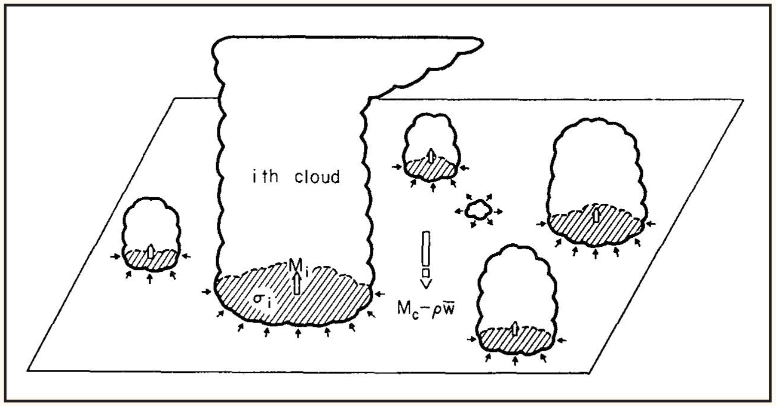
$<\overline{w\,h}>$ Total transport of h

Recall : $<\ \ >$ is ensemble average over the sub-domains with $\sigma > 0$.

$<\overline{w'\,h'}>$ Eddy transport of h

It is important to distinguish fluctuation of the total transport from uncertainty of the parameterization.

UNCERTAINTY WITH HIGH RESOLUTIONS



"Consider a horizontal area - large enough to contain an ensemble of cumulus clouds . . . ."

– Arakawa & Schubert (1974)

Two contrasting views on the origin of uncertainty:

1. Uncertainty due to a small sample size (standard view ?)

   But uncertainty also depends on the variance of cloud properties.

2. Cloud population itself, which restricts the ability of establishing an equilibrium (e.g., Plant & Craig 2008).

   But the ability also depends on the efficiency of eddy transports.

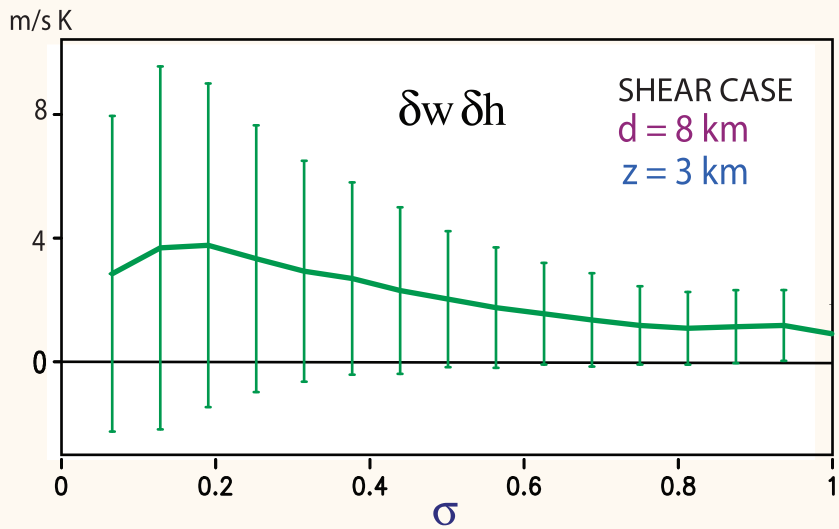
THE ORIGIN OF UNCERTAINTY IN THE UNIFIED PARAMETERIZATION

SUMMARY

$$\overline{w'h'} = (1-\sigma)^2 \left(\overline{w'h'}\right)_E$$

$$\sigma/(1-\sigma)^3 = \lambda \qquad \lambda \equiv \left(\overline{w'h'}\right)_E \Big/ \delta w\, \delta h$$

In this system, the origin of uncertainty is in $\delta w\, \delta h$.



The ratio of the standard deviation to the ensemble average is virtually independent of σ, indicating that the noise is multiplicative.

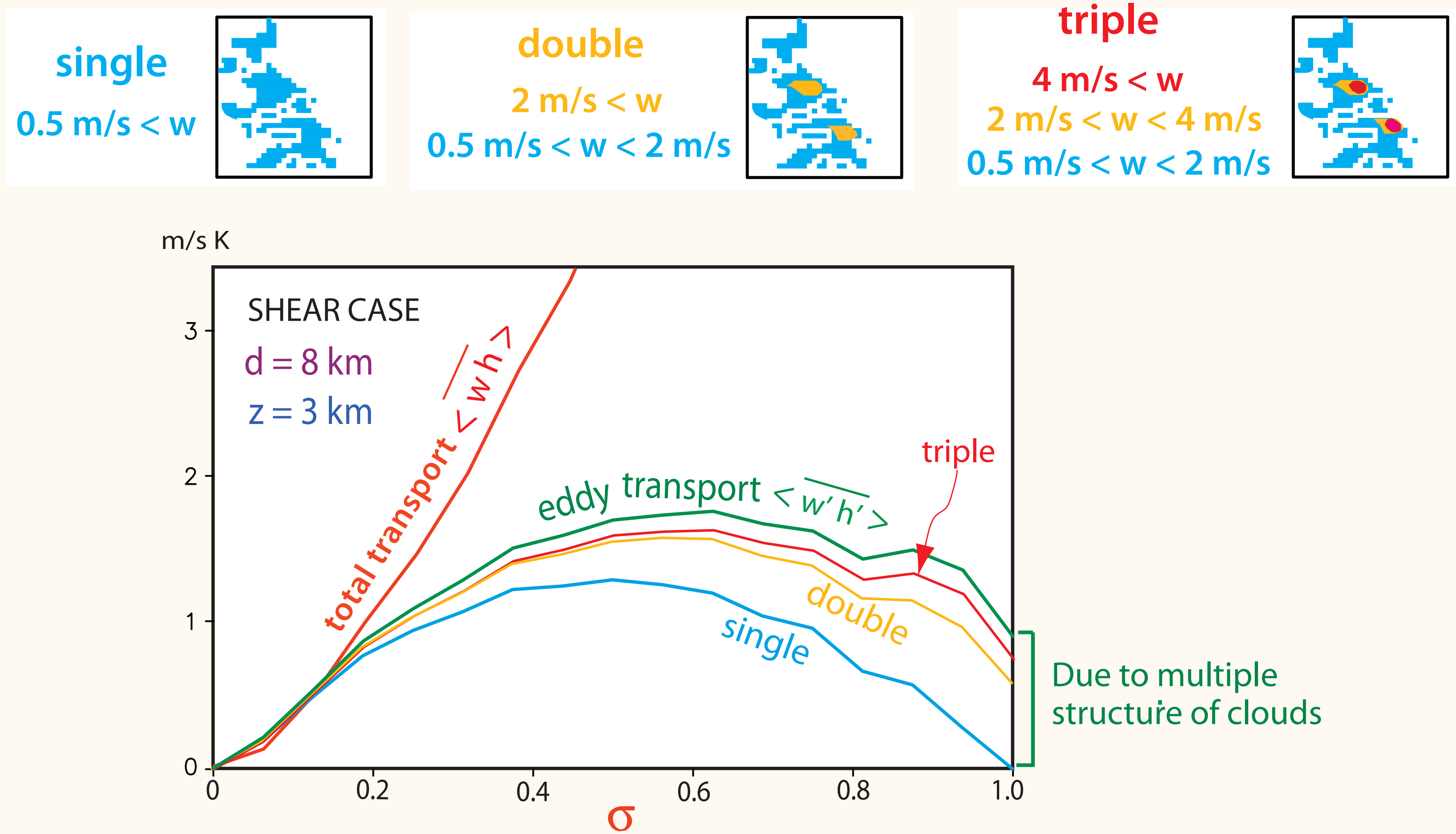
At least in this dataset,
uncertainty of the eddy transport seems to be
due to that of the phase of cloud development.

INTERIM SUMMARY AND FUTURE PROBLEMS

- Parameterization must represent only the eddy effect as far as the transport is concerned.
- When clouds and the environment are horizontally homogeneous, the eddy transport depends on σ through a simple quadratic function.
- The unified parameterization determines σ in terms of the grid-scale destabilization normalized by the eddy transport efficiency.
- The unified parameterization formulates uncertainty of eddy transport in terms of the uncertainty of cloud properties relative to the grid-point values.
- Multiple cloud types do not seem to be important for high resolutions. But in-cloud eddy transport can be important for the "unified parameterization" to be truly unified including stratiform clouds.

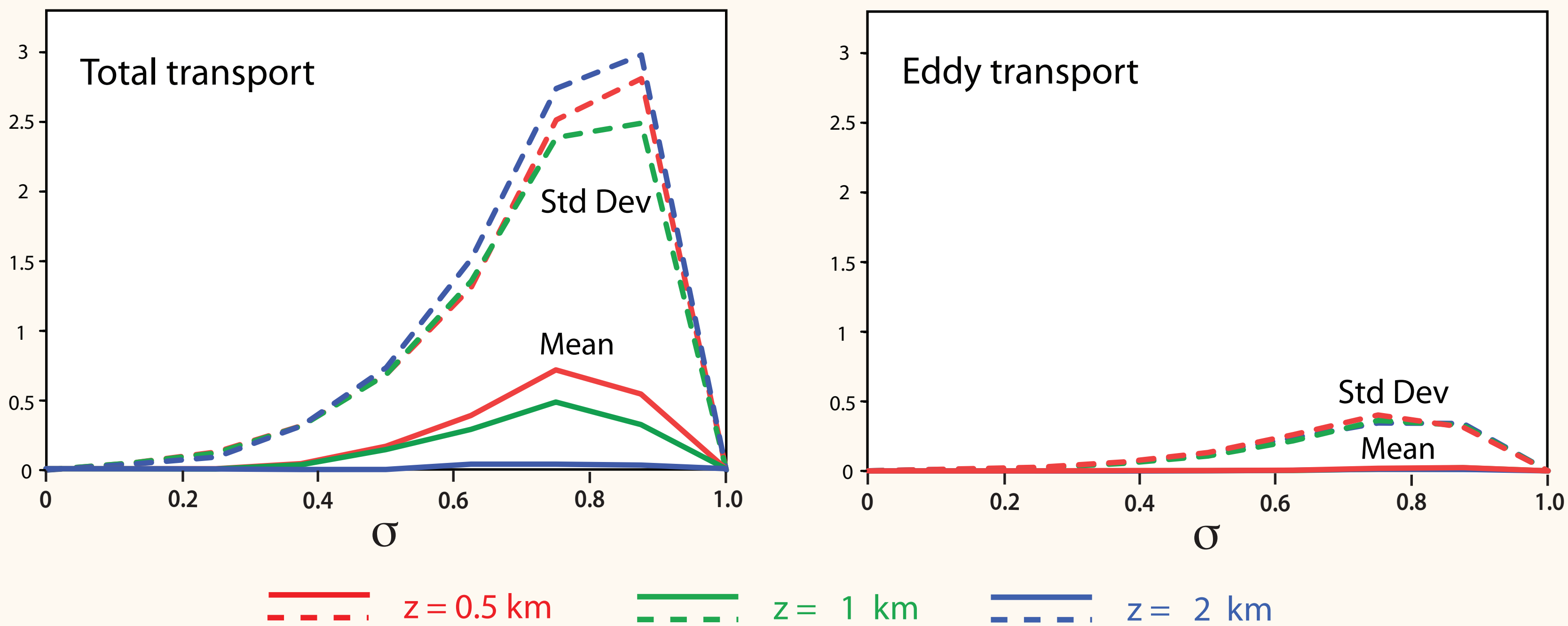
ENSEMBLE-AVERAGE VERTICAL EDDY TRANSPORT

— THE EFFECT OF MULTIPLE STRUCTURE OF CLOUDS —



DIVERGENCE OF THE HORIZONTAL TRANSPORT OF h

Shear case **d= 8 km**



Divrgence of the eddy transport is much smaller than that of the total transport in both means and standard deviations.