Regional Cooperation for Limited Area Modeling in Central Europe

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Issues with computations in TOMs

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Outline

- **Very short "Derivation"of TOMs solver equation,**
- **Issues in `ACDIFV3` routine,**
- **Work already done,**
- **`ZZZ` bug,**
- **Work to be done.**

Solver equation basics

- Parameterization of subgrid vertical transport of prognostic variables by turbulence
- Contribution to tendency:

$$\frac{\partial X}{\partial t} = -\frac{\partial \overline{w'X'}}{\partial z},$$

- $\overline{w'X'}$ is the turbulent flux of X.
- Fluxes computed for u, v, s_{sL} (moist static energy), q_t (total specific water content)
- First order (local) parameterization (K-theory) - assume that flux is proportional to the local gradient:

$$\overline{w's'_{sL}} = K_{s_{sL}} \frac{\partial \overline{s_{sL}}}{\partial z}$$

- Next, compute the s_{sL} flux from it's tendency via a diffusion equation:

$$\frac{\partial s_{sL}}{\partial t} = \frac{\partial \left(K_{s_{sL}} \frac{\partial \overline{s_{sL}}}{\partial z} \right)}{\partial z}$$

TOMs solver equation

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- As in K-theory, only assume that flux is proportional also to third order moments - account for nonlocal influences. Most general form of equation:

$$\overline{w's'_{sL}} + A_t \frac{\partial \overline{w's'_{sL}}}{\partial t} = -K''_H \frac{\partial s_{sL}}{\partial z} + A_1^{s_{sL}} \frac{\partial \overline{w'^3}}{\partial z} + A_2^{s_{sL}} \frac{\partial \overline{w's'^2_{sL}}}{\partial z} + A_3 \frac{\partial \overline{w'^2 s'_{sL}}}{\partial z}$$

- Closure relations - express the third order moments with second order moments, following the method of *Canuto et al., 2007*:

$$\begin{aligned}
\overline{w's'^2_{sL}} &= -\tau_k \overline{w's'_{sL}} \frac{\partial \overline{w's'_{sL}}}{\partial z}, \\
\overline{w'^2 s'_{sL}} &= -\frac{3}{10} \tau_k \overline{w'^2} \frac{\partial \overline{w's'_{sL}}}{\partial z}, \\
\overline{w'^3} &= -\frac{6}{100} \tau_k^2 \overline{w'^2} \left(E_{s_{sL}} \frac{\partial \overline{w's'_{sL}}}{\partial z} + E_{q_t, s_{sL}} \frac{\partial \overline{w'q'_t}}{\partial z} \right),
\end{aligned}$$

- Expressions for $A_1^{s_{sL}}$, $A_2^{s_{sL}}$, A_3, A_t deduced by writing the full prognostic equations for $\overline{w's'_{sL}}$, $\overline{w'q'_t}$, $\overline{s'^2_{sL}}$, $\overline{q'^2_t}$, $\overline{w'^2}$ with closure relations and comparing.

TOMs solver equation - next steps

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- Time discretization,
- Use of hydrostatic equation and tendency,
- Some clever tricks using the local first order solution,
- Some approximations,
- Iteration of the deduced implicit equation.

TOMs solver equation - final

- **Final form of the equation in terms of the TOMs correction δs^{+}_{sL}:**

$$
\begin{aligned}
\frac{\delta s^{+[i+1]}_{sL}}{\delta t} = \frac{\partial}{\partial p}\Bigg(& \left(\left(-g\rho K''_H - g\rho K''_H \frac{T''_H T^{s_{sL}}_{**}}{\delta t} \right) \frac{\partial \left(\delta s^{+[i+1]}_{sL} \right)}{\partial z} + \rho K''_H T''_H (\{T_*^{-1}\}^{s_{sL}} \widehat{\frac{\delta s^{+[i+1]}_{sL}}{\delta t}}) \right. \\
& - g\rho K''_H \frac{T''_H T^{s_{sL}}_{**}}{\delta t} \frac{\partial \left(s^{loc}_{sL} - s^{-}_{sL} \right)}{\partial z} + \rho K''_H T''_H (\{T_*^{-1}\}^{s_{sL}} \widehat{\frac{s^{loc}_{sL} - s^{-}_{sL}}{\delta t}}) \\
& \left. - g\rho K''_H \frac{T''_H T^{sq}_{cr}}{\delta t} \frac{\partial \left(\overbrace{K^{sq}_{cr} \widehat{e_k}} \left(q_t^{+[i]} - q_t^{-} \right) \right)}{\partial z} \right)
\end{aligned}
$$

$$
\begin{aligned}
\{T_*^{-1}\}^{s_{sL}} = & g \left(K^{(A_1)} \frac{6}{100} \overbrace{\frac{\partial s_{sL}}{\partial z} \frac{\tau_k}{\widehat{e_k}}} \frac{\partial \left(E_{s_{sL}} 2A_z \tau_k^2 \widehat{e_k} \right)}{\partial z} - K^{(A_2)} \overbrace{E_{s_{sL}} \frac{\tau_k}{\widehat{e_k}}} \frac{\partial \left(\tau_k \overline{w' s'_{sL}}^{[i]} \right)}{\partial z} - K^{(A_3)} \frac{3}{10} \frac{1}{\widehat{e_k}} \frac{\partial \left(2A_z \widehat{e_k} \tau_k \right)}{\partial z} \right), \\
T^{s_{sL}}_{**} = & - K^{(A_1)} \frac{6}{100} E_{s_{sL}} \frac{\partial s_{sL}}{\partial z} 2A_z \tau_k^3 + K^{(A_2)} E_{s_{sL}} \frac{\tau_k^2}{\widehat{e_k}} \overline{w' s'_{sL}}^{[i]} + K^{(A_3)} \frac{3}{10} 2A_z \tau_k, \\
T^{sq}_{cr} = & - K^{(A_1)} \frac{6}{100} \frac{\partial s_{sL}}{\partial z} \frac{\tau_k}{\widehat{e_k}}, \\
K^{sq}_{cr} = & E_{q_t, s_{sL}} \tau_k^2 2A_z.
\end{aligned}
$$

Issues in ACDIFV3

- ACDIFV3 is the TOUCANS subroutine where TOMs contributions to fluxes are calculated.
- It contains all variable definitions:
  ZT_INSOQ_2A1,ZT_INSOS_2CR,ZCROSSQ,ZTSTAR,ZTSTAR2,ZKTROV, ZTSTAR,ZTSTAR2,ZKTROV,ZKTROV2,ZXSTAM,ZXSTAP,ZDIFTS2,ZDIFSO, ZDIFSI,ZDIFQI,ZN1,ZDIFTSTOM,ZCORS,ZSCG0,ZMUL,ZSUB1,ZELIM and many more.
- Also contains solver algorithm.
- Known issues (found by Ivan):
  - ZPT_INSO_3II should be divided by PF_EPS,
  - One multiplication by ZTKE_CEPS2 from the calculation of variable ZT_INSS2 should be deleted,
  - One multiplication by RG from the calculation of variables ZT_INSS and ZT_INSSQ should be deleted,
  - The ZZZ variable probably should not be divided by TSPHY($\triangle t$). Not 100% sure, because if this bug is corrected, the solver becomes numerically unstable.

Work already done

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- Derivation of the solver equation redone to find possible mistakes,
- Code restructured, to check the code flow,
- All variables checked and compared with the equations,
- First three bugs mentioned by Ivan confirmed and corrected,
- A new bug found, the variable `ZKTROV2Q` not initialized at the top level,
- Two variables which should be initialized before the solver loop, were initialized inside the loop,
- Two lines of code from debugging were left.

All these bugs corrected with no solver stability issues.

ZZZ bug

- ZZZ - an auxiliary variable in the ACDIFV3 routine, present throughout the routine.
- In the code, it is divided by the model time step.
- Derivation of slides 1 to 4 and of solver algorithm had to be done also with the spatially discretized variables in the code so we could compare it to equations to see if this is really a bug, which it is.
- If it is corrected, the solver becomes numerically unstable.
- Reason - the division by $\triangle t$ in the code effectively lowers the TOMs contributions by a factor of 180 (the time step in seconds), which ofcourse makes the solver stable, but makes the TOMs contributions wrong.

Work to be done

- All code is bug free, but the solver is numerically unstable, because of the correction of the ZZZ bug.
- Strongly suspect the "protection from non-linear instability"part of the code, written by Jean-Francois, since it contains the ZZZ variable. and is the only part of the code that we were not yet able to fully understand.
- The algorithm is similar to the protections employed in the mass-flux scheme, giving us a clue.
- The topic of my next stay in Prague right after working days.