Shallow convection scheme and its deficits

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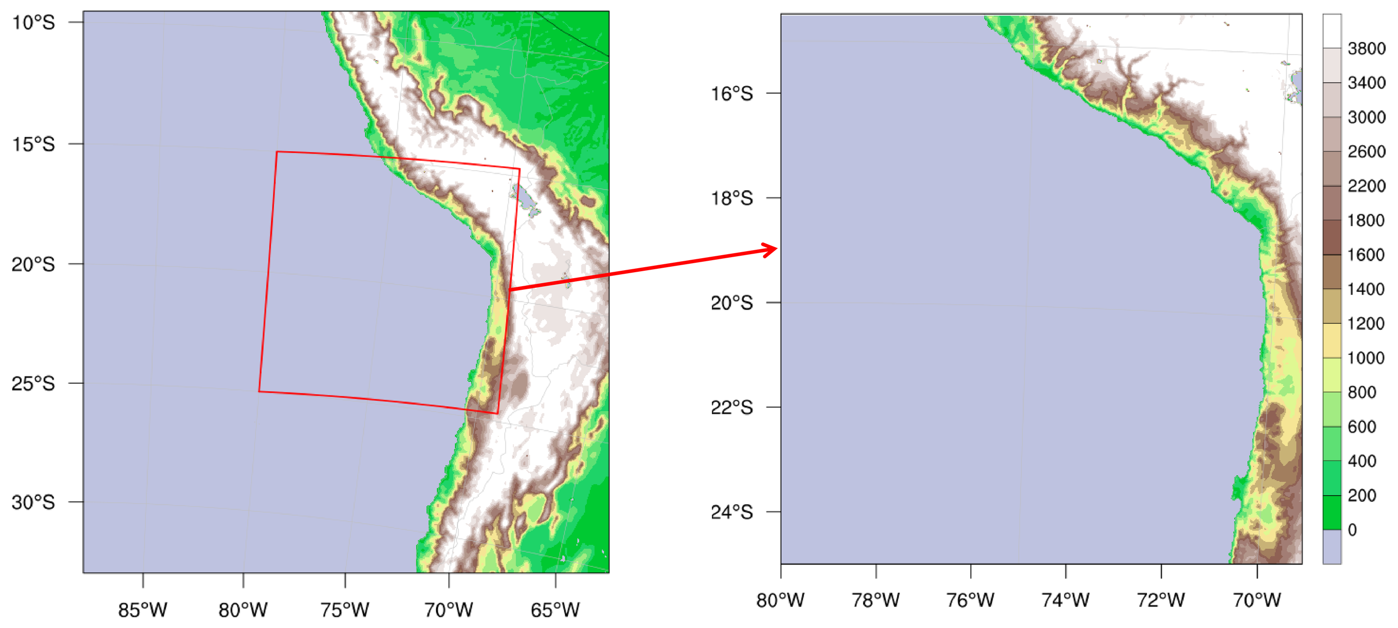
Description

The simulation of shallow clouds like stratocumulus clouds in the south east pacific is a challenge for either global as for regional models. In this case aerosol cloud interaction and effects of a changing aerosol load on stratocumulus clouds is investigated with COSMO-ART (Vogel et. al, 2009). The region in the south east pacific is known to be characterized by a persistent layer of stratocumulus clouds and their existence is a result of a complex chain of interactions between several processes. Due to the complexity of the system and that processes take place on very small scales atmospheric models encounter difficulties in capturing this cloud layer in a realistic way.



7km domain   Nested 2.8km domain

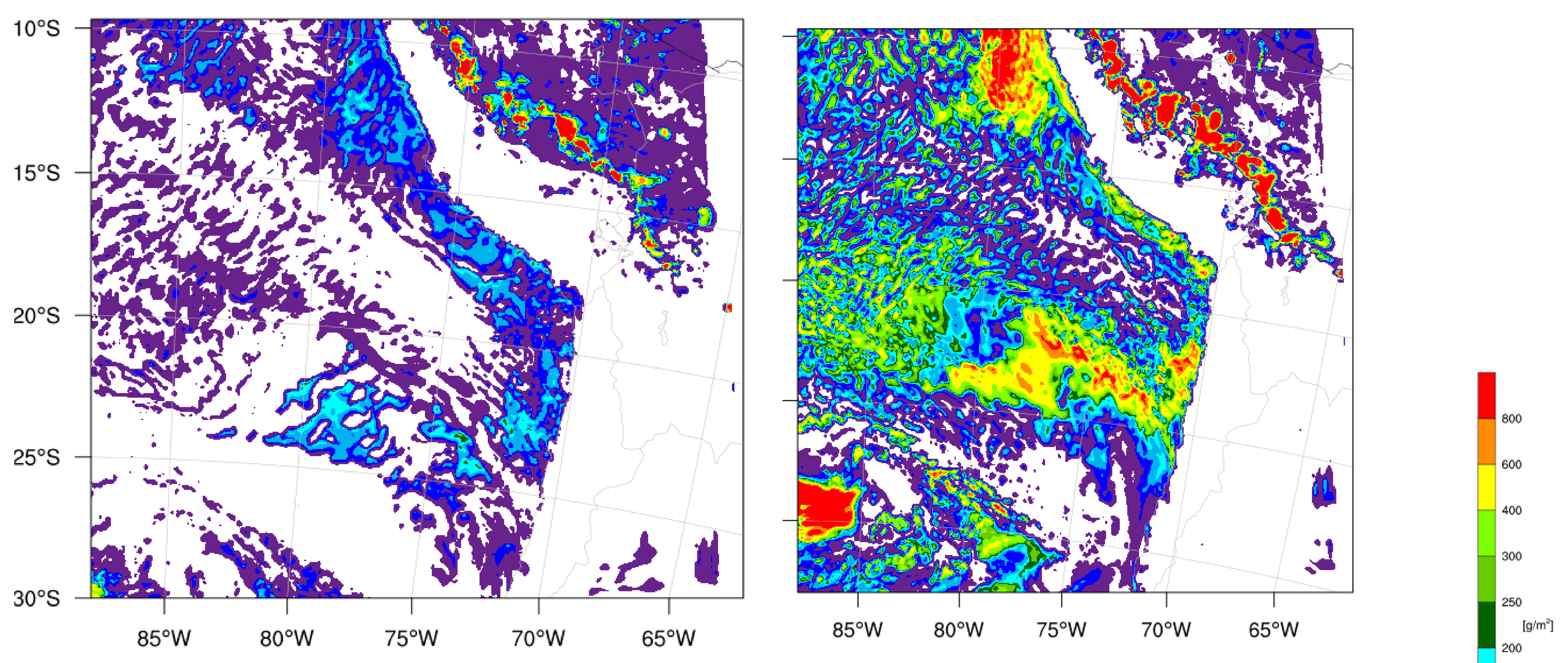
Simulations with a grid spacing of 7km and 2.8km revealed sensitivities and deficits of the parameterization of shallow convection within COSMO.

Sensitivities by changing parameter of the convection scheme

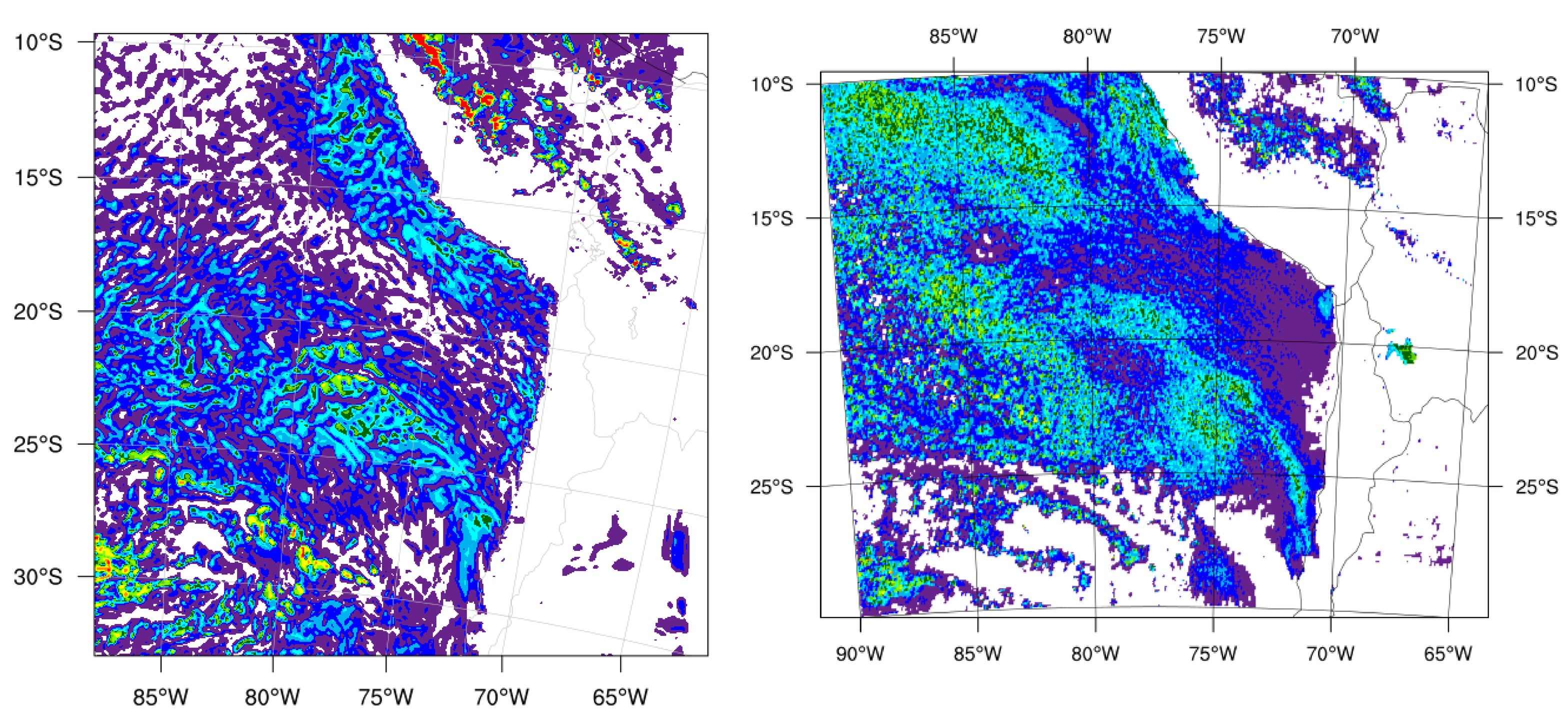
We found a major sensitivity on cloud evolution due to the parameterization of the dynamic detrainment of updraft mass flux M_u:

$$D_u^D = \begin{cases} \dfrac{(1-b_u)M_{u_{k+\frac{1}{2}}}}{\Delta z_k} & if\ k = k_T, \\ b_u M_{u_{k+\frac{1}{2}}} & if\ k = k_T - 1, \\ 0.0 & else. \end{cases}$$

- b_u is the fraction of M_u which is allowed to penetrate into the stable layer above ($k_T - 1$) and to detrain there.
- Parameter is tunable and tests showed sensitivities of the Liquid Water Path (LWP) by changes of b_u.



7km domain: LWP with b_u= 0.33   7km domain: LWP with b_u= 0.15



7km domain: LWP with b_u= 0.23   7km domain: LWP from satellite observation

- Changed b_u=0.23 to better fit with observations → agreement with Zhang et. al 2011
- Changed fractional entrainment and detrainment rates to ε = δ = 0.0025 m^{-1} according to large-eddy-simulations of Siebesma and Holtslag (1996)

Siebesma, A. P., and A. A. M. Holtslag. "Model impacts of entrainment and detrainment rates in shallow cumulus convection." *Journal of the atmospheric sciences* 53.16 (1996): 2354-2364.

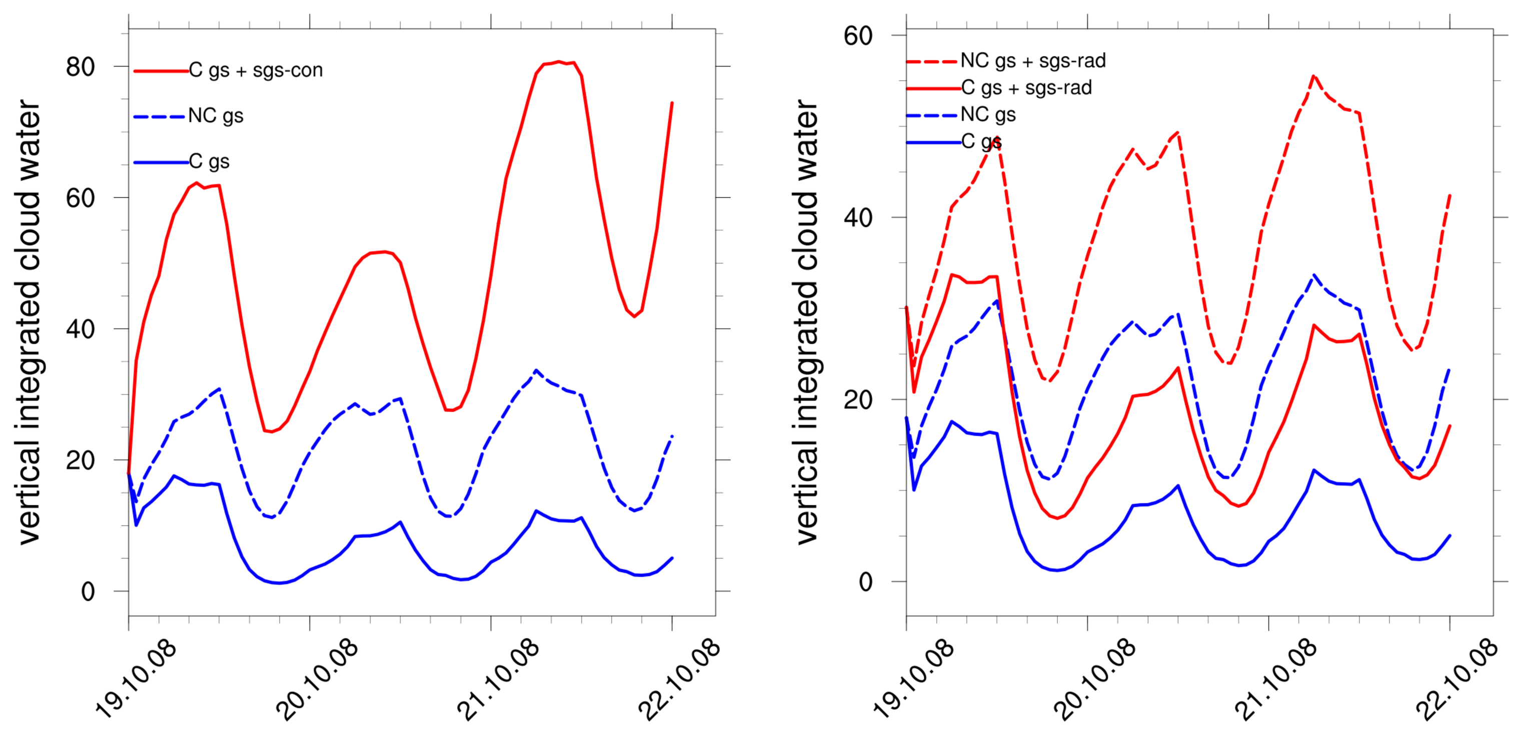
Vogel, B., et al. "The comprehensive model system COSMO-ART–Radiative impact of aerosol on the state of the atmosphere on the regional scale." *Atmospheric Chemistry and Physics* 9.22 (2009): 8661-8680.

Zhang, Chunxi, Yuqing Wang, and Kevin Hamilton. "Improved representation of boundary layer clouds over the Southeast Pacific in ARW-WRF using a modified Tiedtke cumulus parameterization scheme*." *Monthly Weather Review* 139.11 (2011): 3489-3513.

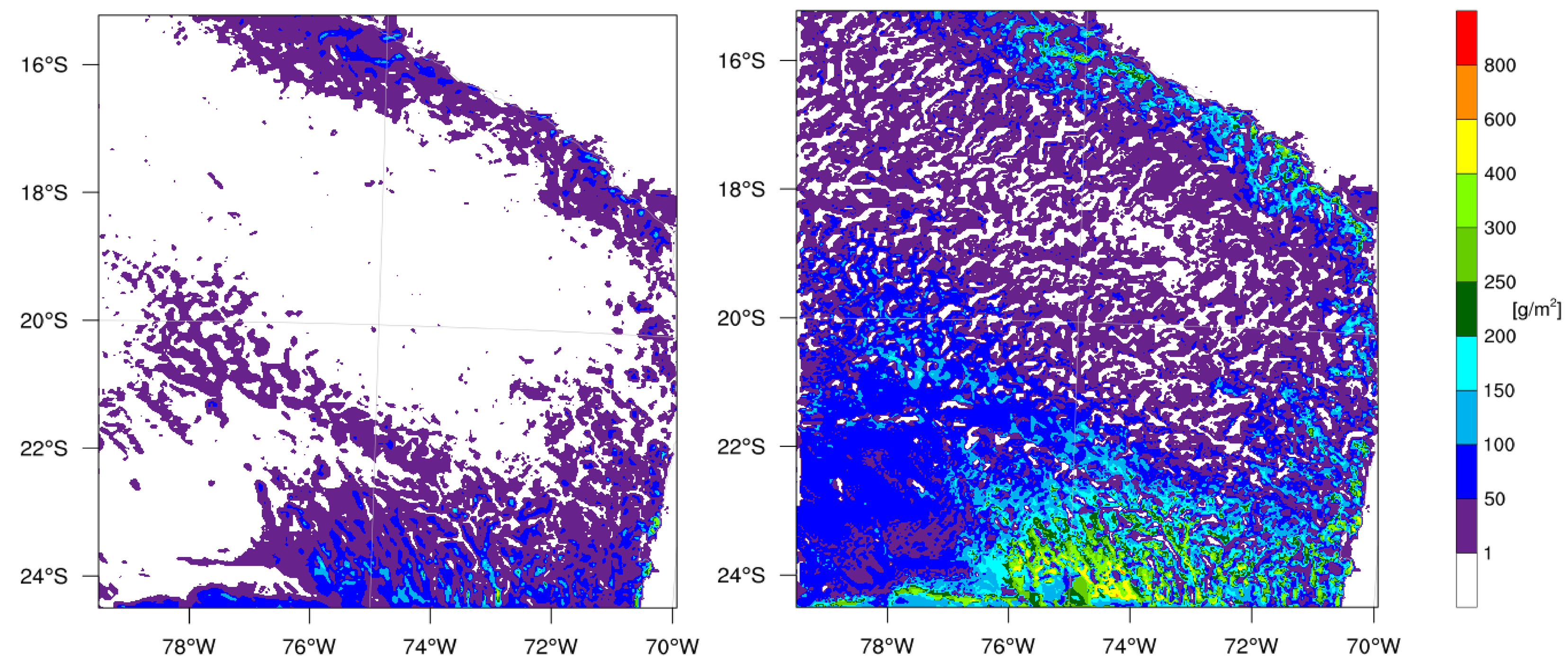
Simulations with and without shallow convection scheme

Nested domain (2.8km):

- higher resolution should lead to better resolved grid scale structures and less need for parameterization but convection parameterization still very active → major fraction of LWP produced by the convection parameterization which is not aware of aerosol characteristics
- grid scale LWP of simulation without shallow convection parameterization (NC) is higher compared to simulation with parameterization (C)
- sum of both grid scale (gs) and subgrid scale (sgs) LWP due to convection is higher in simulation C as gridscale LWP in NC → "no convective drizzle"
- radiation relevant LWP (sgs-rad + gs) is a factor 2 higher in the simulation NC than in simulation C → convection parameterization has no impact on cloud droplet sizes → impact on radiation



2.8km domain: timeseries of spatial averaged LWP g/m² (only over water). On the left: Simulation with shallow convection parameterization (C) and switched off parameterization (NC). Displayed is gridscale LWP (gs) and sum of gridscale and convective subgrid scale LWP (sgs-con). On the right: Like left, but sum of gridscale (gs) and subgrid scale radiation relevant LWP (sgs-rad), latter is diagnosed in radiation scheme.



2.8km domain: gridscale LWP   2.8km domain: subgridscale LWP due to convection parameterization

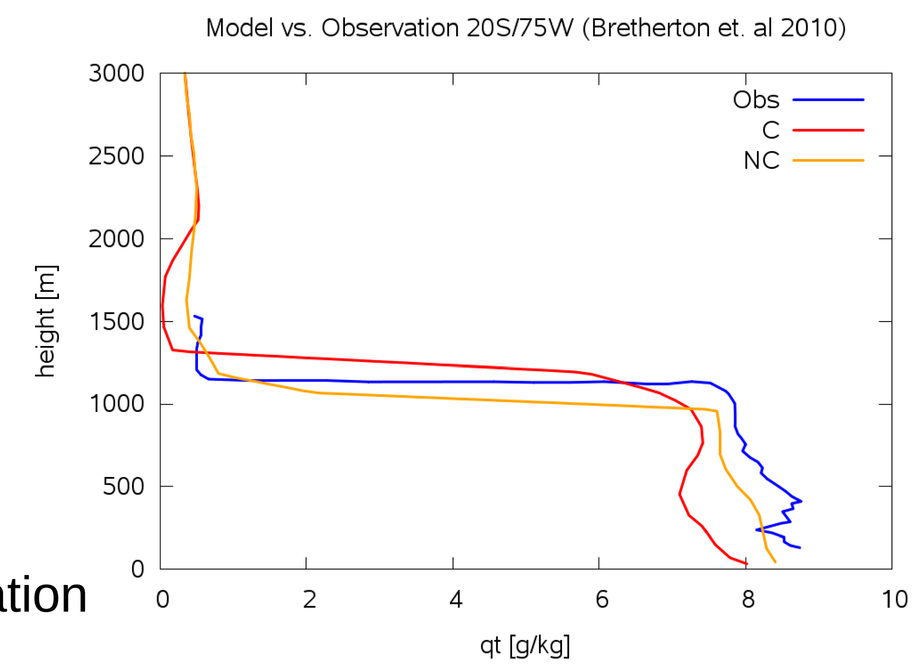
Two major drawbacks:

- lack of scale awareness → assumptions valid for coarser grid resolution
- lack of aerosol awareness → major disadvantage if aerosol cloud interactions are to be investigated

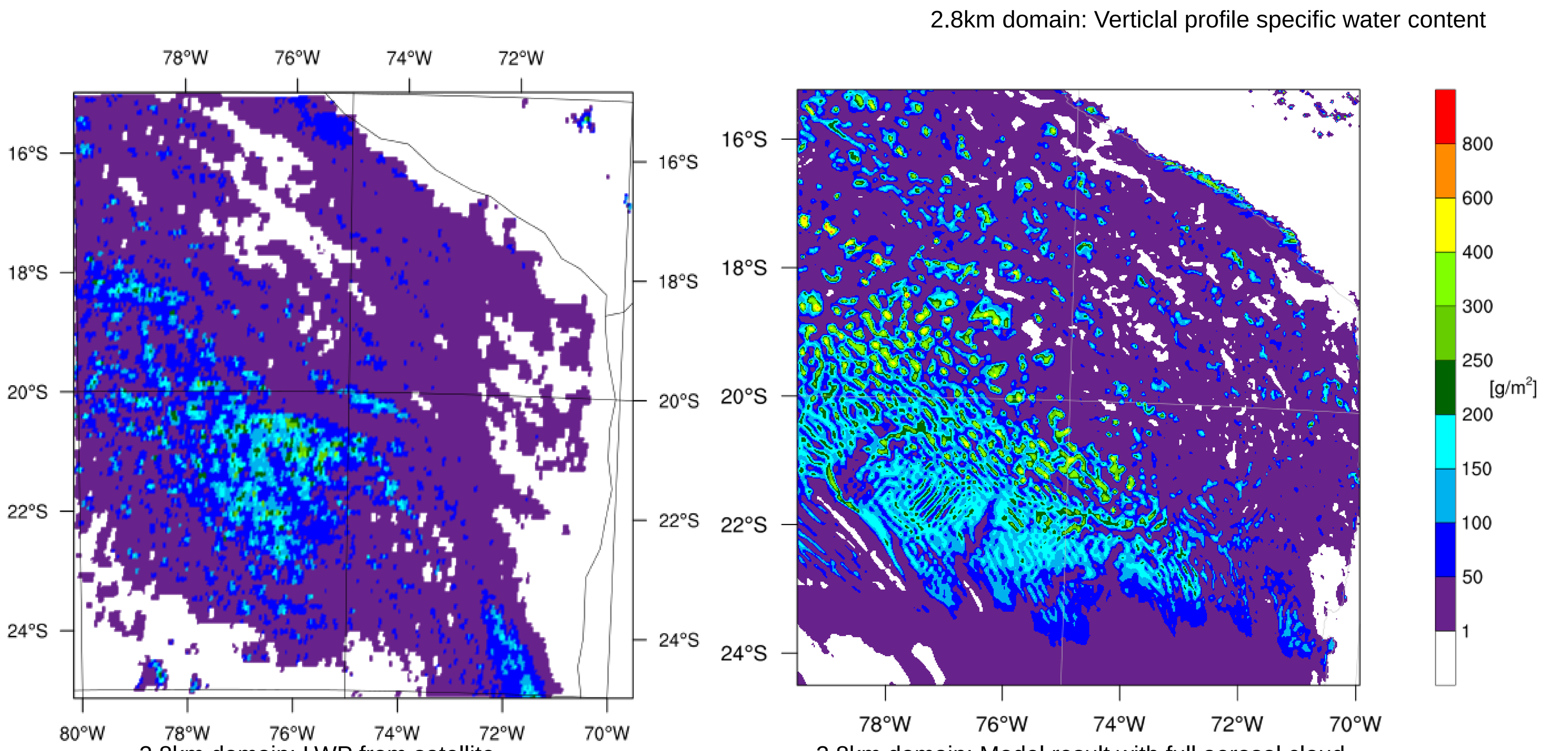
Simulation with prognostic aerosol cloud interaction

- convection scheme produced much LWP in coastal region which is not seen in observational data
- simulation with convection parameterization showed deviation of 2g/kg deviation in vertical profile of specific humidity

→ Improvement for both points by switching off convection parameterization



2.8km domain: Verticlal profile specific water content



2.8km domain: LWP from satellite observation   2.8km domain: Model result with full aerosol cloud interaction but without shallow convection parameterization

Conclusion

- Recommendation of revision of shallow convection parameterization and for its default parameters
- Including aerosol processes for subgrid scale convective processes is urgently needed!