Turbulence closure of sub grid scale processes:

Why do we need that?

It’s a consequence from numerical treatment of non-linear model equations

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The primitive equations:

\[
\partial_t (\rho \phi_k) + \nabla \cdot \left( \rho \phi_k \mathbf{v} \right) + \mathbf{c}^{\phi_k} = \mathbf{S}^{\phi_k}
\]

\[
\phi_k \in \{1, u, v, w, c_{pd}, T, q_x\}
\]

advection flux density
molecular flux density
pure source term
scalar variables
linear or non-linear functions in all model variables
(dependent on a list of general valid parameters)
simplified for efficiency reasons using effective parameters

\[
\nabla \cdot \mathbf{c}^{\phi_k} = \sum_j \left[ \delta_{ij} \left[ p - \left( \lambda - \frac{2}{3} \mu \right) \nabla \cdot \mathbf{v} \right] - \mu \left( \partial_j \mathbf{v} + \partial_i \mathbf{v} \right) \right] = \nabla \cdot \left( -\mu \nabla \mathbf{v} \right) + \partial_j \left( p \left( \lambda + \frac{2}{3} \right) \nabla \mathbf{v} \right)
\]

\[
\partial_j \zeta = \partial_j \zeta + \partial_j \zeta' = \partial_j \zeta - \partial_j \zeta'
\]

Numerical scheme solves filtered equations:

- Filter may be a resolution dependent moving grid-cell volume-average
- Filter removes SGS variability

Non-linearity causes generation of statistical moments:

- Non-commutability of filter and (e.g.) multiplication

\[
\rho \phi_k \mathbf{v} = \rho \phi_k \mathbf{v} + \rho \phi_k'' \mathbf{v}''
\]

SGS covariance:
roughness layer terms

Local parameterizations:
- molecular flux densities
- phase changes sources (cloud microphysics)
- radiation flux convergence

\[
p = \rho R_d \left[ 1 + \left( \frac{R_v}{R_d} - 1 \right) q_v - q_c \right] T_v
\]
The concept of “topographic approximation”:

- **Sub grid scale slope** of the model layers or non-atmospheric inclusions

- **Averaging and differentiation** in space (flux divergence) can no longer be commuted

\[
\overline{\partial_j \phi} = \overline{\partial_j \phi} + \overline{\partial' \phi'}
\]

with respect to \(\overline{Z}_\sigma\) (including metric terms of filtered topography)

- **Roughness terms** in the averaged model equations

\[
\overline{\partial' \phi'} = -\partial_z \phi \overline{\partial_j \overline{Z}_\sigma'}
\]

- **Wake turbulence production** for TKE

- **Only slope correction terms** have to be parametrized.

For any **real surface** of the earth, there exists an “**equivalent topographic surface**”, which has the same **surface area** as the real surface.

- **Free atmospheric boundary layer**

- **Shifted filtered topography excluding small scale modes that do not contribute to sub grid scale slope correction terms**

- **Equivalent topography covered by model layers**

- **Lowest full model level roughness layer**: may be contained in transfer layer, if excluded from model domain (where atmospheric budget equations are applied)
The filtered model equations:

\[ \partial_t (\bar{\rho} \hat{\phi}_k) + \nabla \cdot \left( \bar{\rho} \hat{\phi}_k \mathbf{v} + \rho \phi_k \mathbf{v}^* - a^0 \nabla \phi_k \right) + \nabla' \left( \rho \phi_k \mathbf{v} - a^0 \nabla \phi_k \right) = Q^\phi_k (\phi, \bar{p}) + \Delta Q^\phi_k (\phi^*, p^*) \]

extended, parametrized (non-linear) source term function
applied to GS variables

neglecting correction from Coriolis force

residual SGS flux density

roughness layer modification of transport

(extended, non-linear) source term function
applied to GS variables

\[ \Delta Q^\phi_k (\phi^*, p^*) \]

extended SGS source term correction also including roughness layer effects (form drag)

\[ q^2 = \frac{1}{\bar{\rho}} \sum_{i=1}^3 \rho v_i^2 \]

2 SKE

SGS contribution by cloud microphysics

SGS contribution by cloud microphysics
and radiation

functions in various covariance terms of scalar variables

\[ \bar{p} = \bar{\rho} R_d \left[ 1 + \left( \frac{R_v}{R_d} - 1 \right) q_v - q_c \right] T + R_d \left[ 1 + \left( \frac{R_v}{R_d} - 1 \right) \rho q_v^* T^* - \rho q_c^* T^* \right] \]

\[ Q^\phi_k \begin{cases} S^\phi_k & , \phi_k \text{ is a scalar} \\ - \delta_{i3} \bar{\rho} g - 2 \bar{\rho} (\Omega \times \mathbf{v})_i - \partial_i p & , \phi_k = v_i \end{cases} \]

\[ S^\phi_i \]

\[ \text{static pressure gradient (from molecular transport)} \]

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Parameterizations in terms of grid scale (GS) variables:

• Further information (assumptions) about these additional covariance terms has to be introduced:
  
  functions in all GS model variables \( \bar{\rho}, \bar{\phi}, \bar{p} \)
  
  dependent on a list of additional parameters \( \beta \)

  \( \{ \text{GS parameterizations due to SGS variability} \} \)

• Closure assumptions are additional constraints that can’t be general valid

  Ð distinguish different SGS flow structures more or less according to the length scales of their motions
  Ð each with specific parameterization assumptions

  **Turbulence:** isotropic, normal distributed, only one characteristic length scale at each grid point, forced by shear and buoyancy

  **SGS Circulation:** non isotropic, arbitrarily skewed and coherent structures of several length scales, supplied by various pressure forces

  **Convection**

  Kata- and anabatic density circulations:

  large vertical scales of coherence, full microphysics, forced by buoyancy feedback

  Horizontal shear eddies:

  produced by strong horizontal shear e.g. at frontal zones; dominated by horizontal grid scale

  Wake eddies:

  produced by blocking at SGS surface structures (form drag forces)

  Breaking gravity wave eddies: belong to wave length of instable gravity waves of arbitrary scales
Closure strategies:

- Describing the covariance terms within different frameworks all based on first principals
- Introduction of closure assumptions by application of a related truncation procedure
- Finding a flow structure separation according to the validity of closure assumptions
- Setting up a consistently separated set of parameterization schemes being to some extend general valid

- Two different frameworks available:
  - Higher order closure (HOC): Using budget equations for needed statistical moments (that always contain new ones, even such of higher orders) and truncating the order of considered moments
    - Second order closure: fits very well to turbulence
  - Conditional domain closure (CDC): Using budget equations for conditional averages of model variables (e.g. according to classes of vertical velocity) and building the needed covariance terms by the related truncated statistics
    - Mass flux closure (bi- or tri-modal distribution): fits very well to convection
General second order budget equation:

(including roughness layer terms in topographic approximation)

\[
\begin{align*}
D_t (\rho \phi \psi^r) &= \partial_t (\rho \phi \psi^r) + \nabla \cdot (\rho \phi \psi^r \hat{v} + \rho \phi \psi^r \hat{v}^r) + \phi^r \hat{e}^r + \psi \hat{e}^g = \\
&= \left(\hat{e}^w \cdot \nabla \phi + \hat{e}^g \cdot \nabla \psi\right) - \left(\rho \psi^r \hat{v}^w \cdot \nabla \phi + \rho \phi \hat{v}^w \cdot \nabla \psi\right) \\
&\quad + \left(\hat{e}^w \cdot \nabla \phi + \hat{e}^g \cdot \nabla \psi\right) \\
&\quad + \left(\phi^r \hat{Q}^w + \psi \hat{Q}^g\right)
\end{align*}
\]

- molecular flux density \( e^\phi := -a^\phi \nabla \phi \)
- neglected outside the laminar layer
- vanishing for conservative variables
- slope correction of flux vectors
- virtual potential temperature
- pressure transport
- buoyancy source
- pressure correlation
- sheared production
- molecular dissipation
- extended source term correlation
- sub grid scale macroscopic transport

\[
\vec{z} := \begin{pmatrix}
\gamma_1 \\
\gamma_2 \\
\gamma_3
\end{pmatrix}
\]

\[
x_3 = z, \sigma = \text{const}
\]

\[
\delta_{ij} \frac{g}{\theta_v} \rho \phi \theta^r_v \approx - \phi^r \partial_j \bar{p}
\]

\[
\phi \partial_z \left( \hat{p} \partial_j \bar{z}_j \right)'
\]

\[
\phi \partial_z p \left( \partial_j \bar{z}_j \right)'
\]

\[
\text{return-to-isotropy}
\]

\[
\text{wake production}
\]
Postulates of pure turbulence:

- **Equilibrium** of the source terms in all 2-nd order budgets:
  - neglect of local time derivative
  - neglect of (grid scale and sub grid scale) transport
  - neglect of correlations with pure source terms of 1-st order budget equations

- **Neglect** of all roughness layer terms

- **Spectral density** of 2nd-order moments follows a **power law** in terms of wave length in each sample direction (inertial sub range spectrum):
  - whole SGS spectrum in a given sampling direction is determined by a **single** peak wave length $L_p$

- **Peak wave length** is the **same** for samples in all directions: **isotropic** length scale

- **Pressure fluctuations** can be described by an **incompressible Bernoulli equation**

  - pressure correlation and dissipation can be closed using a **single** turbulent master length scale $\ell$ for each location according to Rotta and Kolmogorov

**Turbulence** is that class of SGS structures being in agreement with turbulence closure assumptions!
The moist extension:

- Inclusion of sub grid scale condensation achieved by:
  - Using conservative variables with respect to condensation:
    \[ q_w = q_c + q_v \]
    \[ \theta_w = \theta - \frac{L_c}{c_p d} q_c \]
  - Correlations with condensation source terms are considered implicitly for non precipitating clouds.

- Solving for water vapor \( q_v \) and cloud fraction \( r_c \) by using the statistical saturation adjustment scheme (according to Sommeria/Deardorff):
  - Normal distribution of oversaturated cloud water \( \Delta q_{sat} \) (assumed for turbulence, but not e.g. for convection!)
  - Expressing variance of \( \Delta q_{sat} \) by variance of \( \theta_w \) and \( q_w \), both generated from the turbulence scheme
The coarse resolution extension:

- Application of turbulence approximations only to small SGS scales \( L \leq \min\{L_p, \Delta x\} \)
- separation of the sub grid scale flow in different classes with specific closure assumptions

- turbulent budgets with additional production terms due to shear terms with respect to the separated sub grid scale circulation flow of
  - wake vortices by SSO (sub grid scale orography) blocking or gravity wave breaking
  - horizontal shear vortices [already operational in ICON]
  - surface induced density flow patterns [only very crude]
  - shallow and deep convection patterns [not yet operational active]

Production terms dependent on:
- specific length scales \( L_c \) and a specific velocity scale \( (=\sqrt{\text{CKE}}) \)
- and other circulation-scale

Production terms depend on:
- turbulent length scale \( L_p \) and the turbulent velocity scale \( (=\sqrt{\text{TKE}}) \)
- turbulence-scale moments

\( Q_{\text{TKE}}^C \) is the scale interaction term shifting SKE from the circulation part of the spectrum (CKE) to the turbulent part (TKE) by virtue of shear generated by the circulation flow patterns.
Single column solution for turbulent flux densities:

1. Using closure assumptions valid for pure turbulence:
   - 2-nd order budgets reduce to a 15X15 linear system of equations built of all (traceless) second order moments of the set \{\theta_w, q_w, u, v, w\} of almost conserved variables.
   - and a prognostic equation for TKE

2. Using general boundary layer approximation:
   - neglect derivatives of mean quantities along filtered topographic surfaces compared to derivatives normal to that surfaces

Flux gradient representation of the only relevant vertical flux densities:

\[
\begin{align*}
\bar{f}_z &= \bar{\rho} \bar{\phi} \bar{w} = \bar{\rho} \bar{\phi} \bar{w} - \bar{\rho} K^\phi \partial_z \bar{\phi} \\
K^\phi &= \ell \cdot \mathbf{S}^\phi \cdot q \\
\mathbf{S}^\phi &= \ell, \text{vertical wind shear} \text{ and } \text{buoyancy (thermal stratification)}.
\end{align*}
\]
The roughness- and laminar-layer extension:

- **Averaging** the L-filtered 1-st and 2-nd order budget equations that have been solved by applying HBA in an accordingly **rotated** system.

\[
s^2(\sigma) = \left[ \nabla_h (\mathbf{h} \mathbf{L}) \right]_{L}^{2}
\]

variance of the surface slope

\[
s_0^2 = \left[ \nabla_h \mathbf{Z} \right]_{L}^2 = \tan^2(\alpha_0)
\]

with respect to horizontal scale \( L \)

\[
\Gamma := 1 + s_0^2 + s^2 = 1 + \tan^2(\alpha) = \left( \frac{1}{\cos^2(\alpha)} \right)
\]

equation for \( \tan^2(\alpha) \)

\[
\nabla \cdot \mathbf{F} = \nabla \cdot (\tilde{\rho} \hat{\mathbf{v}}) + \partial_z \left[ \Gamma \cdot \tilde{f}^0 \right]_{L}
\]
effective flux divergence for scalars

\[
\nabla \cdot \mathbf{F}^v + \partial_i p = \nabla \cdot (\tilde{\rho} \hat{v}_i \hat{\mathbf{v}}) + \partial_i \left( \tilde{p} + \frac{1}{3} \sum_{j=1}^{3} \rho \hat{v}_j \hat{v}_j \right)_{L} + \partial_z \left[ \Gamma \cdot \tilde{f}^v \right]_{L} - p \left( \partial_i \mathbf{Z} \right)_{L}
\]
effective flux divergence for momentum

\[
\begin{align*}
\rho q_{L}^2 &= \rho q_{L}^2 \\
\end{align*}
\]

\[
\begin{align*}
\Gamma \tilde{f}_{L} = \rho q_{L}^2 \\
\end{align*}
\]

2 TKE

\[
\begin{align*}
\Gamma &:= \frac{1}{\sqrt{\Gamma}} \\
\end{align*}
\]

General boundary layer approximation:

- **iso surface** with an area being \( \sqrt{\Gamma} \) times the horizontal area

\[
\tilde{F}^v_L = -\tilde{\rho} \left( 1 + \frac{k^\phi}{K^\phi} \right) K^\phi \partial_z \hat{\phi}
\]
equation for \( \tilde{F}^v_L \)

- **Not yet implemented completely**
- **Drag flux density only by SSO scheme**

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Iterative solution for TKE and the stability-functions:

\[ r_p = \left( \frac{\bar{p}}{p_r} \right)^{\frac{R_d}{c_{pd}}} \quad r_v := 1 + \left( \frac{R_v}{R_d} - 1 \right) \hat{q}_v - \hat{q}_c \]

\[ T_c = \frac{L_c}{c_{pd}} \quad \alpha := \partial_T q_{vs}(t) \quad r_T := \frac{1}{1 + \alpha T_c} \]

saturation fraction

\[ \hat{\vartheta}_v := r_T \left( r_v \vartheta_c - \frac{R_v}{R_d} \hat{\vartheta}_v \right) \quad \hat{\vartheta}_w := \left( \frac{R_v}{R_d} - 1 \right) \hat{\vartheta} + \frac{r_c}{r_p} \cdot \hat{\vartheta}_v \quad r_\theta := r_v - r_c \alpha \hat{\vartheta}_v \]

\[ F_T^M := (\partial_z \hat{u})^2 + (\partial_z \hat{v})^2 \quad + F_C^M \quad F^H := \frac{g}{\hat{\theta}_v} \cdot (\partial_w \hat{\vartheta}_w + \partial_h \hat{\theta}_w) \]

\[ \frac{1}{\ell(z)} = \frac{1}{\kappa z} + \frac{1}{\ell_m} + a_{\text{stab}} \frac{\sqrt{F^H}}{q} \]

\[ \partial_t \left( \frac{1}{2} \bar{p} q^2 \right) + \partial_z \left[ -\bar{p} \ell S q \partial_z \left( \frac{1}{2} q^2 \right) \right] = \bar{p} q \ell \left[ S^M r_T^M F_T^M - S^H F^H \right] - \frac{q^3}{\alpha^{MM} \ell} \]

\[ G_T^M := \frac{\ell^2}{q^2} F_T^M \geq 0 \quad G^H := \frac{\ell^2}{q^2} F^H \]

\[ \left[ \frac{1}{\alpha^H} + \left( 3 r^H \alpha^HH + 12 \alpha^M \right) \right] \cdot S^H + \left[ \left( 9 r^H \alpha^H + 12 \alpha^M \right) \right] \cdot S^H + \left[ \frac{1}{\alpha^M} + 9 r^M \alpha^H G^H + 6 r^M \alpha^M G^T \right] \cdot S^M = 1 - 3 c^H =: b_H \]

\[ \left[ \frac{1}{\alpha^M} + 9 r^M \alpha^H G^H + 6 r^M \alpha^M G^T \right] \cdot S^M = 1 - 3 c^M =: b_M \]

\[ S^H = \frac{b_H a_{MM} - b_M a_{HM}}{a_{HH} a_{MM} - a_{HM} a_{MH}} \quad S^M = \frac{b_M a_{HH} - b_H a_{HM}}{a_{HH} a_{MM} - a_{HM} a_{MH}} \]

\[ \alpha^M = 0.92, \quad \alpha^H = 0.74, \quad c^H = 0.08, \quad c^H = 0.0, \quad \alpha^{MM} = 16.6, \quad \alpha^{HH} = 10.1, \quad \kappa^o := \Gamma \cdot \left( 1 + c_d s^2 \right) \cdot \phi = v_i \]

\[ a_{MM} = a_{HH} = a_{HH} \]

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Time-Height cross sections:

- **Stratification:**
  - Stable
  - Non stable residual layer
  - Non stable mixed layer

- **Low level jet**
- **Mixed layer**
turbulent kinetic energy (TKE) [m^2/s^2]

due to vertical shear

due to positive buoyancy

Lon = -1 1, Lat = -1 1
Further development:

- **Common version with ICON**: Revised organization, numerical schemes and security limits  
  - Almost ready in ICON

- Introduction of an optional **prognostic** treatment of scalar (co-)variances  
  - Test-version ready

- Consolidation of the separate treatment of non turbulent SGS processes  
  - Running

- Introduction of a **3D-extension**:  
  - TKE-advection  
  - Diffusion by horizontal shear eddies  
  - Running

- Introduction of the vertically resolved **roughness layer**  
  - Planned

- **Documentation**  
  - Prepared
Thank You for attention!
Current model realization:

- in **COSMO_EU and _DE:**
  - **Prognostic TKE equation**
  - Implicit consideration of **SGS condensation** by use of **statistical saturation adjustment scheme**
    - In the **operational** configuration, a **different SGS condensation** diagnosis is used for **radiation!**
  - **Additional** (crude representations of) **shear production** due to sub grid scale
    - **horizontal shear modes,**
    - **topographic wakes,**
    - **surface induced density flows** (to be revised)
    - **convection** (only in test version)

  being together **always a positive source,** even in **very stable situations**
  without mean vertical wind shear!

  - **More processes** can be described compared to the diagnostic scheme.
  - **No Critical Richardson number** (**realisable** scheme even for **very stable stratification**)
  - In principal we can do it **without a minimal diffusion coefficient.**
  - Development of **inversions** and turbulence **near the jet stream** or **convective cells** can be described **more physically.**

  - **TKE-advection** and the (**vertically resolved**) **roughness layer** are **not yet implemented!**
Separated semi parameterized TKE equation (neglecting laminar shear and transport):

\[ \frac{1}{2} \left( \frac{1}{\rho} \cdot \partial_t q^2 \right) = \nabla \cdot \left( \frac{\rho q^2 \hat{\mathbf{v}}}{\nabla} + \hat{\rho}_k q_k^2 \hat{\mathbf{v}} \right) + \sum_{i=1}^{3} \left( \partial_i \left( \rho v_i \hat{\mathbf{v}} \right) \right) \]

\[ \partial_t \left( \frac{1}{2} \rho \cdot q^2 \right) = \frac{1}{2} \nabla \cdot \left( \rho \cdot q^2 \hat{\mathbf{v}} \right) + \sum_{i=1}^{3} \left( \partial_i \left( \rho v_i \hat{\mathbf{v}} \right) \right) \]

with respect to the separation scale \( L \)

\( \Gamma \): correction factor in case of sloped model layers

\[ \partial_t \left( \frac{1}{2} \rho \cdot q^2 \right) = \frac{1}{2} \nabla \cdot \left( \rho \cdot q^2 \hat{\mathbf{v}} \right) + \sum_{i=1}^{3} \left( \partial_i \left( \rho v_i \hat{\mathbf{v}} \right) \right) \]

transport (advection + circ. diffusion + turb. diffusion)

time tendency

\[ q^2 := \frac{\hat{\rho}_k q_k^2}{\hat{\rho}} \]

buoyant part of \(- \mathbf{v} \cdot \nabla \rho \)

expressed by turbulent flux gradient solution

buoyant and wake part of \(- \hat{\mathbf{v}}_L \cdot \left( \nabla \hat{\rho} \right) \)

to be parameterized by a non turbulent approach

mean (horizontal) shear production of circulations,

\[ \mu \sum_{i=1}^{3} \left| \nabla v_i \right|^2 \]

according Kolmogorov

shear production by sub grid scale circulations

\[ \partial_t \left( \frac{1}{2} \rho \cdot q^2 \right) = \frac{1}{2} \nabla \cdot \left( \rho \cdot q^2 \hat{\mathbf{v}} \right) + \sum_{i=1}^{3} \left( \partial_i \left( \rho v_i \hat{\mathbf{v}} \right) \right) \]

eddy-dissipation rate (EDR)

labil: \( > 0 \)
neutral: \( = 0 \)
stabil: \( < 0 \)

WakeNet workshop
Matthias Raschendorfer
Oberpfaffenhofen: 10-11.05.2010
Effect of the density flow driven circulation term for stabile stratification:

\[ D_t (\overline{\rho \text{TKE}}) \approx -\overline{\rho w''} \cdot \partial_z \hat{u} + \frac{g}{\theta_v} \overline{\rho \theta_v w''} - \varepsilon \]

- Even for vanishing mean wind and negative turbulent buoyancy there remains a positive definite source term
- TKE will not vanish
- Solution even for strong stability

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pow_1/3 (eddy dissipation rate (EDR) [m^2/s^3])

out_usa_8135 (Lat -2.0025)

- Reference

out_usa_8136 (Lat -2.0025)

- Including horizontal shear – and SSO-production

out_usa_8137 (Lat -2.0025)

- Including horizontal shear –, SSO- and convective production

out_usa_8135

- Pot. temperature [K]

st_time=00z01may2010 pr_hour=18hr – 19hr

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INPUT-parameters for the turbulence scheme:

**itype_turb:** type of turbulence parameterisation

1: **former calculation of the turbulent diffusion coefficients** in the atmosphere using subroutine “parura”

3: **new turbulence scheme** with prognostic TKE equation, using subroutine “turbdiff”

5_8: different versions of a more simple Prandtl/Kolmogorov-approach introduced for comparison

**imode_turb:** modus for calculation of vertical turbulent flux divergences

0: **implicit** treatment of the dry part of **vertical diffusion** like before, using a **concentration condition** at the lower boundary

1: like 0, but with a **flux condition** at the lower boundary

2: **explicit** treatment of vertical diffusion

3: **alternative implicit** treatment of vertical **diffusion based on the fluxes in conservative variables** (going to be changed in order to get rid of explicit SGS condensation corrections)

**itype_sher:** type of wind shear calculation in TKE equation

1: only **turbulent vertical shear** forcing of **horizontal wind**

2: turbulent **isotropic 3D-shear** forcing of wind

3: **non isotropic 3D-shear** forcing by considering a **separated horizontal shear mode**
icldm_turb: treatment of clouds with respect to turbulence
-1: ignoring cloud water completely (pure dry scheme)
0: no clouds considered (all cloud water is evaporated)
1: only grid scale condensation possible
2: sub grid scale condensation by one of the two versions of subroutine “coud_diag”

itype_wclld: type of new cloud diagnostics in subroutine “coud_diag”
1: diagnosis of water clouds, using subroutine “cloud_diag“ with that version based on relative humidity (similar to the procedure of the radiation scheme but without special tuning)
2: diagnosis of water clouds, using the statistical cloud scheme in subroutine “cloud_diag “.

icldm_rad: treatment of clouds with respect to radiation
0: radiation does not “see” any clouds
1: radiation “sees” only grid scale clouds
2: radiation “sees” clouds, being diagnosed by one of the two versions of subroutine “coud_diag”
3: radiation “sees” clouds, being diagnosed with the former scheme but with a correction concerning the convective cloud cover
4: radiation “sees” clouds, being diagnosed exactly with the former scheme
**lexpcor:** switches on the above mentioned **explicit correction**

---

**ltmpcor:** switches on the calculation of temperature tendencies related to **conversions of inner energy to TKE**, (should be FALSE, because the effect is **very small**)

**lnonloc:** switches on the **non local option** (is **not tested yet** and should be FALSE)

**lcpfluc:** switches on the effect of **fluctuating humidity on the heat capacity** of air in the calculation of the sensible heat flux (should be FALSE, because the effect is **only small**)

---

**limpltkedif:** switches on the implicit calculation of TKE-Diffusion

**ltkesso:** wake production of TKE due to the influence of sub grid scale orography (SSO) active

**ltkecon:** TKE production due to kinetic energy transfer from sub grid scale convection active (only test version)
Length scale (factors) for turbulent transport:

- **tur_len** = 500.0 asymptotic maximal turbulent distance [m]
- **pat_len** = 500.0 length scale of subscale surface patterns over land [m] (scaling the circulation term)
- **c_diff** = 0.20 length scale factor for vertical TKE diffusion (c_diff=0 means no diffusion of TKE)
- **a_hshr** = 0.2 length scale factor for separated horizontal shear mode

Dimensionless parameters used in the sub grid scale condensation scheme (statistical cloud scheme):

- **clc_diag** = 0.5 cloud cover at saturation
- **q_crit** = 4.0 critical value for normalized over-saturation (original setting q_crit=0.16)
- **c_scld** = 1.00 factor for liquid water flux density in sub grid scale clouds

Minimal diffusion coefficients in [m^2/s]:

- **tkhmin** = $1.0 \times 0.4$ for scalar (heat) transport
- **tkmmin** = $1.0 \times 0.4$ for momentum transport

Numerical parameters:

- **epsi** = 1.0E-6 relative limit of accuracy for comparison of numbers
- **tkesmot** = 0.15 time smoothing factor for TKE and diffusion coefficients
- **wichfakt** = 0.15 vertical smoothing factor for explicit diffusion tendencies
- **securi** = 0.85 security factor for maximal diffusion coefficients