RC-LACE stay report

Adjusting the TOUCANS code to distinguish between vertical levels used by the turbulence scheme and the model dynamics

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1 Introduction and motivation

This report summarizes the work carried out during research stays in 2024 and 2025, accounted for under "Physics" and "Dynamics & Coupling" areas of RC LACE. The primary objective was to enable a safe decrease of the lowest model level. To achieve this, the TOUCANS code was adjusted to enable decoupling the forcing level for surface turbulent fluxes from the lowest model level. The same forcing level is also used for screen-level interpolation and thus generally located above 10-m. Consequently, turbulence calculations in the ALARO CMC, i.e., TOUCANS scheme, are performed on a smaller number of vertical levels (1:KLEVTUR) than in the model dynamics (1:KLEV). Finally, between half levels $\widetilde{KLEV}$ and $\widetilde{KLEVTUR}$, the assumption of constant turbulent fluxes is employed, enabling the application of Monin-Obukhov similarity theory. The report is organized as follows. An overview of necessary TOUCANS code modifications is given in Section 2. The preliminary tests with the modified code are presented in Section 3. Finally, a conclusion and plan for further work are given in Section 4.

2 The related modifications of the TOUCANS code

The changes described below were implemented in **CY46T1mp_op3**, used operationally at CHMI. To enable using only KLEVTUR number of levels in TOUCANS subroutines below **aplpar.F90**, the following two arrays are created: ZAPHISUR (geopotential thickness of the lowest layer in the model dynamics) and ZAPRSSUR (pressure thickness of the lowest layer in the model dynamics). For the same reason, vertically uniform correction (PBUDTH) of thermal radiation flux (PFRTH) due to surface temperature update is extracted from **arp_ground_param.F90** to **aplpar.F90**. Furthermore, the call to **acptke.F90** subroutine was modified to use the local 3D array ZFTCNS instead of PFTCNS (passed outside the **aplpar.F90**), avoiding issues with non-contiguous arrays caused by partial slicing of PFTCNS's middle dimension. Finally, the Turbulence Kinetic Energy (TKE) tendency, which was originally uninitialized, caused dimensional inconsistencies when passed to **mf_phys.F90** with KLEVTUR < KLEV. It was therefore set to a constant value below KLEVTUR, ensuring a dimensionally consistent and physically reasonable vertical profile. Code modifications encompass the following subroutines:

```
module/
    └── yomdimv.F90
├── namelist/
    └── namdim.nam.h
├── phys_dmn/
    └── aplpar.F90
        ├── actkehmt.F90
        │   └── actkecls.F90
        ├── acmixelen_updn.F90
        ├── acpblh_up.F90
        ├── acpblh_tke.F90
        ├── acclph.F90
        ├── acpbl_wind.F90
        ├── acdtheta_s1.F90
        │   └── actheta_s1.F90
        ├── acmixelen.F90
        ├── acmrip.F90
        │   └── acscctr.F90
        ├── accldia.F90
        ├── actkecoefk.F90
        ├── acptke.F90
        ├── acdifv1.F90
        ├── arp_ground_param.F90
        ├── acdifv2.F90
        └── acdifv3.F90
└── setup/
    └── sudim.F90
```

The number of vertical levels in the turbulence scheme is set by the NFLEVTUR parameter in the namelist NAMDIM (KLEVTUR locally in **aplpar.F90**; KLEVTUR=NFLEVTUR $\leq$ KLEV). We emphasize that KLEVTUR also indicates the index of the forcing level.
It was agreed that the first version of the modified code would not affect LCOEFK_TOMS branch. However, the preliminary code inspection revealed a mixing length correction at the lowest model level, applied only within **acdifv3.F90**, which requires further clarification.

3 Results

This chapter presents the preliminary results of KLEVTUR tests, elaborates on necessary concept adjustments, and demonstrates their impact. Details are given in the next two sections.

3.1 *The preliminary tests and adjustment of the concept*

Preliminary tests were performed for a 24 June 2022 mesoscale convective system case on CHMI's operational domain using 87 vertical levels. To validate the new code, a simulation was run with KLEV = KLEVTUR = 87, which should yield results identical to the original code. This identity was confirmed through spectral norm analysis, after which experiments with KLEVTUR < KLEV were conducted.

The results of the latter suggested a strong sensitivity to the placement of the forcing height, which for KLEVTUR = 86 and KLEV = 87 already appeared too high (z $\sim$ 30-m). Consequently, a new configuration with KLEV = 88 was prepared, introducing an additional level below the lowest level of the reference configuration and a minor adjustment to the two subsequent levels (see Table 1 for details). Thereby, several associated experimental setups were prepared, as shown in Table 2. They were initialized from 0^{th} coupling file, with all GFL fields set to zero.

Table 1: Height of model levels for old and new vertical levels configuration (in meters).

Level	Old configuration	New configuration
88	/	3.34
87	10.04	10.02
86	31.28	27.93
85	55.68	55.68
84	83.95	83.95

Table 2: Experimental settings of vertical levels

Experiment	KLEVTUR	KLEV
N87a	87	87
N88a	88	88
N88b	87	88
N88c	86	88

The N88c simulation crashed after $\sim$ 13 h, likely due to the combined effect of a suboptimal definition of the KLEV = 88 configuration (all associated experiments produced SMILAG messages; growing with the decrease of KLEVTUR) and the depth of the constant-flux layer. Consequently, it was excluded from further tests. Furthermore, the comparison of momentum and heat turbulent diffusion tendencies for N88a and N88b-adjust experiments revealed considerable differences near the surface (Figs. 1a-c):

- a zero value at full level KLEV for N88b, while N88a exhibits maximum for wind and a non-zero value for temperature; and
- a pronounced spike at full levels KLEVTUR and/or KLEVTUR+1 for N88b

This was accompanied by considerably stronger wind at KLEV = 88 compared to N88a, along with progressively distorted wind speed and temperature fields over time at several subsequent levels (not shown), indicating that an adjustment of the KLEVTUR concept is required.

To obtain a smooth tendency profile and a non-zero value at the full level KLEV, turbulent fluxes between half levels $\widetilde{KLEVTUR} - 1$ (the lowest level at which fluxes are diagnosed from full level gradients and based on the TKE formalism; e.g., [3, 4, 5, 6]) and $\widetilde{KLEV}$ (the surface) are linearly interpolated in height. The surface turbulent fluxes are computed using the adjusted bulk formulation, in which the forcing level is tied to the full level KLEVTUR rather than KLEV, as follows:

$$\overline{(\psi' \mathrm{w}')}_{\mathrm{s}} = \mathrm{C}_{\psi}\sqrt{[\overline{\mathrm{u}}^2(\mathrm{Z}) + \overline{\mathrm{v}}^2(\mathrm{Z})]}\left[\overline{\psi}(\mathrm{Z}) - \overline{\psi}_{\mathrm{s}}\right] \tag{1}$$

where ψ=(u, v, $\mathrm{s_L}$, $\mathrm{q_t}$) denotes zonal/meridional wind, static energy, and total specific moisture, respectively; the subscript "s" indicates surface values; Z is the forcing level height; while C_{ψ} are drag coefficients for momentum and heat/moisture (see [1] and [2]).

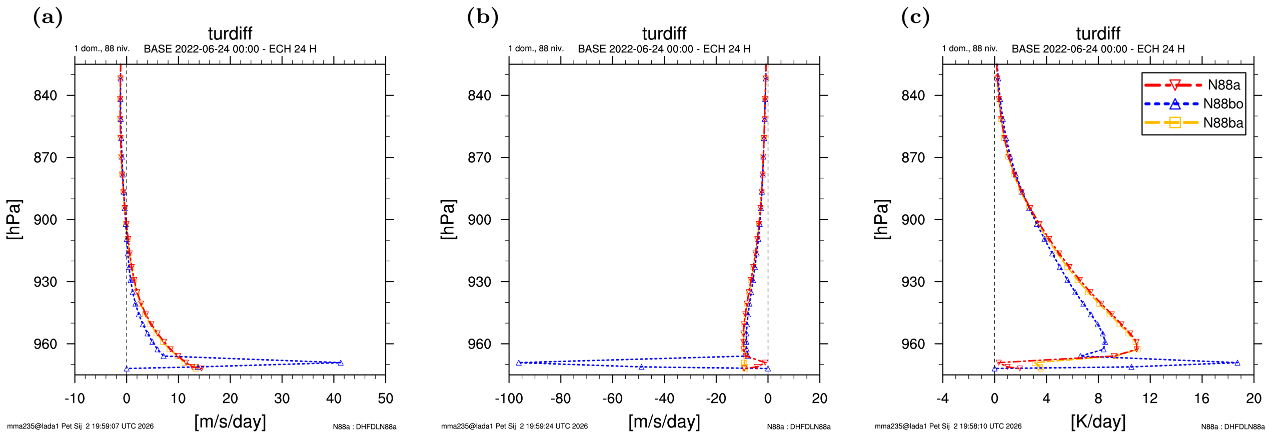

Figure 1: Domain-averaged vertical profiles of turbulent diffusion tendency after 24-h of integration for: **(a)** zonal wind, **(b)** meridional wind and **(c)** temperature; N88a, N88bo and N88ba correspond to N88a (red), original N88b (blue) and adjusted N88b settings (orange; see first paragraph of page 5 for details), respectively.

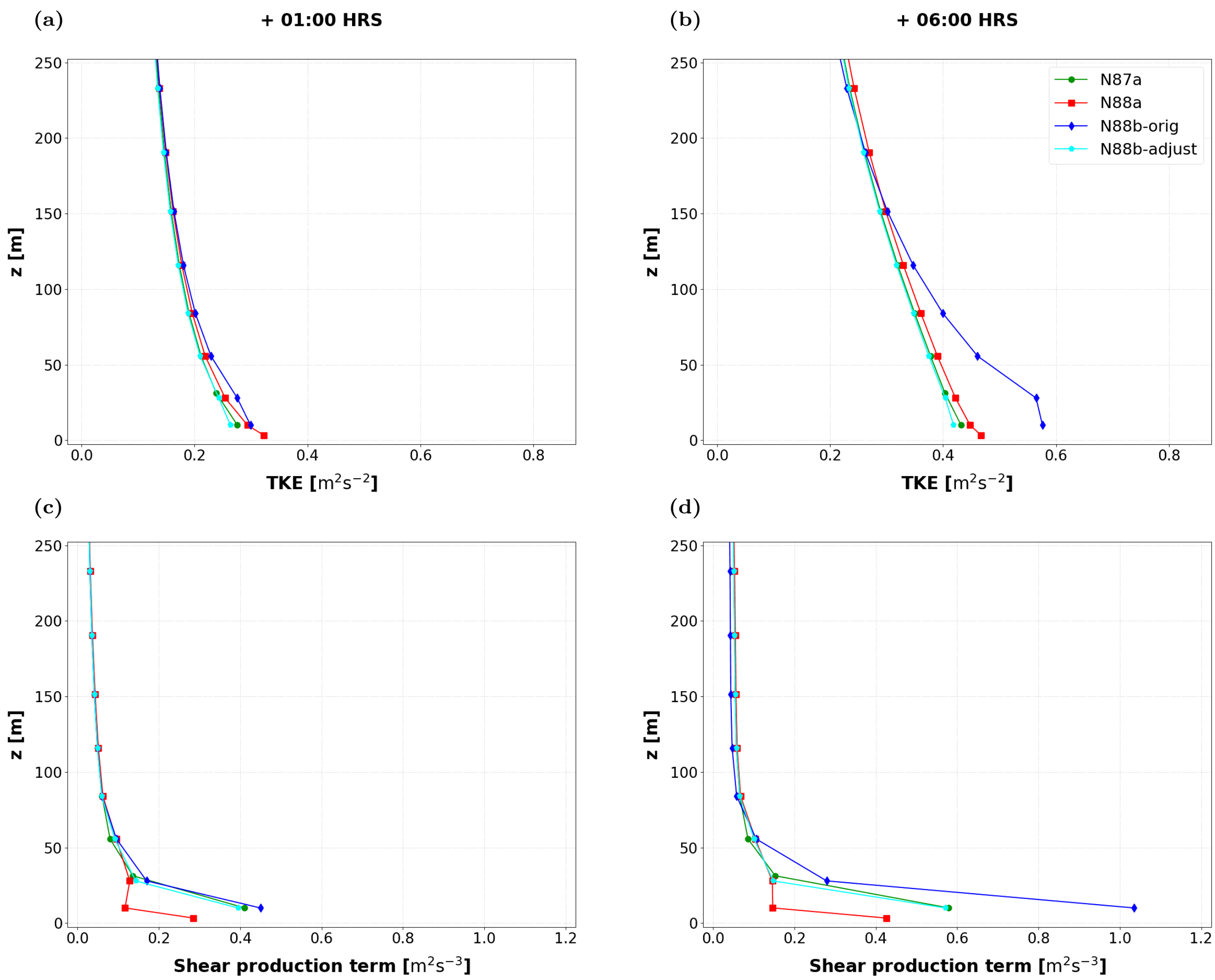

Figure 2: Domain-averaged vertical profiles of: **(a)-(b)** Turbulent Kinetic Energy (TKE) and **(c)-(d)** Shear production term, after 1-h and 6-h of integration.

3.2 *The impact of adjusted KLEVTUR concept*

Compared to the original N88b experiment (N88bo on the legend), the domain-averaged turbulent diffusion tendency profile of the adjusted one (N88ba on the legend) closely matches that of N88a and ensures a smooth near-surface transition (Fig. 1a-c). In addition, the corresponding profiles of TKE and its shear production term approach those of the N87a experiment, i.e., the one with a comparable forcing height. In contrast, N88b-orig considerably deviates for both quantities (Fig. 2a-d), particularly near the surface. A similar behavior is also observed for turbulent heat and moisture fluxes (Fig. 3a-d).

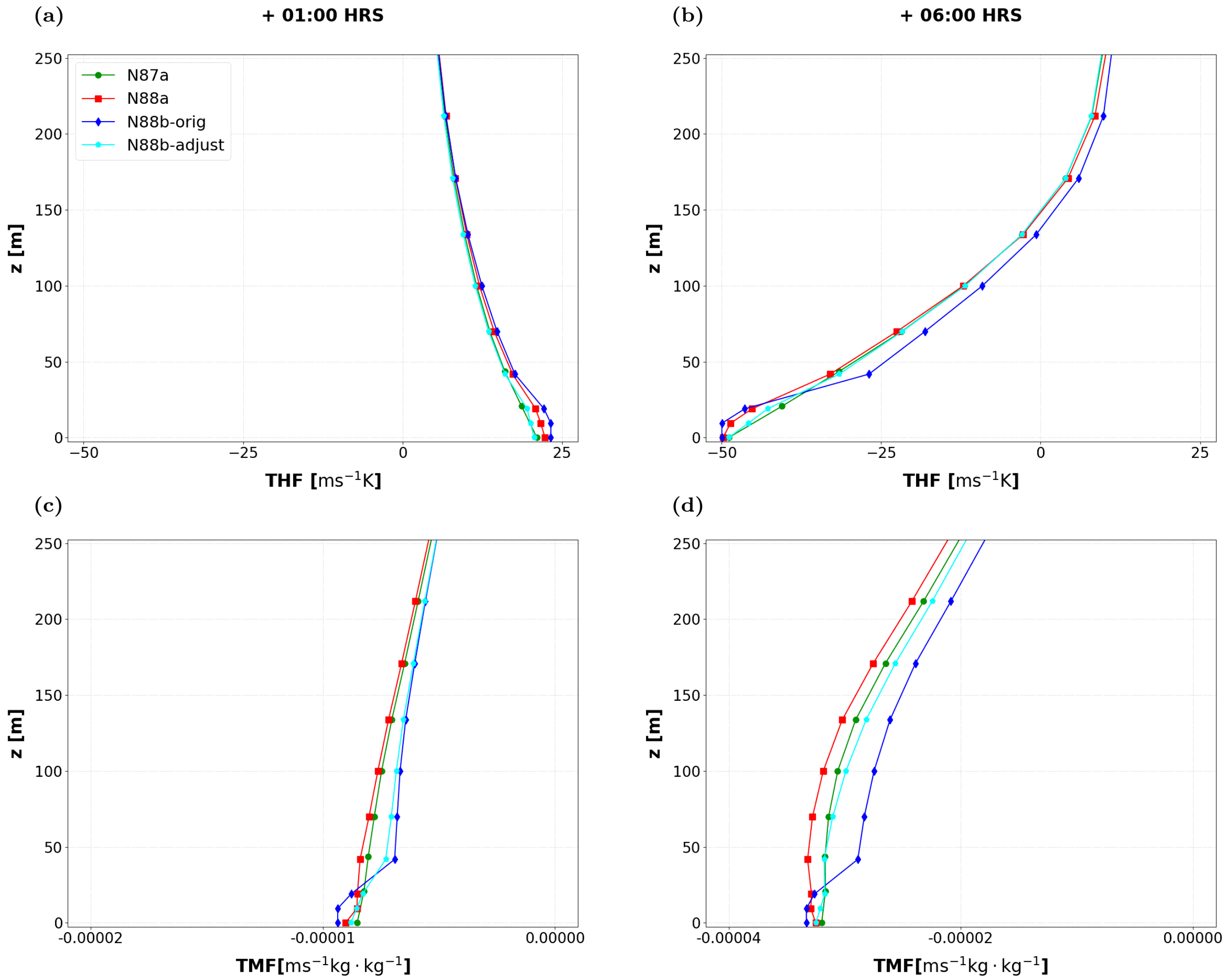

Figure 3: Domain-averaged vertical profiles of: **(a)-(b)** Turbulent Heat Flux (THF) and **(c)-(d)** Turbulent Moisture Flux (TMF), after 1-h and 6-h of integration.

The differences in turbulence quantities are also reflected in mean fields. A systematic difference in the temperature at level 87 (z $\sim$ 10-m) emerges between the N88a and N87a experiments,

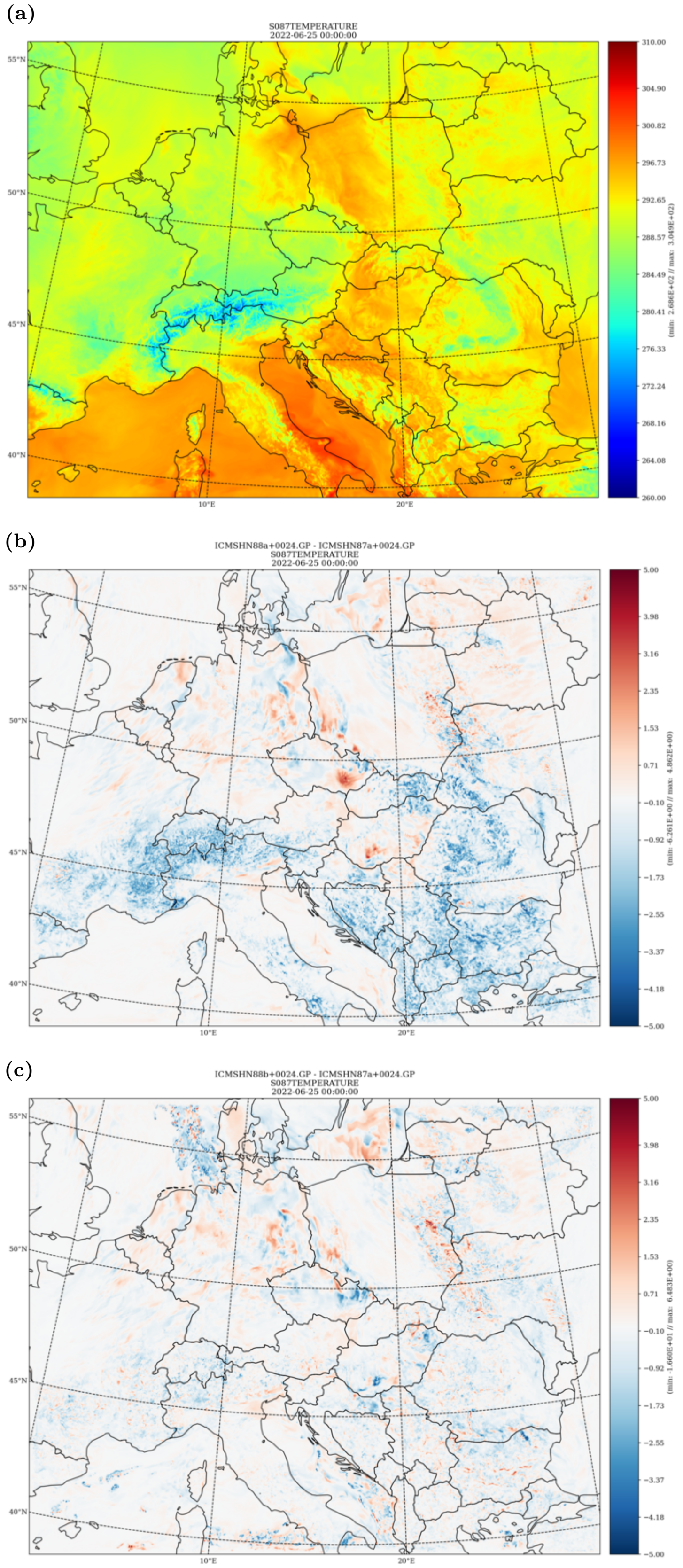

Figure 4: (a) Temperature at model level 87 after 24-h of integration for the reference configuration (N87a); **(b)-(c)** relative differences of N88a and N88b-adjust experiments with respect to N87a.

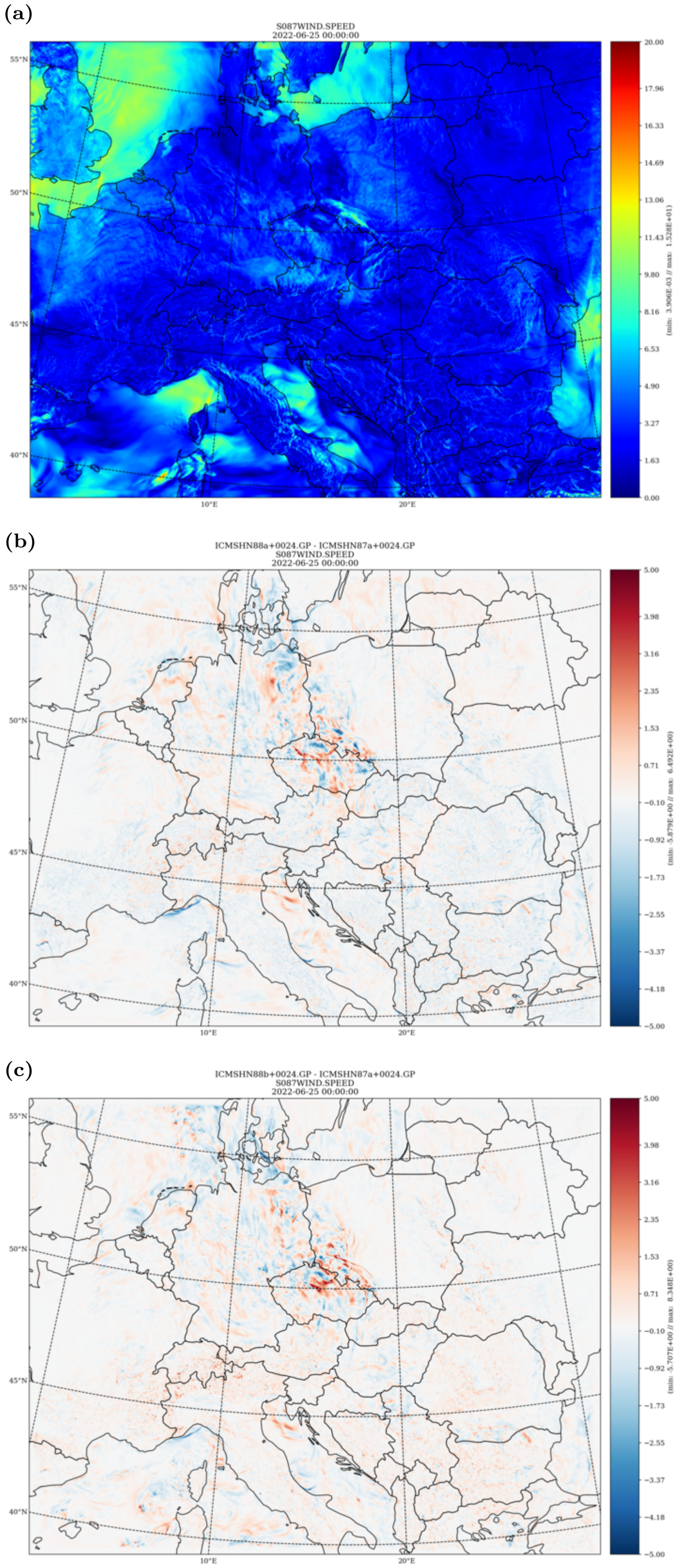

Figure 5: **(a)** Wind speed at model level 87 after 24-h of integration for the reference configuration (N87a); **(b)**-**(c)** relative differences of N88a and N88b-adjust experiments with respect to N87a.

particularly over mountainous regions (Fig. 4a-c). In contrast, differences between N88b-adjust and N87a are smaller and spatially more random. The screen-level and surface patterns are similar but of opposite sign (not shown). Finally, wind speed differences for both N88a and N88b-adjust with respect to N87a are comparable in magnitude (Fig. 5a-c), which requires further investigation.

4 Conclusions and future work

During mentioned research stays, the TOUCANS code was successfully modified to allow using a different number of vertical levels in the model dynamics and the turbulence scheme. This enables a safe decrease of the lowest model level in the former, while ensuring that the forcing level in the latter remains above the screen-levels for wind and temperature/humidity.

Preliminary tests with the new code and KLEVTUR = KLEV produced results identical to those of the old code. However, experiments with KLEVTUR < KLEV suggested that the initial concept, assuming a constant-flux layer extending from half level $\widetilde{KLEVTUR}$ to the surface, requires revision. In the revised formulation, the constant-flux assumption is applied only at the half level $\widetilde{KLEV}$, for which turbulent fluxes are computed using mean fields from full level KLEVTUR and the surface. In addition, linear interpolation is applied in layers between half levels $\widetilde{KLEV} - 1$ and $\widetilde{KLEVTUR}$. This adjustment ensures a smooth near-surface tendency profile and its non-zero values at full level KLEV. Moreover, the results closely match the reference experiment (KLEVTUR = KLEV = 87; N87a), which differs only in lacking the additional level in the model dynamics and the remaining part of physics.

The adjusted formulation yields fluxes and mean fields that are also very close to N87a, whereas the configuration with an additional level in both the turbulence scheme and the model dynamics (N88a) exhibits systematic differences in mountainous regions, particularly for the temperature. Further efforts will focus on higher vertical resolution configuration, particularly within the planetary boundary layer, thereby also improving the smoothness of associated η-coordinate coefficients compared to N88a and N88b, as well as on idealized single-column simulations. The work will continue at the Croatian Meteorological and Hydrological Service, and during research stays planned for the next year.

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