THE UNIFIED PARAMETERIZATION:

ITS EMPIRICAL BASIS AND FUTURE PROBLEMS

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"THE UNIFIED PARAMETERIZATION"

An attempt to unify parameterizations in GCMs and CRMs

Generalization, not replacement, of conventional cumulus parameterization to include its transition to an explicit simulation of moist convection.

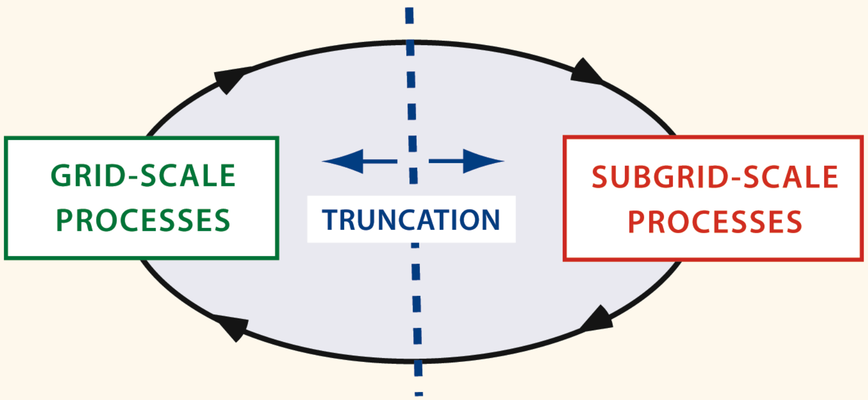
Prerequisite :

The host model can become a CRM when the resolution is sufficiently high.

THE PARAMETERIZATION PROBLEM IN NUMERICAL MODELING

The need for parameterization in numerical modeling

arises from the artificial separation of grid-scale and subgrid-scale processes.



Parameterization must deal with ONLY subgrid ("eddy") processes.

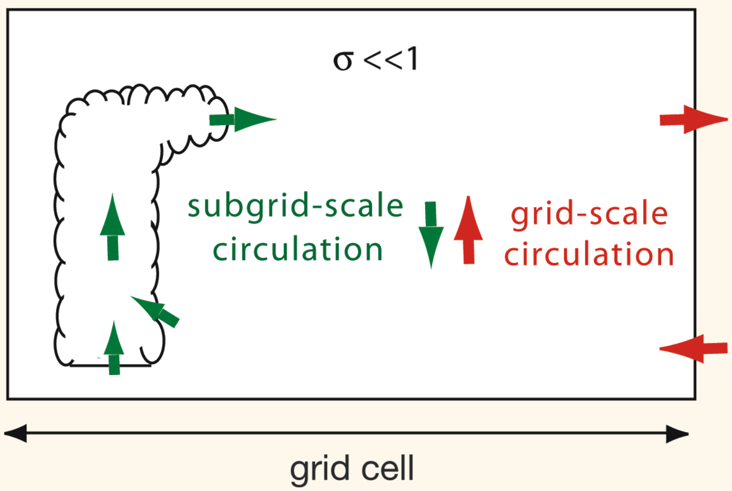
Otherwise, there is a danger of double counting.

OPENING A ROUTE FOR UNIFIED PARAMETERIZATION

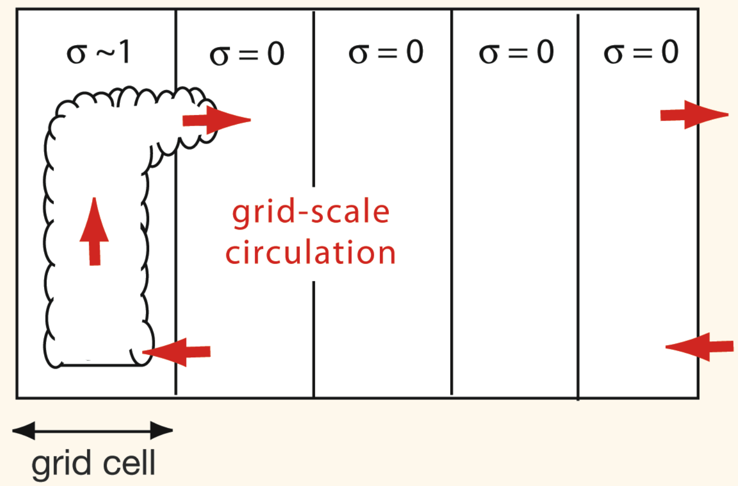
σ : the fractional area covered by *all* convective clouds

– a measure of fractional population of clouds

Conventional parameterizations assume σ << 1, either explicitly or implicitly.



With high resolutions, however, cloud may occupy the entire grid cell.



To open a route, the assumption of σ<<1 must be eliminated.

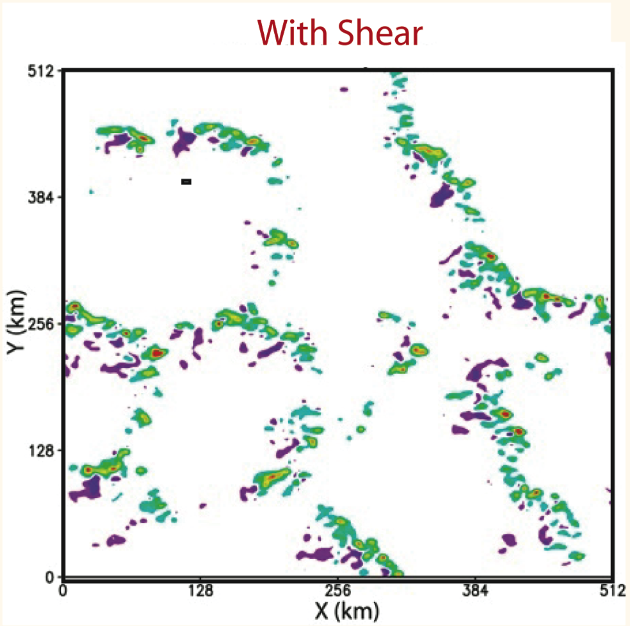
CRM SIMULATIONS USED FOR STATISTICAL ANALYSIS

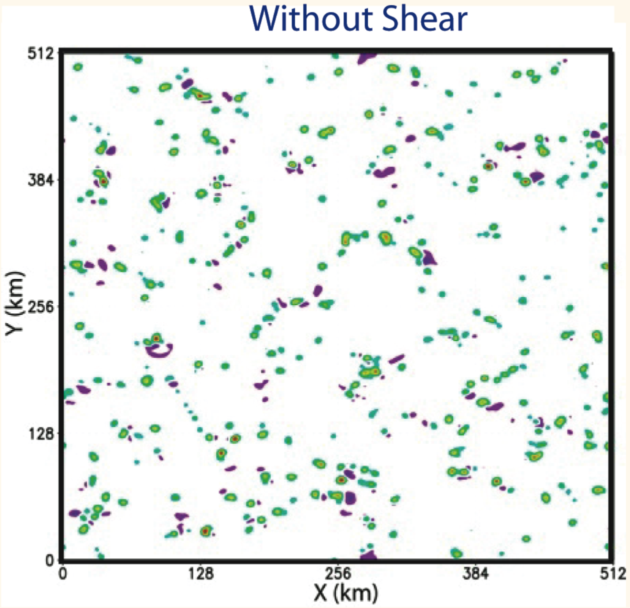
Standard simulations: without cloud-radiation interactions

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

Data used : The last 2 or 12 hours of two 24-hr simulations with 20-min intervals

Snapshots of vertical velocity w at 3 km height



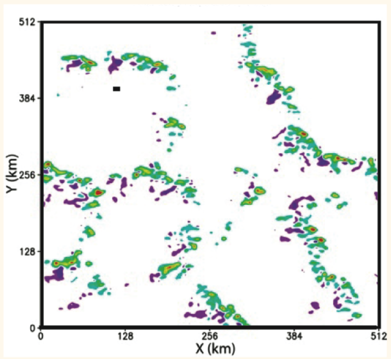


w > 0.5 m/s   w < -0.5 m/s

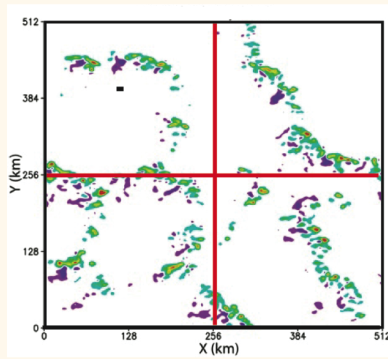
ANALYSIS OF GRID-SIZE DEPENDENT STATISTICS OF THE CRM DATA

The original domain is divided into sub-domains with the same size.

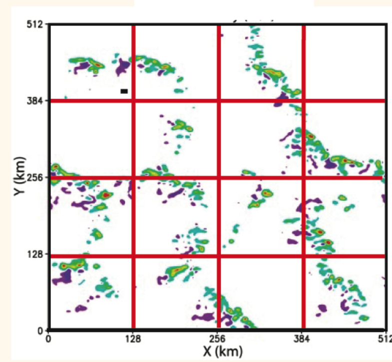
512 km



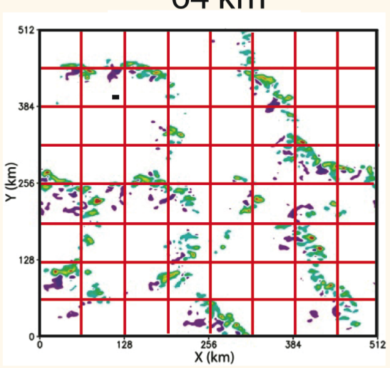
256 km



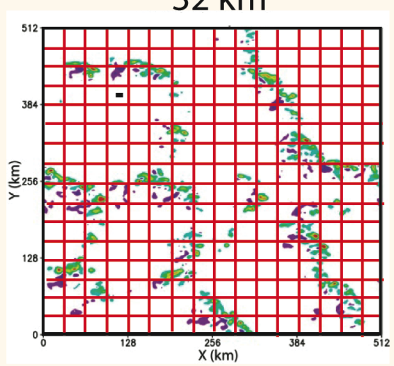
128 km



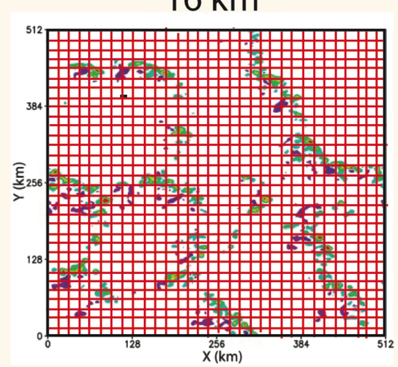
64 km



32 km



16 km



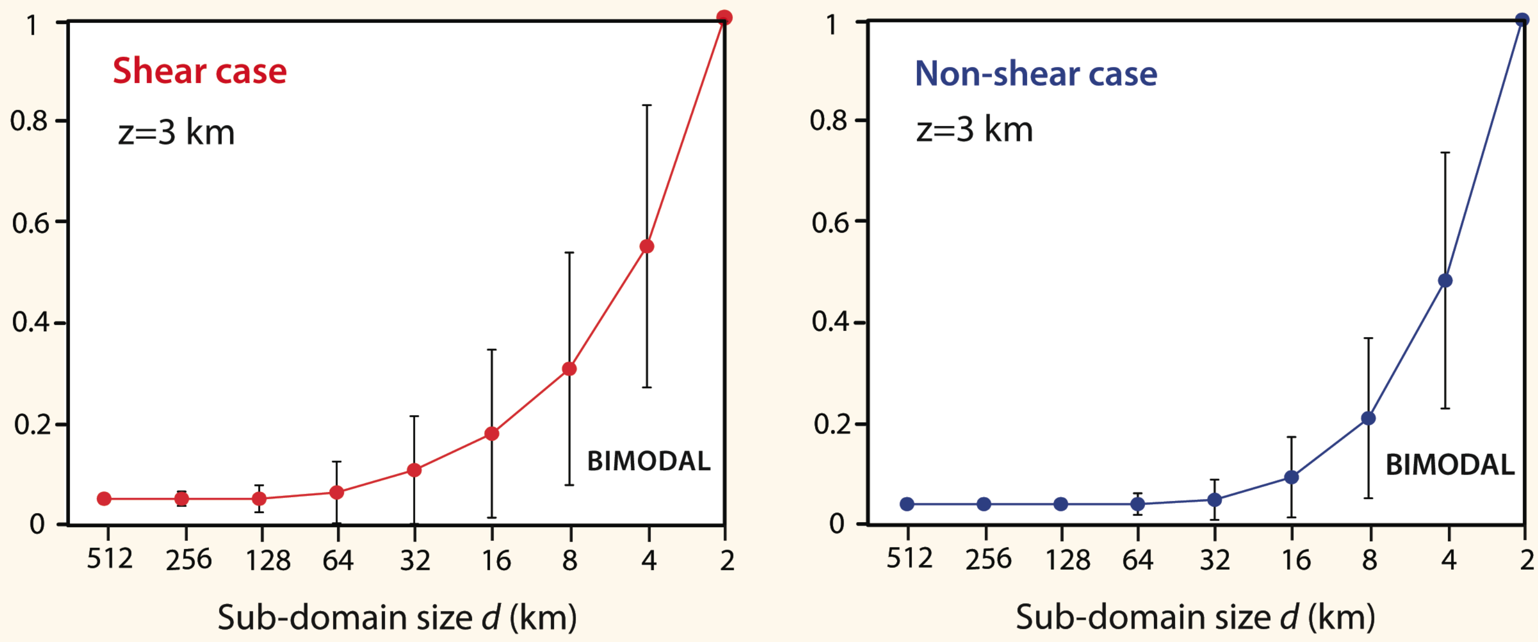
8 km 4 km 2 km

These sub-domains are assumed to represent grid cells of a GCM.

FRACTIONAL CONVECTIVE CLOUD COVER, σ

Measured by the normalized number of grid points in the sub-domain that satisfy w>0.5 m/s

Ensemble average of σ over cloud-containing sub-domains: < σ >



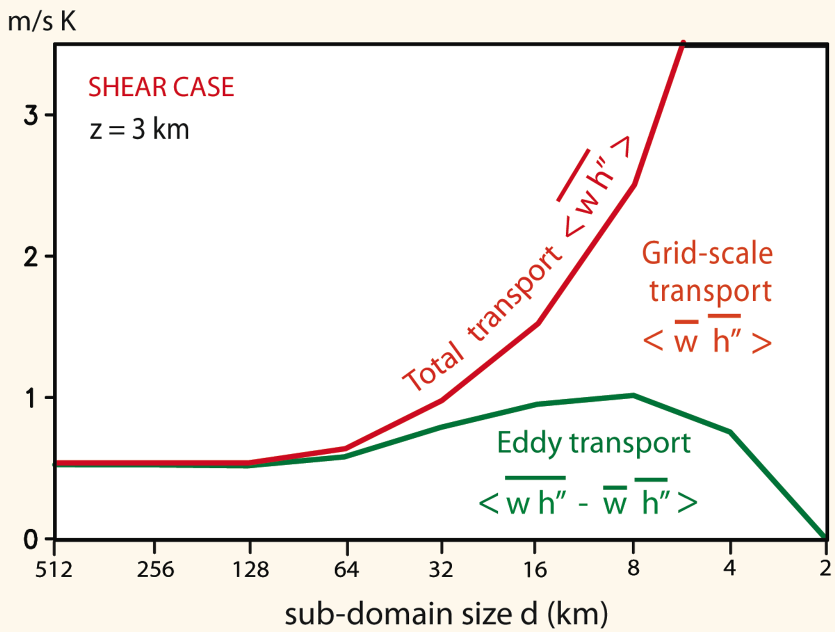
σ<<1 is a good approximation ONLY for low resolutions.

THE GOAL OF THE UNIFIED PARAMETERIZATION

Formulation of vertical eddy transport in a way applicable to any values of σ including $\sigma=1$.

RESOLUTION DEPENDENCE OF

ENSEMBLE-MEAN VERTICAL TRANSPORT OF MOIST STATIC ENERGY



h'' : Deviation of h from its reference value

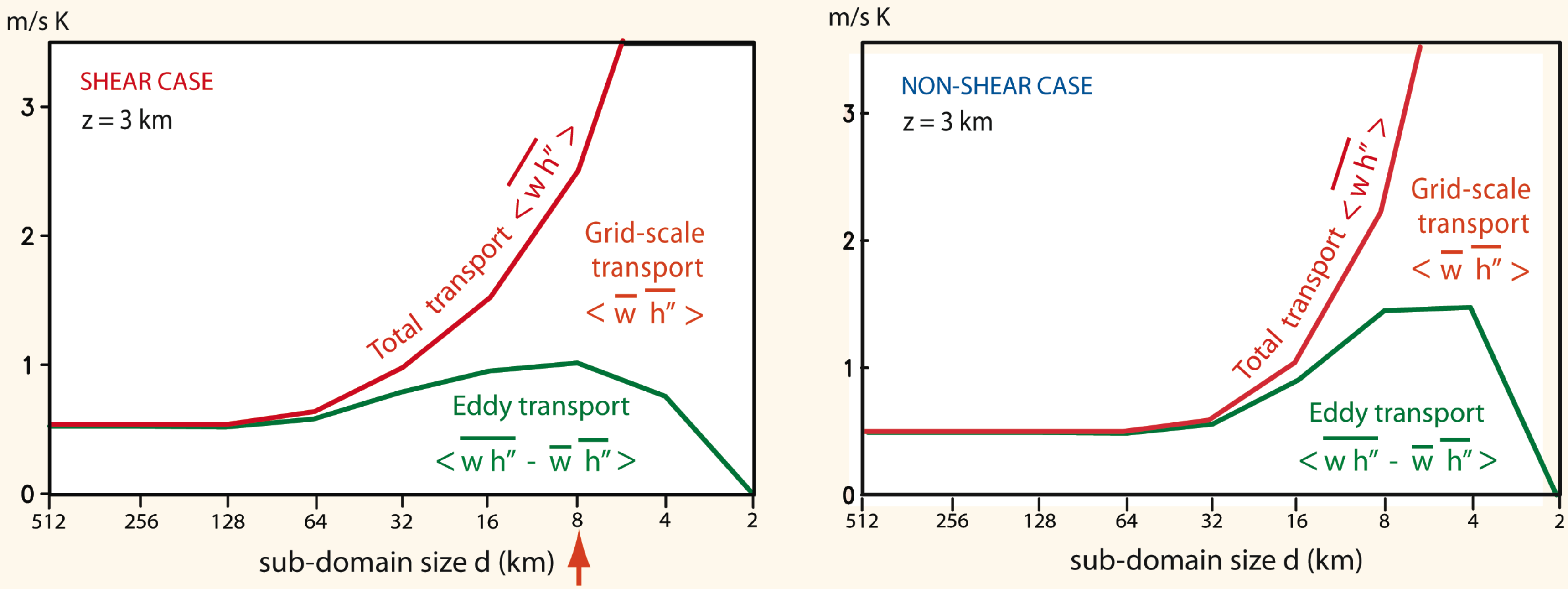
$\overline{(\ )}$: Average over all CRM grid points in the sub-domain

< > : Ensemble average over all cloud-containing sub-domains

In the mesoscale range, the eddy transport is only a fraction of the total transport.

RESOLUTION DEPENDENCE OF

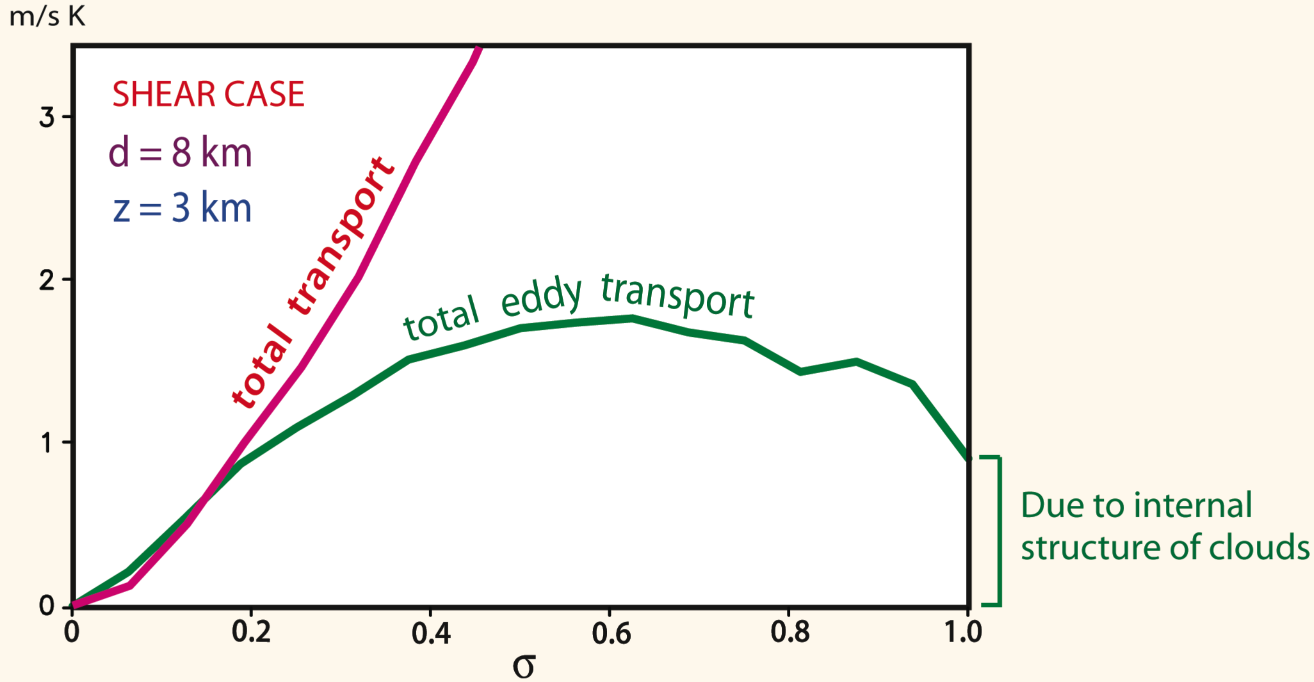
ENSEMBLE-MEAN VERTICAL TRANSPORT OF MOIST STATIC ENERGY



There is no qualitative differene beween the shear and non-shear cases.

σ–DEPENDENCE OF

ENSEMBLE-MEAN VERTICAL TRANSPORT OF MOIST STATIC ENERGY



The relative importance of eddy transport strongly depends on σ.

EDDY TRANSPORT DUE TO HOMOGENEOUS CLOUD/ENVIIRONENT

Most conventional parameterizations assume that

clouds and the environment are horizontally homogeneous individually (possibly except for the existence of convective downdrafts).

In the analysis shown next,

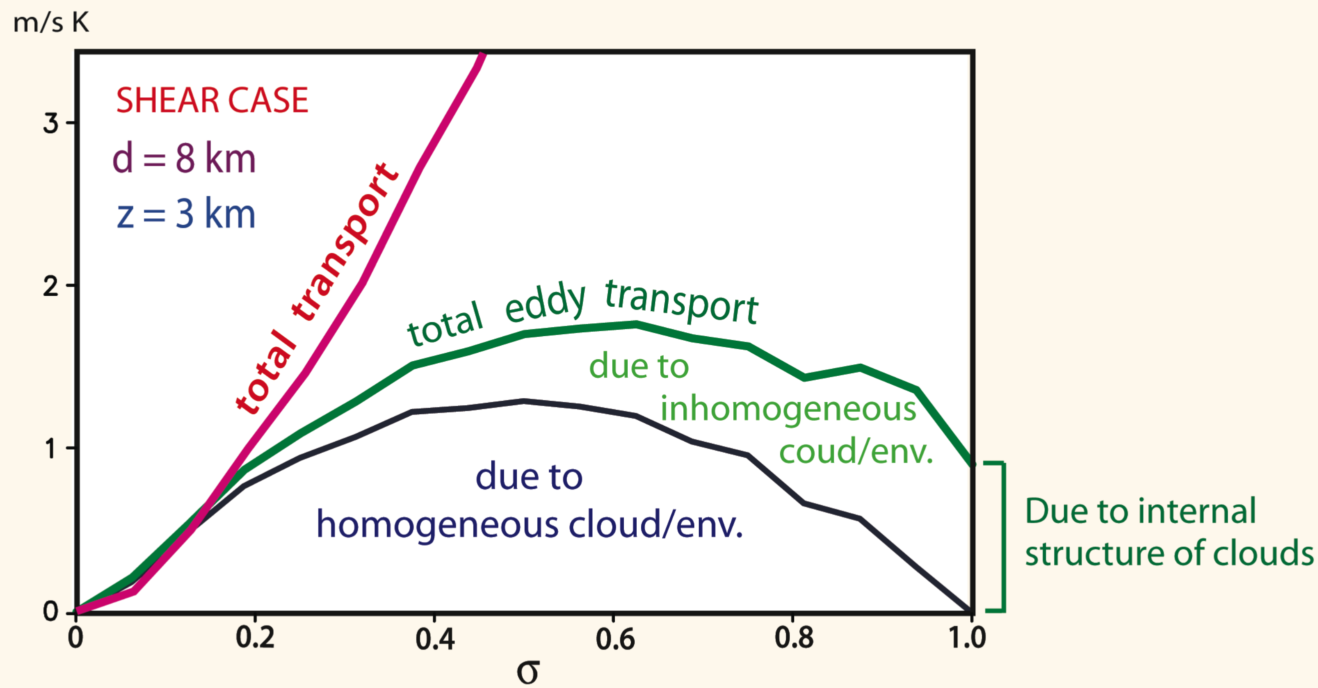
Replace all w_c in the sub-domain with $\overline{w_c}$ Replace all h_c in the sub-domain with $\overline{h_c}$

Replace all $\tilde{w}$ in the sub-domain with $\overline{\tilde{w}}$ Replace all $\tilde{h}$ in the sub-domain with $\overline{\tilde{h}}$

where $(\ )_c$: cloud value $\widetilde{(\ )}$: environment value $\overline{(\ )}$: average over the sub-domain

σ–DEPENDENCE OF

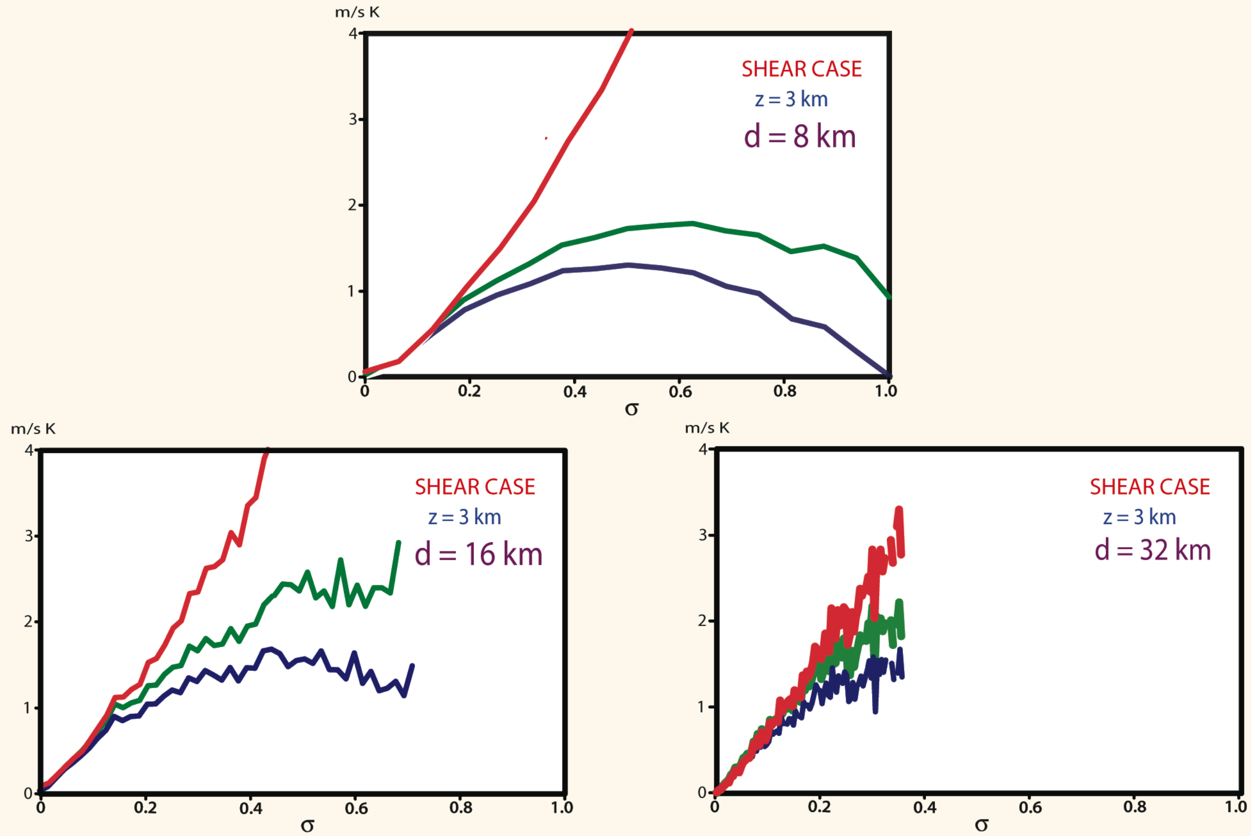
ENSEMBLE-MEAN VERTICAL TRANSPORT OF MOIST STATIC ENERGY



We find the transport "due to inhomogeneous cloud/env." is almost entirely due to inhomogeneity of clouds (not shown).

σ—DEPENDENCE OF

ENSEMBLE-MEAN VERTICAL TRANSPORT OF MOIST STATIC ENERGY



1st step: Formulation of the σ-dependence of the eddy transport by homogeneous clouds/environment

2nd step: Formulation of the σ-dependence of the total eddy transport

VERTICAL EDDY TRANSPORT DUE TO HOMOGENEOUS CLOUD/ENVIRONMENT

ψ : arbitrary thermodynamic variable

Omit the overbars on w_c, ψ_c, $\tilde{w}$, and $\tilde{\psi}$.

We can derive

$$\overline{w\psi} - \overline{w}\,\overline{\psi} = \frac{\sigma}{1-\sigma}\left(w_c - \overline{w}\right)\left(\psi_c - \overline{\psi}\right)$$

eddy transport ↑ Excess w ↑ Excess ψ ↑

Convergence Requirement :

$$\lim_{\sigma \to 1}\left(w_c - \overline{w}\right) = 0 \qquad \lim_{\sigma \to 1}\left(\psi_c - \overline{\psi}\right) = 0$$

↓

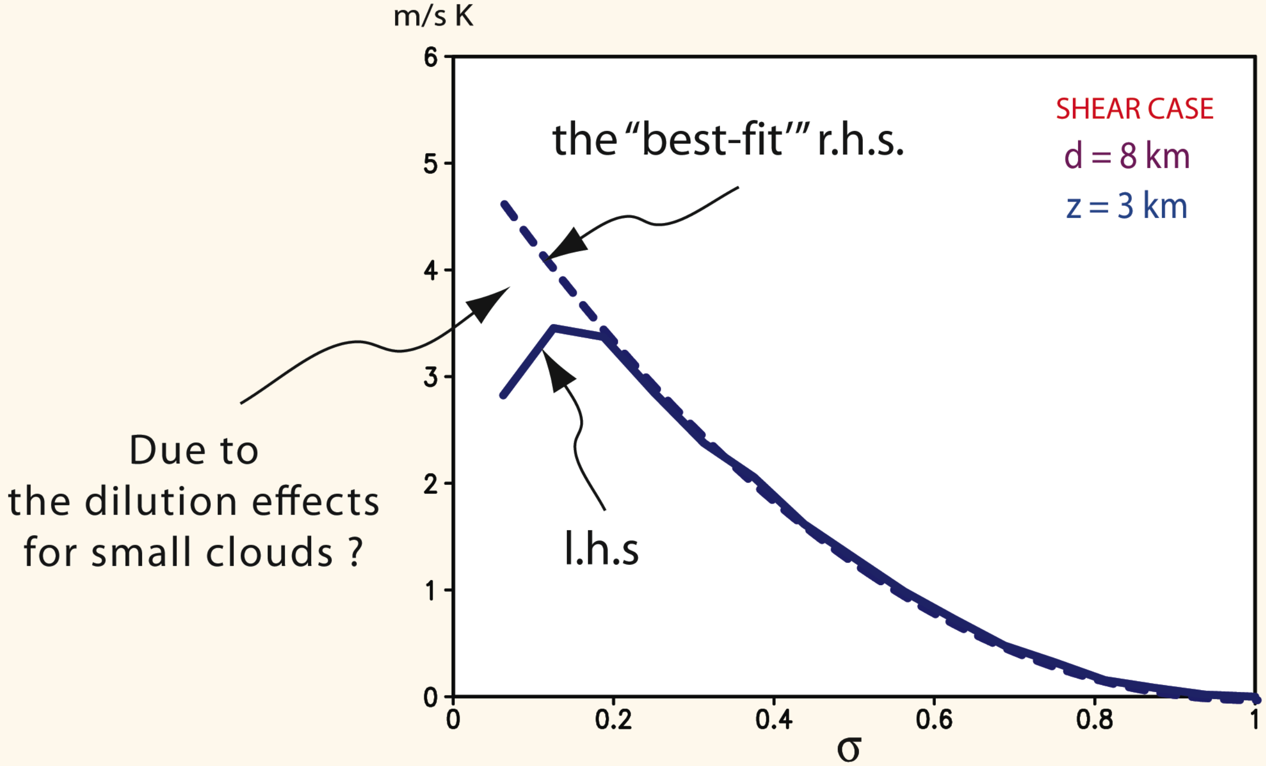
$\left(w_c - \overline{w}\right)\left(\psi_c - \overline{\psi}\right)$ is of the order of $(1-\sigma)^2$ (or higher).

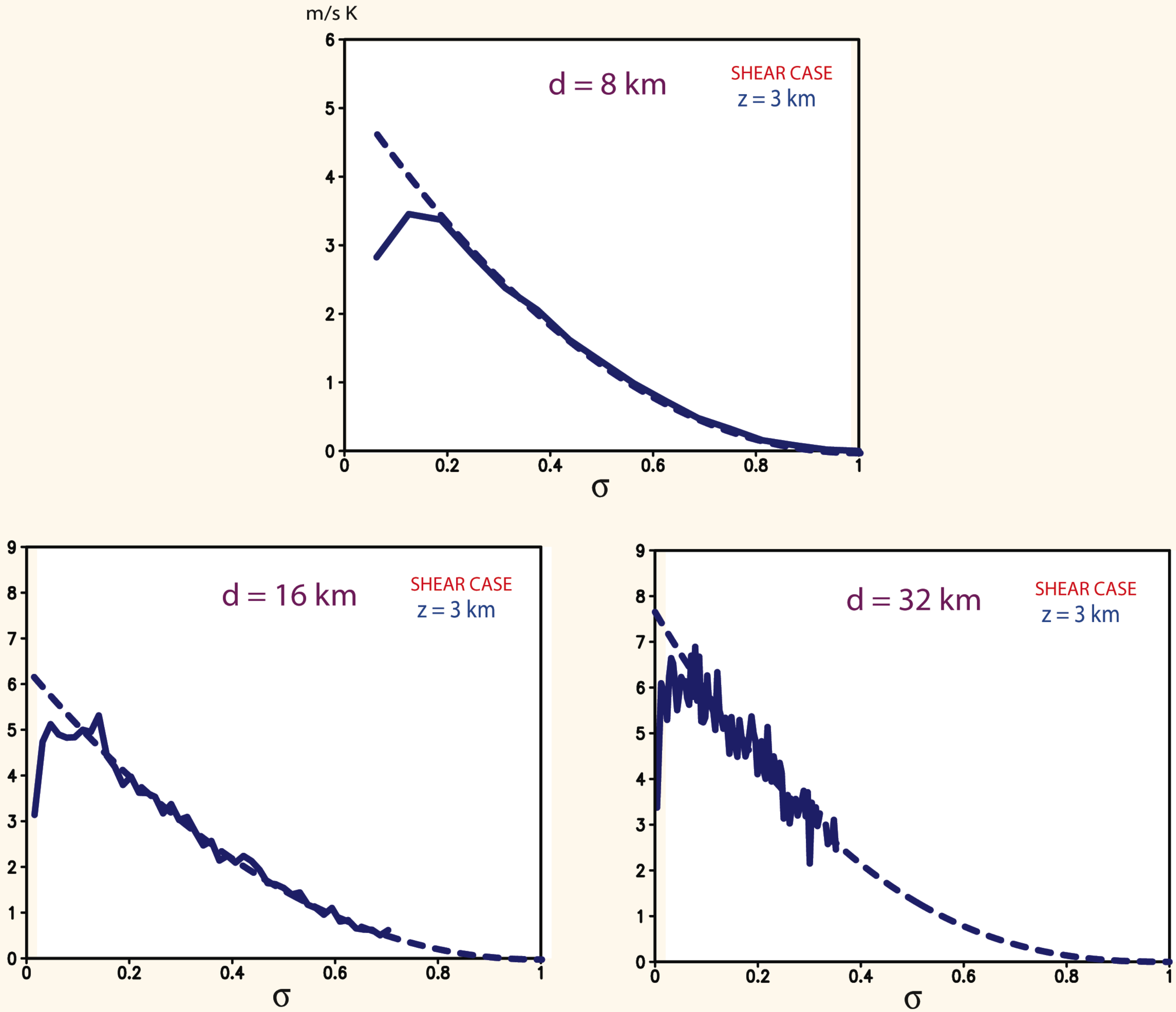
ASSUMED σ–DEPENDENCE

The simplest choice satisfying the convergence requirement :

$$(w_c - \overline{w})(h_c - \overline{h}) = (1-\sigma)^2 \left[(w_c - \overline{w})(h_c - \overline{h})\right]^*$$

the value expected when σ is small



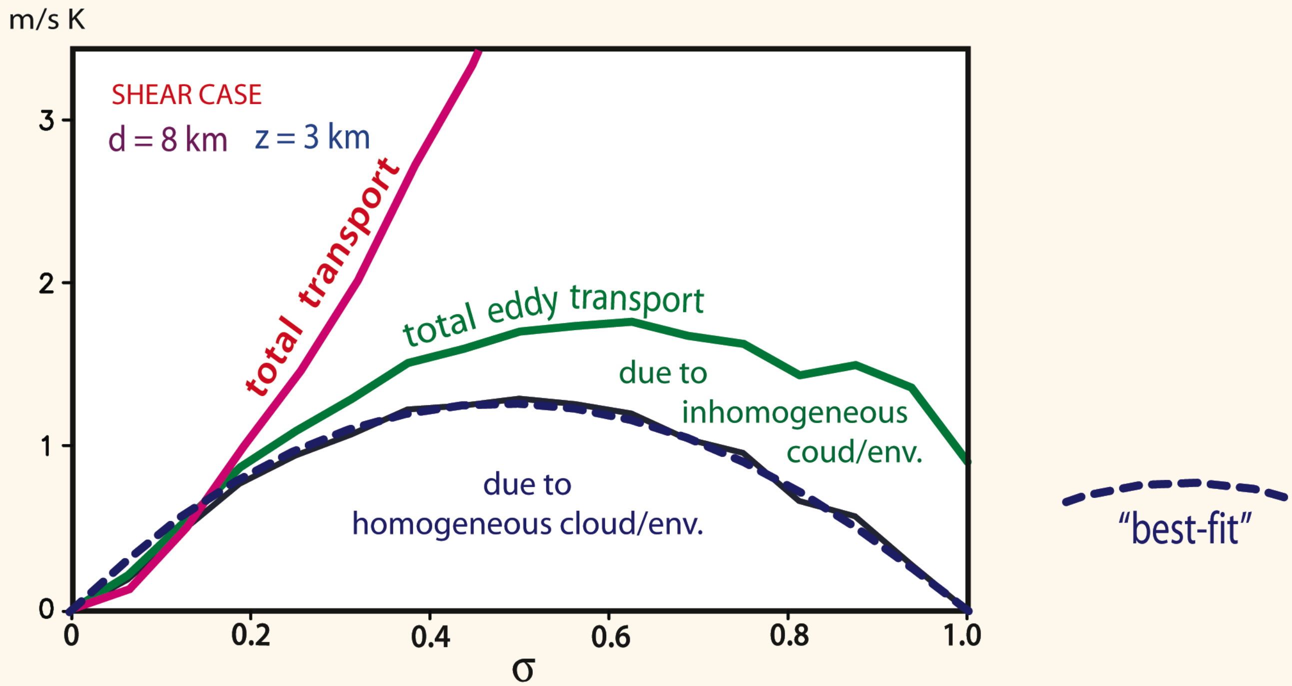

m/s K
d = 8 km
SHEAR CASE
z = 3 km
σ
d = 16 km
SHEAR CASE
z = 3 km
σ
d = 32 km
SHEAR CASE
z = 3 km
σ

σ—DEPENDENCE OF
ENSEMBLE-MEAN VERTICAL TRANSPORT OF MOIST STATIC ENERGY

For homogeneous cloud/env.: $$\overline{wh}-\overline{w}\,\overline{h}=\frac{\sigma}{1-\sigma}\left(w_c-\overline{w}\right)\left(h_c-\overline{h}\right) \quad (1)$$

From the convergence requirement: $$\left(w_c-\overline{w}\right)\left(h_c-\overline{h}\right)=(1-\sigma)^2\left(w_c^*-\overline{w}\right)\left(h_c^*-\overline{h}\right) \quad (2)$$

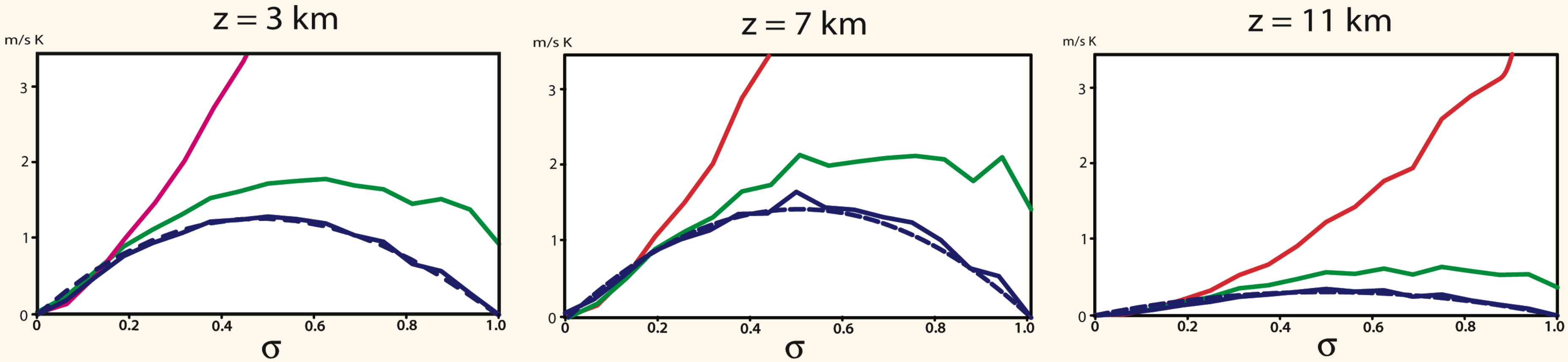
From (1) and (2), $$\overline{wh}-\overline{w}\,\overline{h}=\sigma(1-\sigma)\left(w_c^*-\overline{w}\right)\left(h_c^*-\overline{h}\right) \quad (3)$$



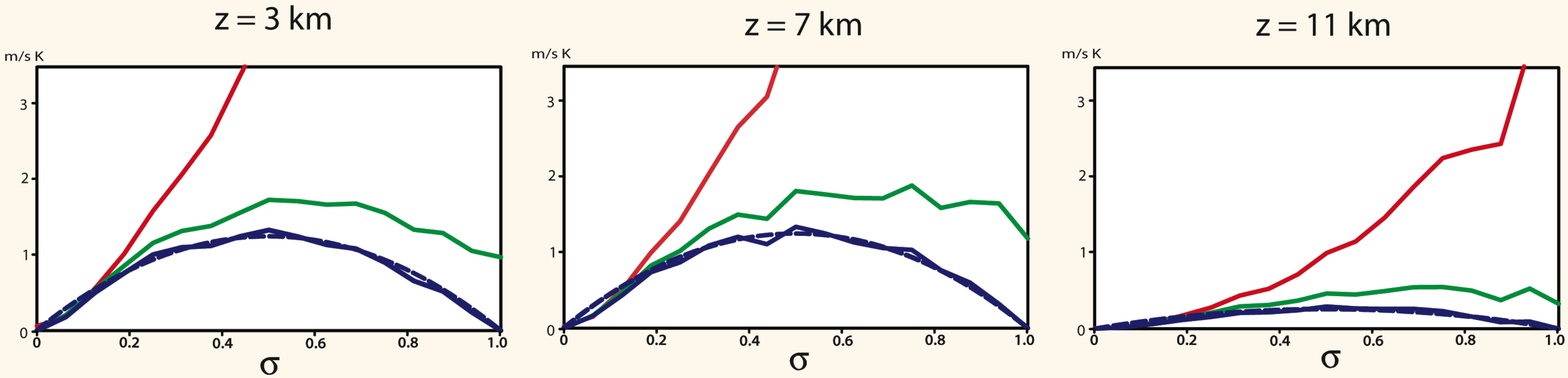
Comparisons OF EDDY TRANSPORTS

WITHOUT/WITH CLOUD-RADIATION INTERACTION AT DIFFERENT LEVELS

Without Cloud-Radiation Interaction



With Cloud-Radiation Interaction



DETERMINATION OF σ

Conventional mass-flux based parameterizations can provide the following information :

(i) Cloud properties relative to the mean field including $\left(w_c{}^* - w\right)\left(h_c{}^* - h\right)$.

(ii) *Total* eddy transport necessary for adjustment to a quasi-equilibrium $\left(\overline{wh} - \overline{w}\,\overline{h}\right)_{adj}$.

(i) and (ii) must satisfy

$$\left(\overline{wh} - \overline{w}\,\overline{h}\right)_{adj} = \frac{\sigma}{1-\sigma}\left(w_c{}^* - \overline{w}\right)\left(h_c{}^* - \overline{h}\right) \qquad (4)$$

Then

$$\sigma = \frac{\left(\overline{wh} - \overline{w}\,\overline{h}\right)_{adj}}{\left(\overline{wh} - \overline{w}\,\overline{h}\right)_{adj} + \left(w_c{}^* - \overline{w}\right)\left(h_c{}^* - \overline{h}\right)}$$

This σ automatically satisfies

$0 \le \sigma \le 1$ including

$\sigma \to 1$ as $\left(\overline{wh} - \overline{w}\,\overline{h}\right)_{adj} \to \infty$.

PRACTICAL APPLICATION OF THE UNIFIED PARAMETERIZATION

$$\overline{wh} - \overline{w}\,\overline{h} = \sigma(1-\sigma)\left(w_c^* - \overline{w}\right)\left(h_c^* - \overline{h}\right) \qquad (3)$$

$$\left(\overline{wh} - \overline{w}\,\overline{h}\right)_{adj} = \frac{\sigma}{1-\sigma}\left(w_c^* - \overline{w}\right)\left(h_c^* - \overline{h}\right) \qquad (4)$$

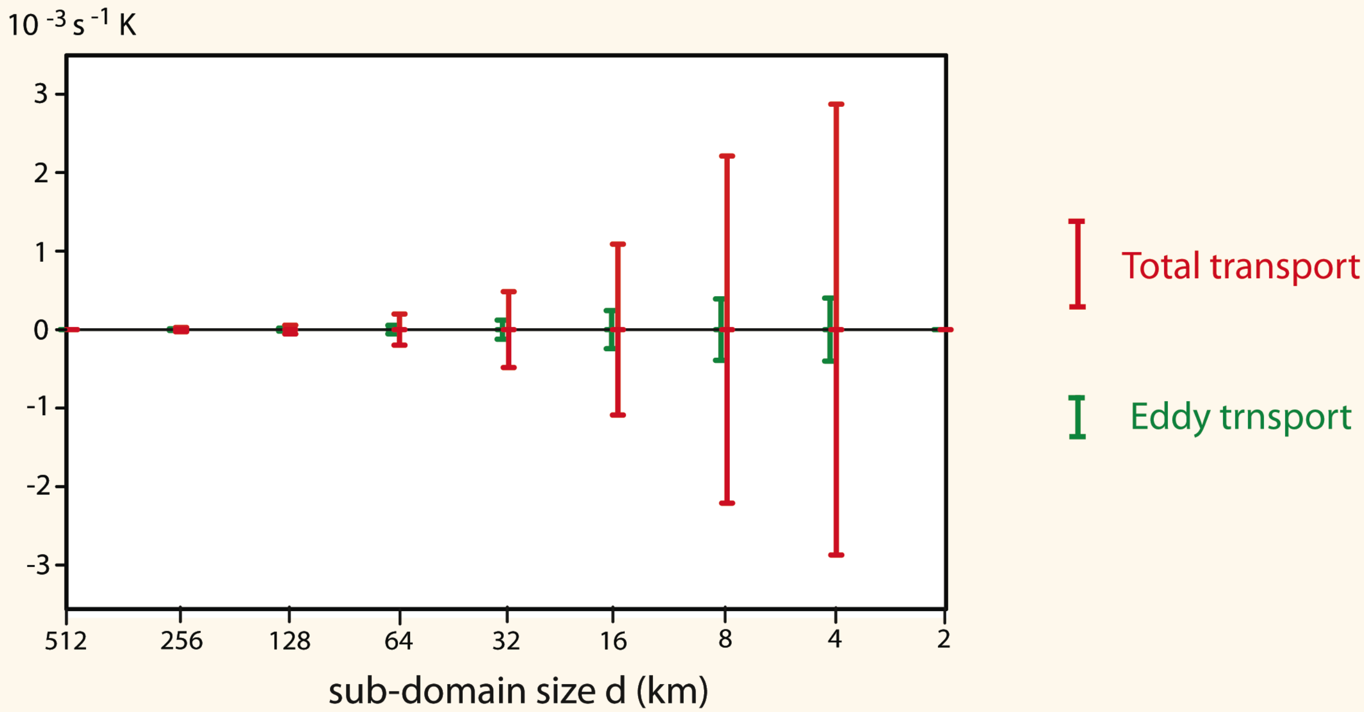
↓

$$\overline{wh} - \overline{w}\,\overline{h} = (1-\sigma)^2\left(\overline{wh} - \overline{w}\,\overline{h}\right)_{adj}$$

This represents relaxed or delayed adjustment

as far as the effect of the eddy transport is concerned.

DIVERGENCE OF THE HORIZONTAL MOIST STATIC ENERGY TRANSPORT



- The ensemble means are negligible compared to the standard deviations.
- The standard deviations of total transport are much larger than those of eddy transport.

→ eddy transport is negligible in most situations.

SUMMARY

Parameterization must deal with ONLY subgrid eddy processes.

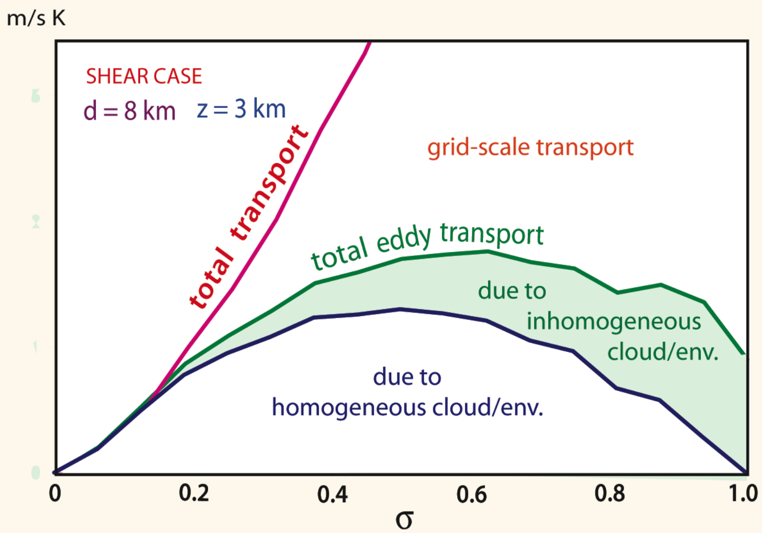
When σ is large, the difference of state variables between clouds and the grid-cell average is small.

Consequently, the magnitude of adjustment toward an equilibrium is limited.

For homogeneous clouds/env., conventional parameterizations give information on σ (though not utilized).

That information provides physical and quantitative basis for partitioning subgrid- and grid-scale transports.

FUTURE PROBLEMS - EDDY TRANSPORTS FOR LARGE σ



The effect of convective downdrafts

As far as the 3 km level is concerned, the eddy transport due to inhomogeneous "environment" is negligible.

The analysis should be extended to lower levels including the sub-cloud layer.

The effects of multiple cloud types, cloud organization, and internal structure of clouds

The relative importance of these effects should be assessed.

When the resolution is high and σ is large, however, these effects are small compared to grid-scale transports.

Unification with parameterization of stratiform clouds

Large σ can appear even with low-resolutions when stratiform clouds dominate.
Then unification with stratiform-cloud parameterization becomes an issue
– geometrical representation, closure based on non-buoyancy, ...