LAND-ATMOSPHERE COUPLING
WITH ICON AND CLM5.0 IN TSMP USING OASIS3-MCT

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HPSC TerrSys

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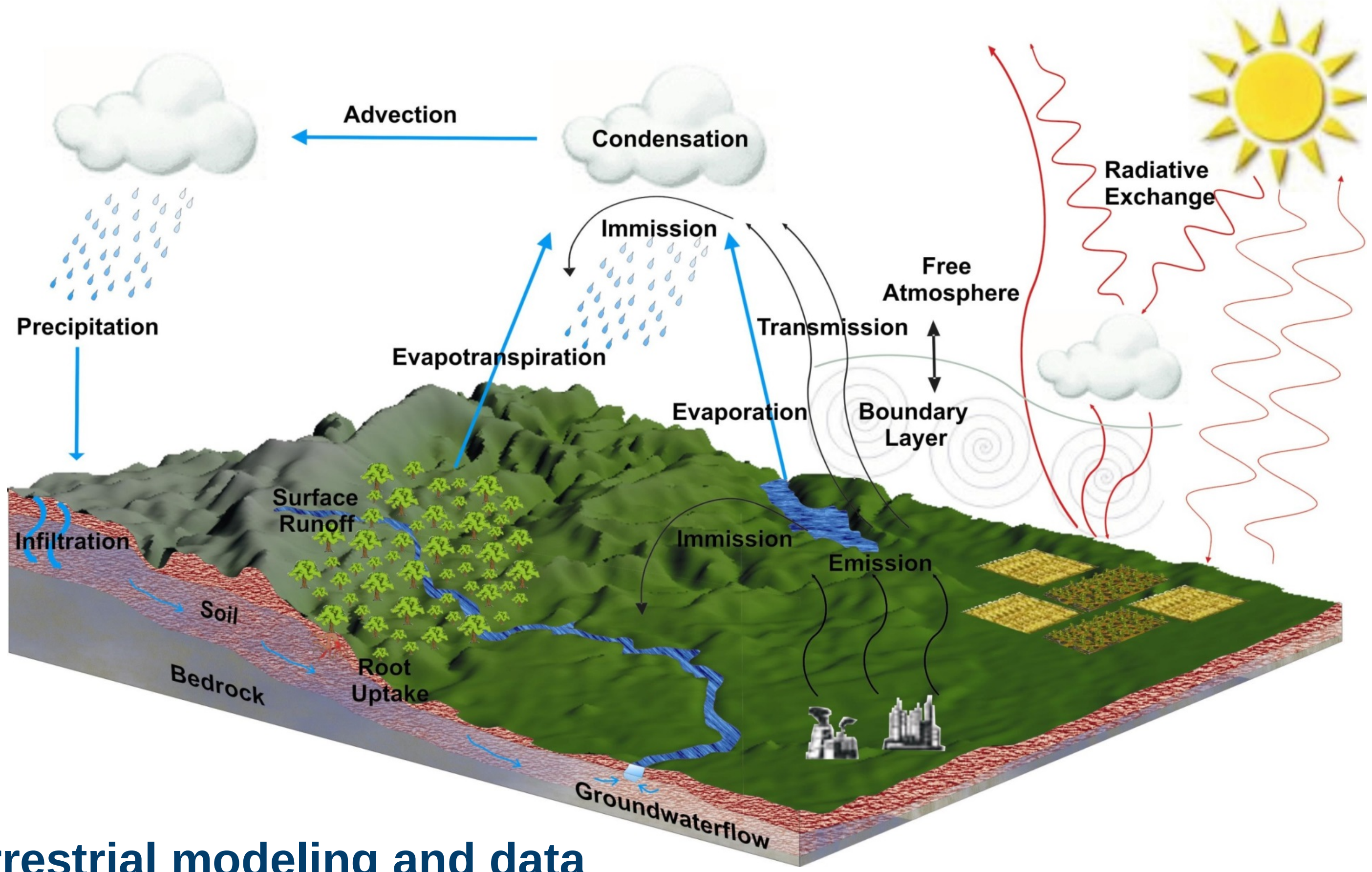
TSMP BACKGROUND

Land-Atmosphere Coupling

Regional Earth System Model

- Terrestrial Systems Modelling Platform (TSMP)
- Groundwater-to-atmosphere simulations
- Since 2014
  - COSMO, CLM3.5, ParFlow
- Wide range of applications



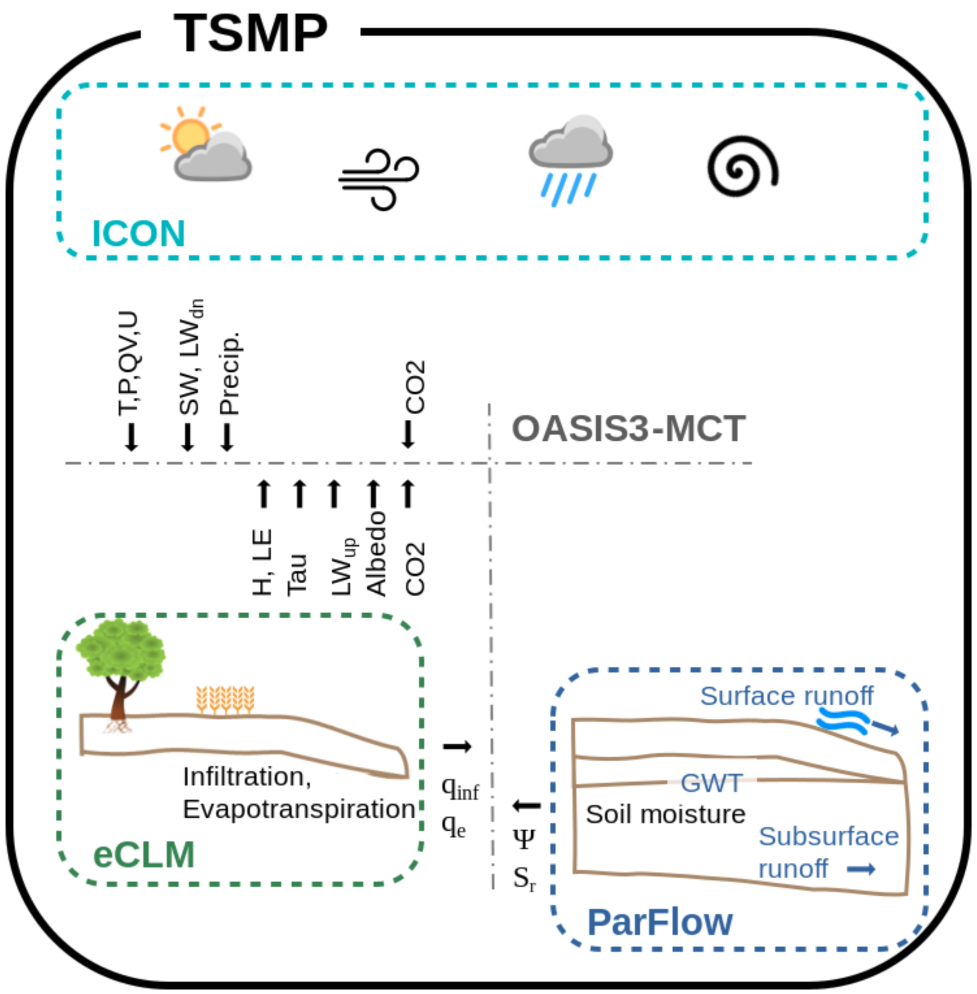
Scale consistent, integrated terrestrial modeling and data assimilation from the subsurface into atmosphere.

COUPLED SYSTEM TSMP

Terrestrial Systems Modelling Platform (TSMP)

Details

- MPMD execution approach
- Modular coupling design
  - Suitable for independently developed codes
- Component models can have different spatio-temporal resolution
- Various configuration options
  - Component models standalone and combinations



ICON MODEL

Atmospheric model in TSMP

Why using ICON?

- Improvements in dynamical core
  - Mass conservation properties
  - Grid elements extent almost identical
- Proven to work at high resolution
- Scales very well

ICON technical details

- Unstructured triangular grid

Courtesy of MPI-M

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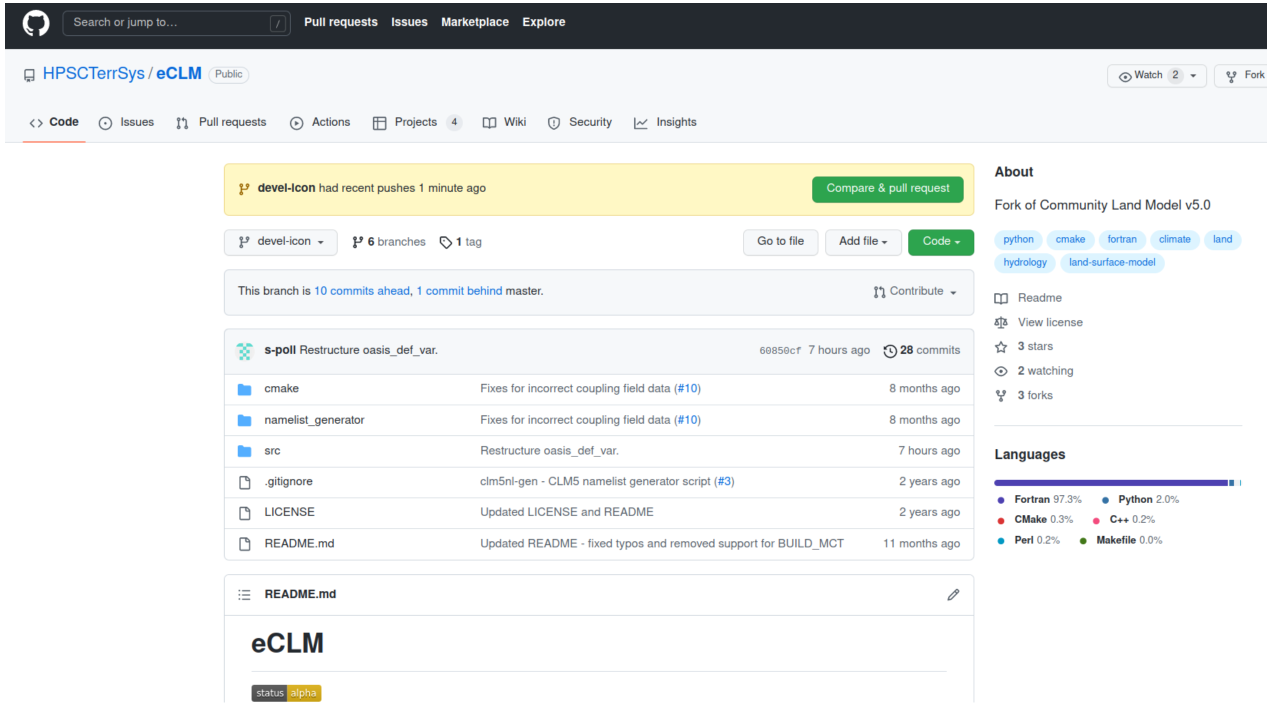
ECLM – FORK OF CLM5.0

Land-surface model eCLM in TSMP

eCLM – Fork of CLM5.0

- Developed by FZJ (IBG-3)
- Same modeling capabilities as CLM5.0
- Simplified infrastructure for build and namelist generation
- Build system is handled entirely by CMake
- Namelist generation through small set of Python scripts

eCLM github
https://github.com/HPSCTerrSys/eCLM



LAND ATMOSPHERE COUPLING

Coupling approaches ICON/CLM in TSMP

Exchange Coefficients Approach

- Coupling via exchange coefficients and surface variables
- Determination of surface fluxes

Flux Inversion Approach

- Coupling via turbulent fluxes
- Determination of exchange coefficients
- Used for recalculation of surface fluxes

Fixed Fluxes Approach

- Coupling via turbulent fluxes
- Direct usage of surface fluxes

Surface flux calculation in ICON/COSMO

$$H_0 = -\rho\, c_p\, C_\theta\, |v_h|\, \left(T_{ke} + \frac{g}{c_p} z_A - T_s\right)$$

$$(L_v E)_0 = -\rho\, L_v\, C_q |v_h|\, (q_{v,ke} - q_{v,s})$$

$$M_{i,0} = -\rho\, C_M\, |v_h|\, u_{i,ke}$$

LAND ATMOSPHERE COUPLING

Coupling strategy and exchanged variables

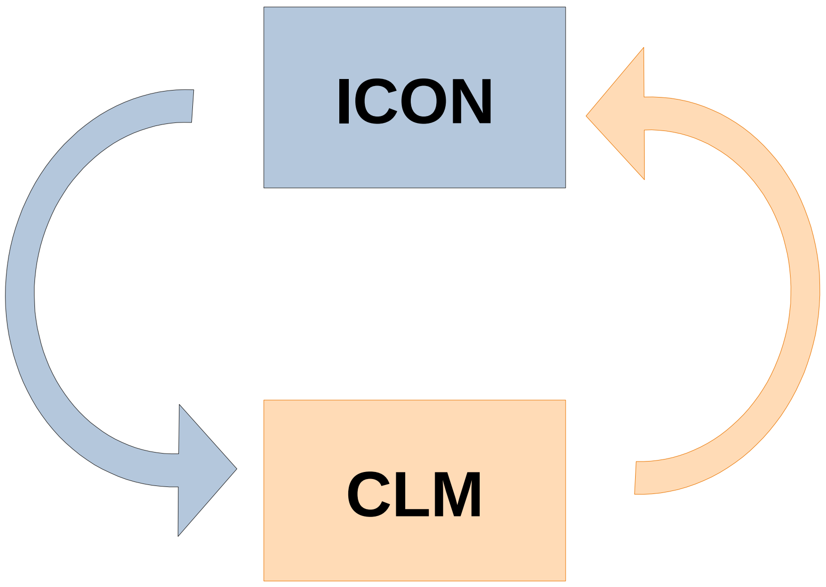
Coupling strategy: Fixed fluxes approach

Version: ICON v2.6.4, eCLM/CLM v5.0, OASIS3-MCT v5.0

Exchanged variables:

ICON to CLM

1. height of lowermost full level (nlev)
2. temperature (nlev)
3. zonal wind (nlev)
4. meridional wind (nlev)
5. water vapor content (nlev)
6. surface pressure
7. surface dir. short-wave rad.
8. surface dif. short-wave rad.
9. surface long-wave down rad.
10. rain precip.
11. snow precip.

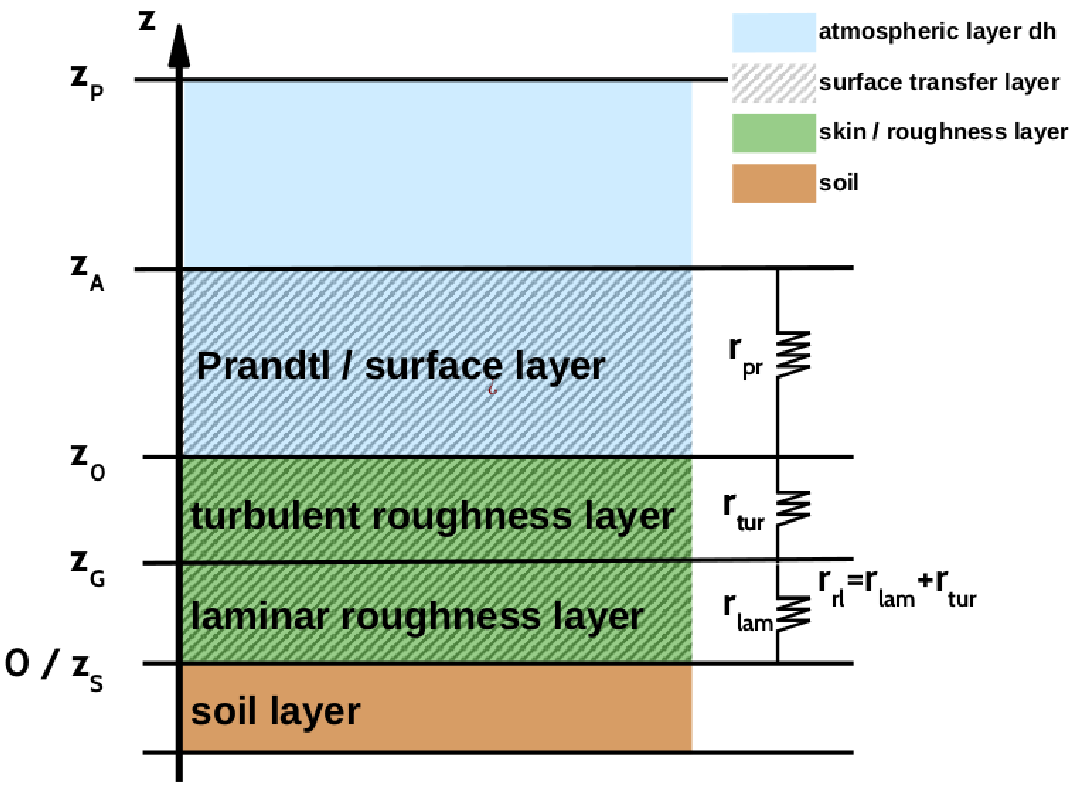


CLM to ICON

1. surface temperature
2. ground emission
3. direct albedo
4. diffuse albedo
5. zonal momentum flux
6. meridional momentum flux
7. sensible heat flux
8. latent heat flux

ICON COUPLING STRATEGY

Updating of lowermost atmospheric level



PBL schemes

- Coupling ICON for NWP (turbdiff) and LES (LEM) mode

LES scheme (Dipankar et al., 2015)

- Smagorinsky turbulence scheme
- MOST based transfer scheme (Louis, 1979)
- Neumann boundary conditions

NWP scheme (Raschendorfer, 2001)

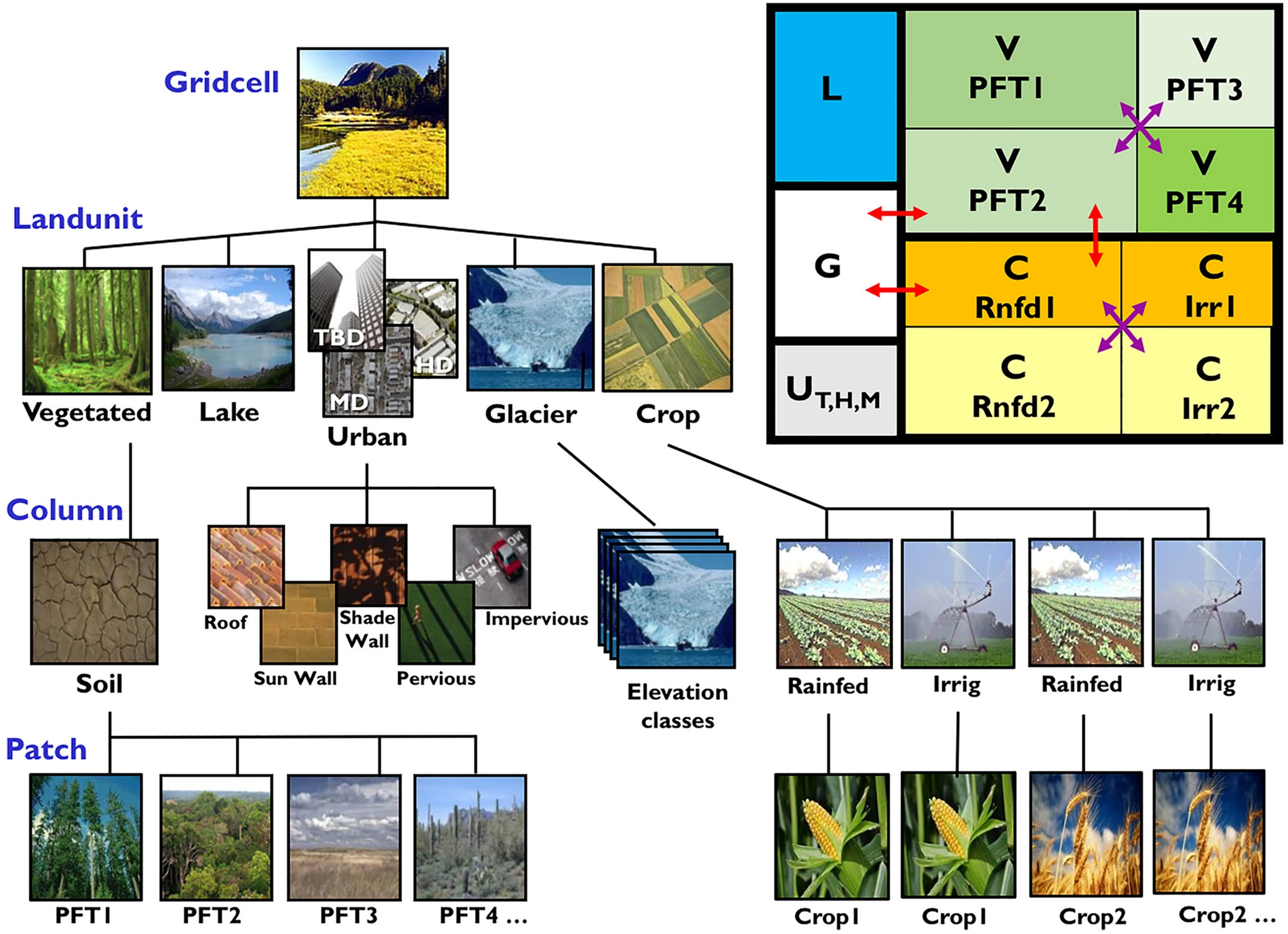
- TKE based hierarchic level 2.5 MY1982
- TKE based transfer scheme (Raschendorfer, 2009)
- Dirichlet boundary conditions

CLM COUPLING STRATEGY

CLM5.0 subgrid hierarchy

CLM subgrid hierarchy

- From gridcell to patch level
- Exchange of quantities on patch level
- Aggregated to gridcell before sending to atmosphere



Lawrence et al. (2019)

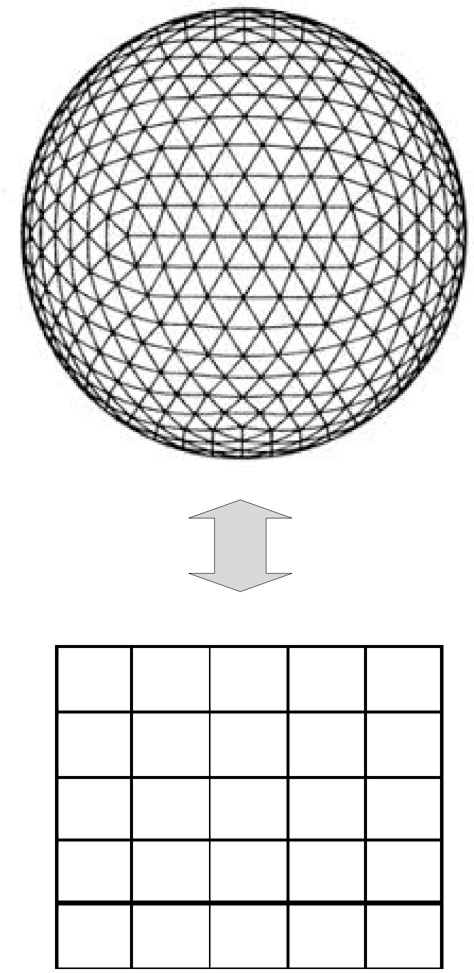
COUPLING INTERFACE

Technical details

OASIS3-MCT creates MPI_COMM_WORLD

Coupling interface

- Explicit coupling between model components
- Sending and receiving in model time loop and processing of coupled quantities in the physics modules
- Interpolation between grids with weighting files or no interpolation
  - Calculation of weight factors beforehand by means of Climate Data Operators (CDO)



Courtesy of DWD

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COUPLING STRATEGY

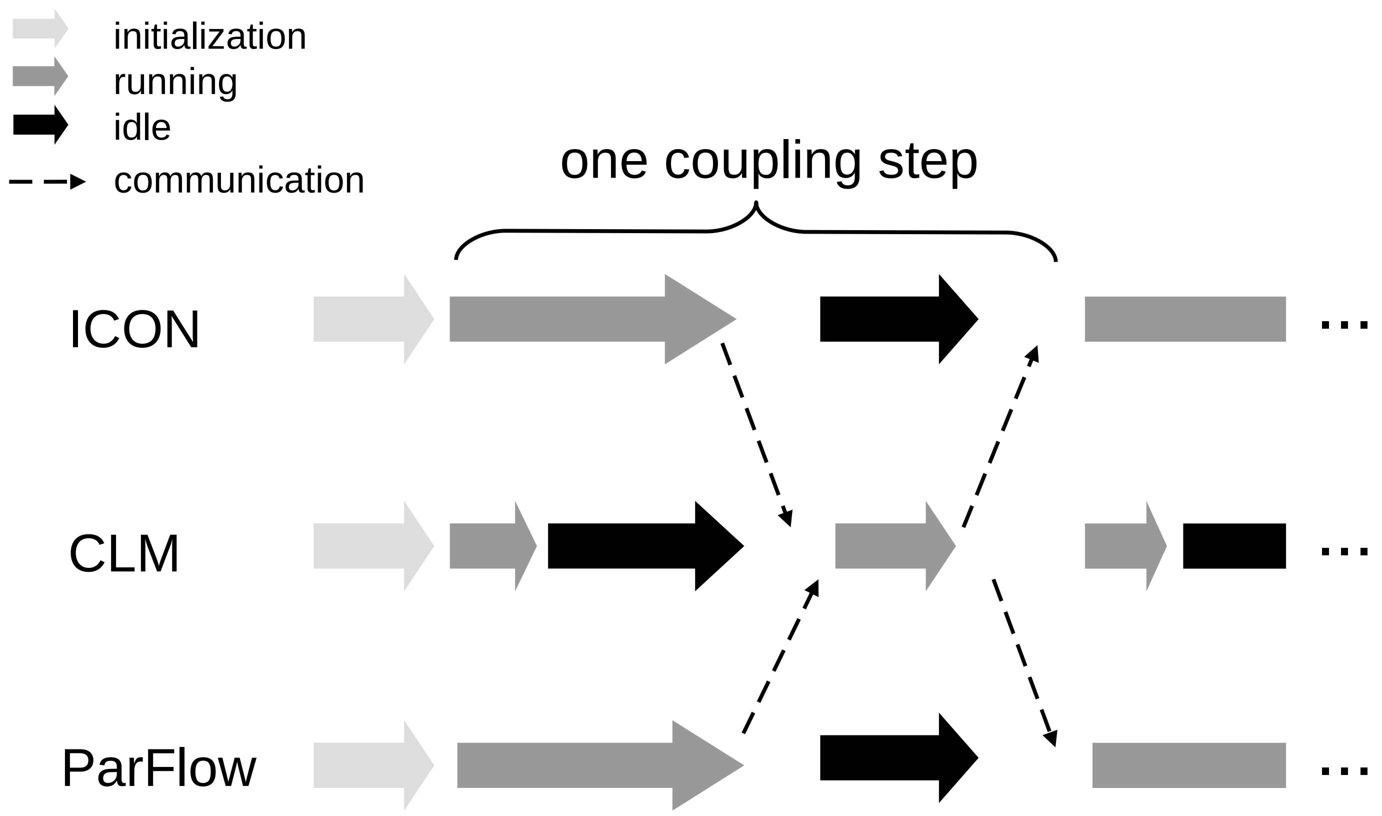
Coupling steps in TSMP

Initialization

- Each component is initialized independently

Coupling time step

- CLM runtime << ICON runtime
- ICON/ParFlow idle during CLM runtime



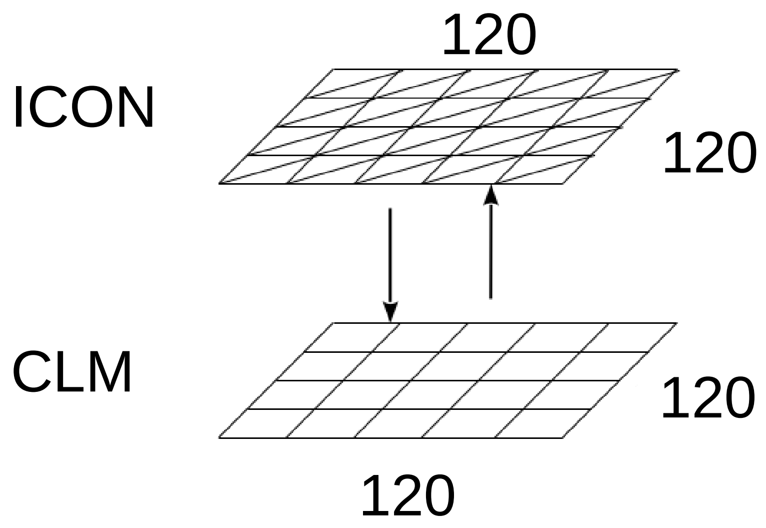
Courtesy of Gasper et al. (2014)

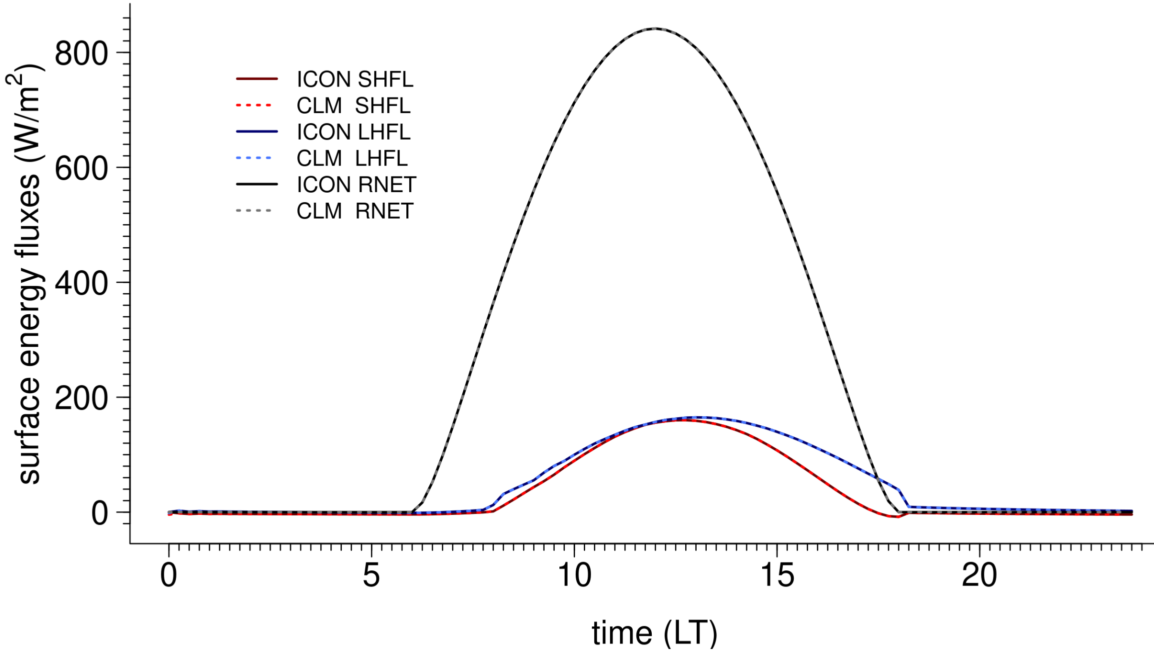
RESULTS

IDEALIZED CASE STUDY

Setup diurnal cycle experiment (ICON + CLM)

	ICON	CLM
Time step	10 s	300 s
Sim. time	24 hours	
Coupl. Frq.	300 s	
Grid spacing	2 km	2 km
Vert. levels	64	10
Init.	Dipankar et al., 2014	Homogeneous soil + veg

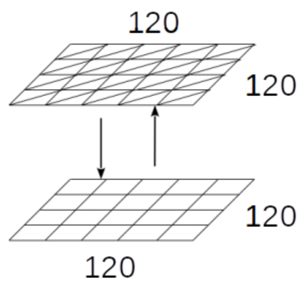




Energy and mass consistent coupling.

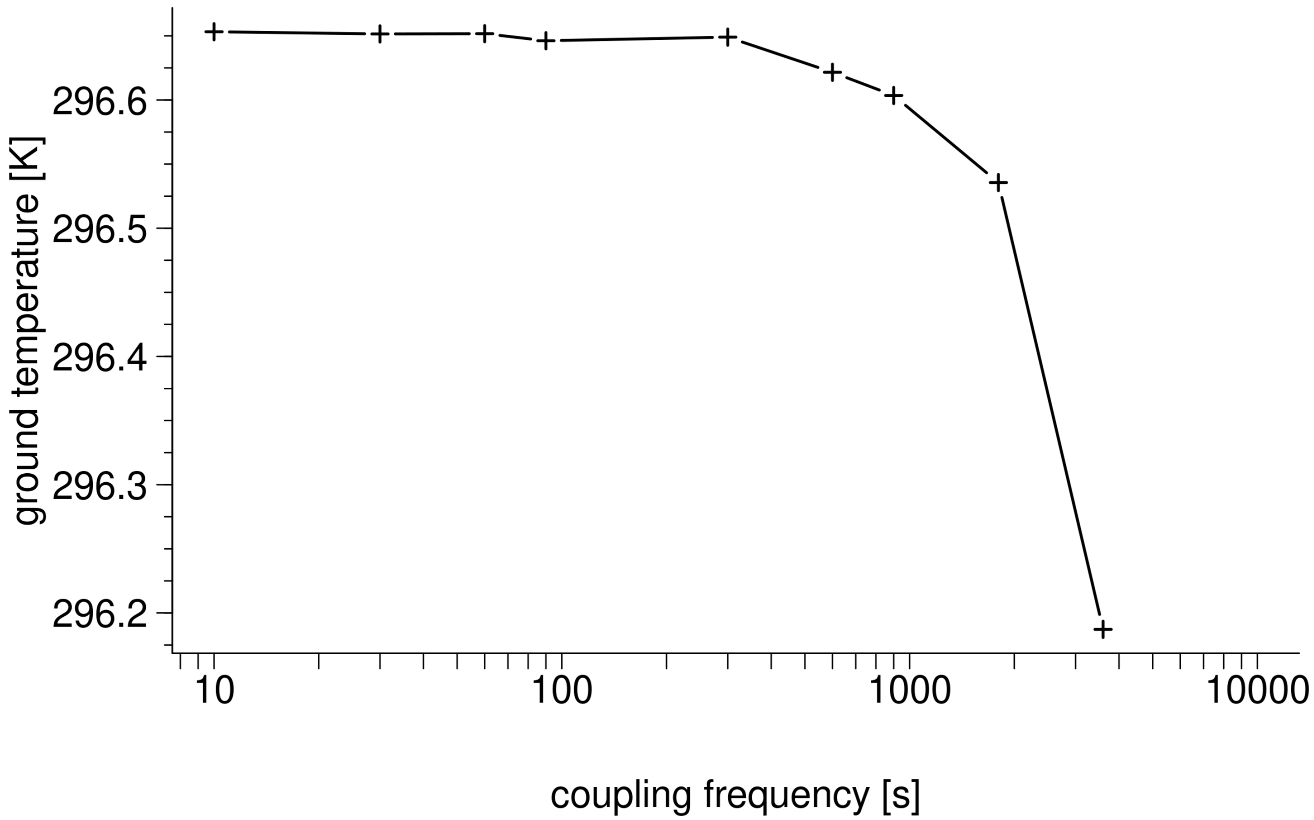
IDEALIZED CASE STUDY

Sensitivity to coupling frequency (ICON + CLM)



	ICON	CLM
Time step	10 s	cpl-frq
End time	6 hours (init: 12LT)	
Grid spacing	2 km	2 km
Vert. levels	64	10

- Asymptotic surface temperature behavior for coupling frequencies <= 300 s



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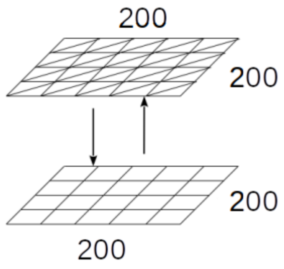
IDEALIZED CASE STUDY

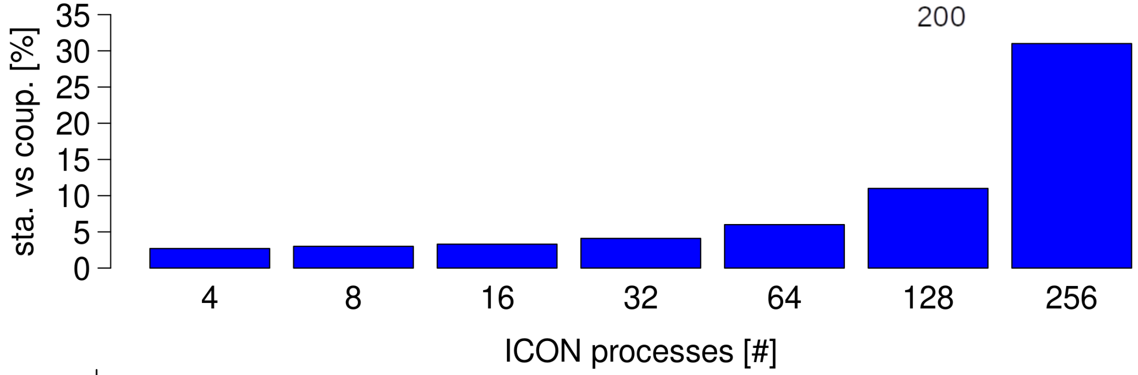
Performance (ICON + CLM)

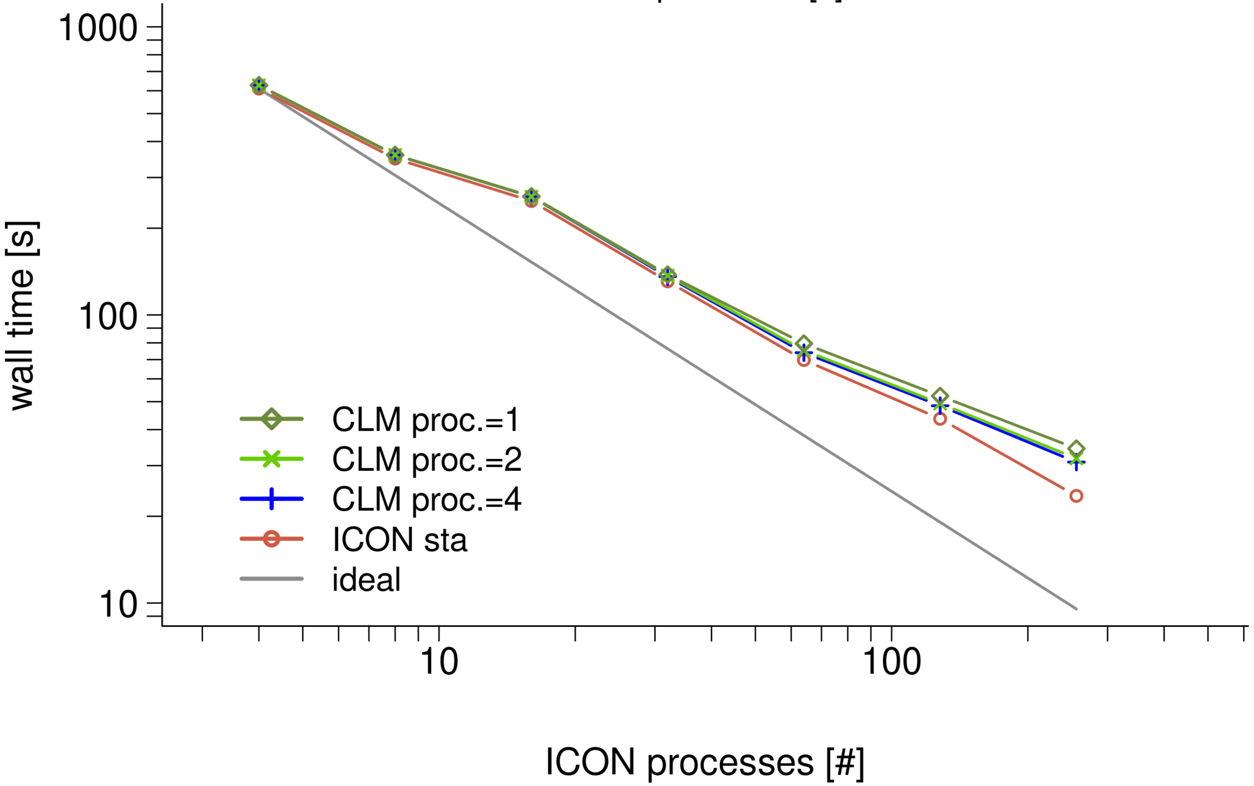
	ICON	CLM
Time step	10 s	300 s
End time	1 hour	
Coupl. frq.	300 s	
Hor. gps	200 x 200	200 x 200
Vert. levels	64	10

Scaling of TSMP

- on JUWELS @JSC







PERFORMANCE

ICON + CLM

Intel® VTune™ Amplifier

Application Performance Snapshot

Application: *icon*
Report creation date: *2022-06-26 14:54:10*
Rank:
Number of ranks: *144*
Ranks per node: *min: 44, max: 48*
OpenMP threads per rank: *MIN:0 MAX:1*
HW Platform: *Intel(R) Xeon(R) Processor code named Skylake*
Frequency: *2.69 GHz*
Logical Core Count per node: *96*
Collector type: *Driverless Perf system-wide counting*

330.93s Elapsed Time

0.81 CPI (MAX 0.86, MIN 0.72)

0.13 GFLOPS Single Precision

110.77 GFLOPS Double Precision

26.40 GFLOPS x87

3.25 GHz Average CPU Frequency

Your application is memory bound.
Use memory access analysis tools like Intel® VTune™ Amplifier for a detailed metric breakdown by memory hierarchy, memory bandwidth, and correlation by memory objects.

	Current run	Target	Delta
MPI Time	20.59%	<10%	
Memory Stalls	45.17%	<20%	
Vectorization	50.67%	>70%	
I/O Bound	0.00%	<10%	

MPI Time

68.15s
20.59% of Elapsed Time

MPI Imbalance
N/A
0.00% of Elapsed Time

TOP 5 MPI Functions	%
Waitall	10.44
Send	3.70
Allreduce	1.84
Alltoallv	1.23
Init	0.98

Memory Footprint

Resident	Per node	Per rank
PEAK	8796.09 MB	260.95 MB
AVG	8349.95 MB	173.96 MB

Virtual	Per node	Per rank
PEAK	21269.09 MB	519.45 MB
AVG	20478.82 MB	426.64 MB

Memory Stalls

45.17% of pipeline slots

Cache Stalls
17.13% of cycles

DRAM Stalls
15.53% of cycles

DRAM Bandwidth	
AVG	135.84 GB/sec
PEAK	191.68 GB/sec
BOUND	76.37%

NUMA
0.30% of remote accesses

Vectorization

50.67% of Packed FP Operations

Instruction Mix

SP FLOPs
0.00% of uOps

DP FLOPs
11.03% of uOps
Packed: 71.50% from DP FP
128-bit: 71.50%
256-bit: 0.00%
512-bit: 0.00%
Scalar: 28.50% from DP FP

x87 FLOPs
4.53% of uOps

Non-FP
84.47% of uOps

FP Arith/Mem Rd Instr. Ratio
0.43

FP Arith/Mem Wr Instr. Ratio
1.46

I/O Bound

0.00%
(AVG 0.01, PEAK 0.05)

I/O	Read	Write
AVG	2.3 MB	27.9 MB
PEAK	0.0 KB	3.9 GB

REAL CASE STUDY

Application regional scale - NRW case study

	ICON	CLM
Sim. date	24th April 2013	
Sim. time	12 hour (init: 6 UTC)	
Coupl. Frq.	300 s	
Time step	10 s	300 s
Grid spacing	R2B11 1.25km	500 m
Vert. levels	80	10

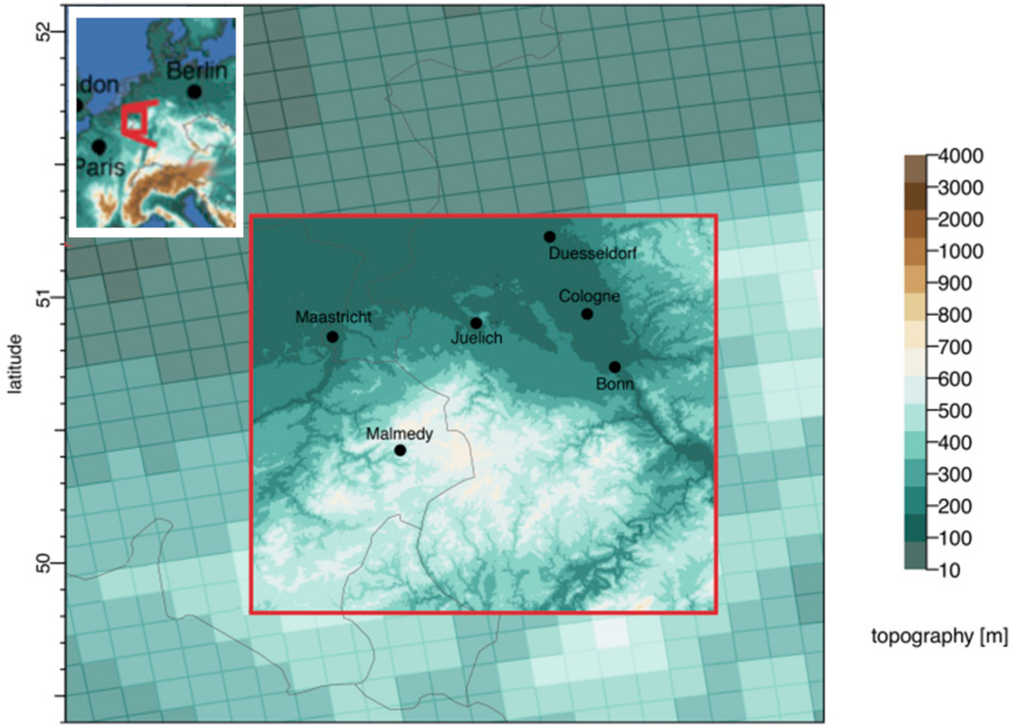


Figure modified from Kollet et al., (2018)

REAL CASE STUDY

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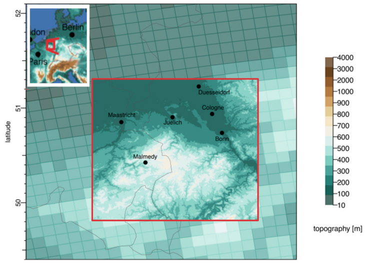
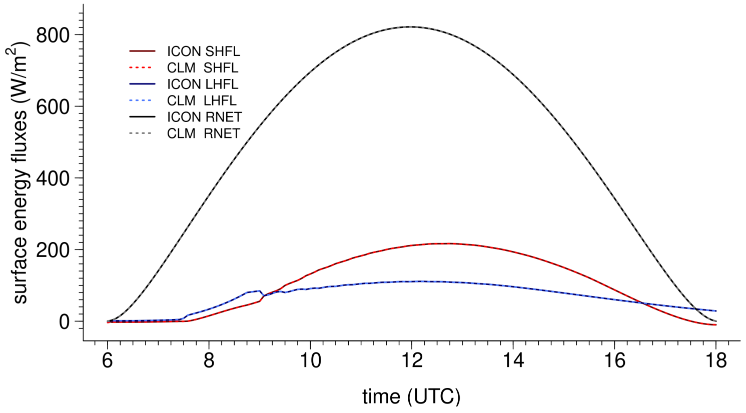
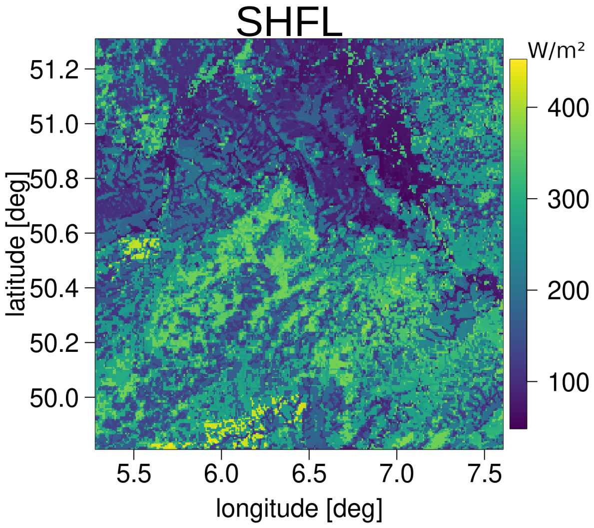
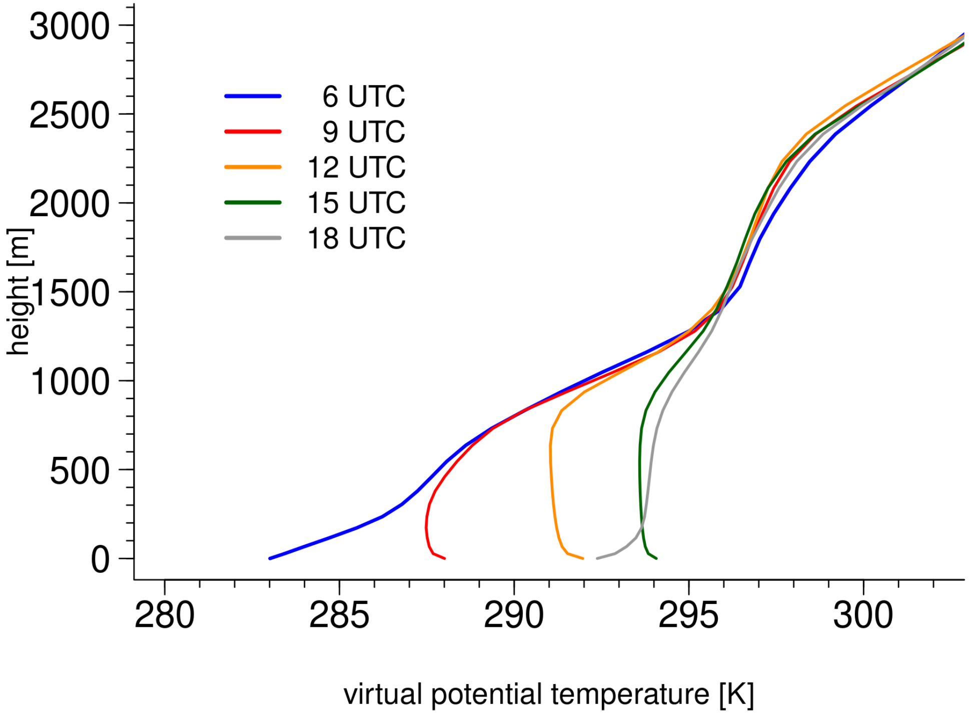


Dom.
Avg.



24th April 2013
12 UTC





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SUMMARY & OUTLOOK

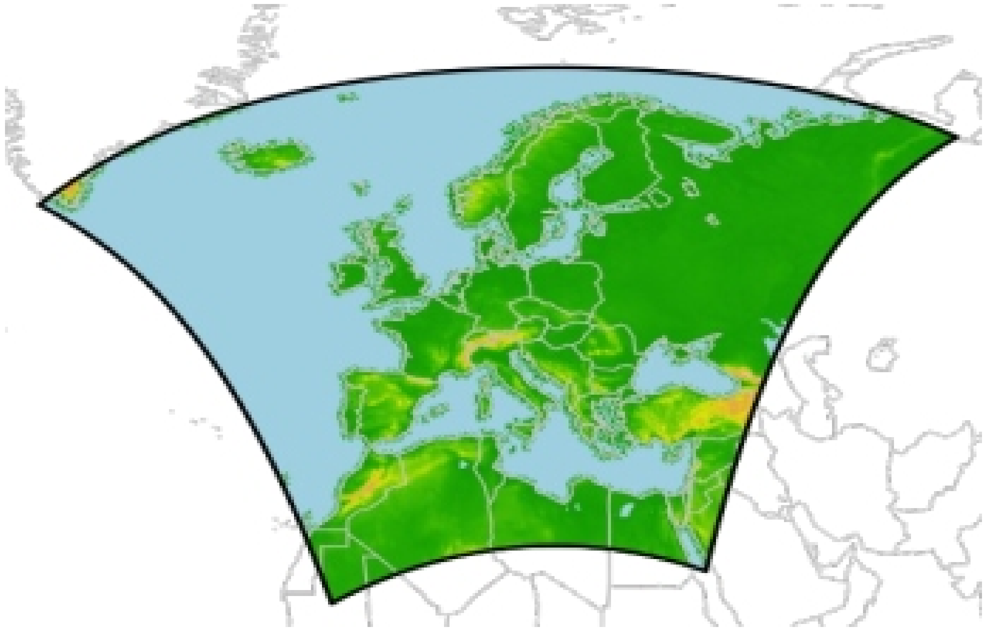
Next steps

Summary

- Energy conservation at land-atm. interface
- Scaling of coupled system follows atm. model

Outlook

- Performance analysis
- EURO-CORDEX domain (3km, 12km)
- Comparison of TSMP (COSMO), TSMP (ICON), ICON sta.



Courtesy of C. Furusho

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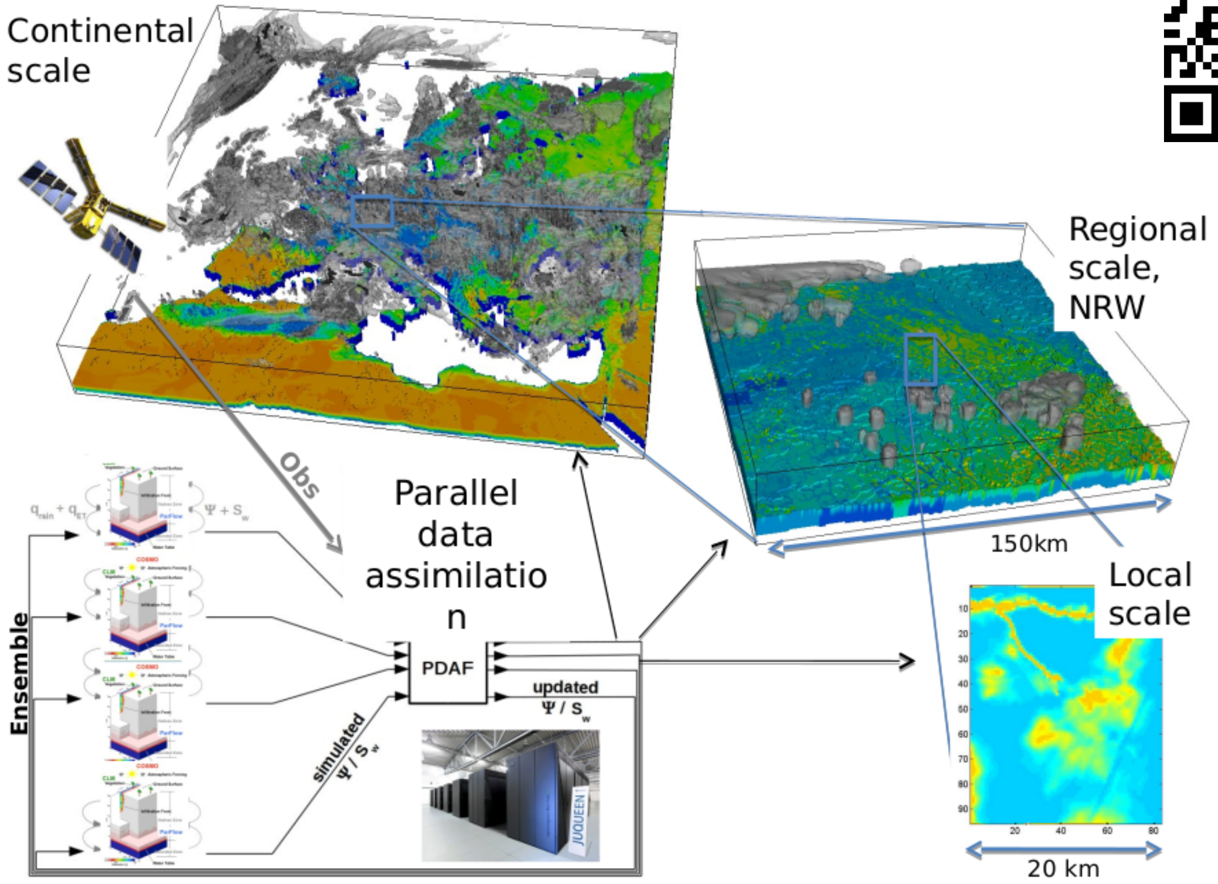
THANK YOU FOR YOUR ATTENTION

TSMP applications



TSMP github

https://github.com/HPSCTerrSys/TSMP/

More information:

https://www.terrsysmp.org/

Contact

s.poll@fz-juelich.de

ATTACHMENT

COUPLING STRATEGY

Introduction of coupling approaches in TSMP

Exchange Coefficients Approach

- Coupling via exchange coefficients and surface variables
- Determination of surface fluxes

Flux Inversion Approach

- Coupling via turbulent fluxes
- Determination of exchange coefficients
- used for recalculation of surface fluxes

Fixed Fluxes Approach

- Coupling via turbulent fluxes
- Direct usage of surface fluxes

Surface flux calculation in ICON/COSMO

$$H_0 = -\rho\, c_p\, C_\theta\, |v_h| \left(T_{ke} + \frac{g}{c_p} z_A - T_s \right)$$

$$(L_v E)_0 = -\rho\, L_v\, C_q |v_h| \left(q_{v,ke} - q_{v,s} \right)$$

$$M_{i,0} = -\rho\, C_M\, |v_h|\, u_{i,ke}$$

Exchange coefficients

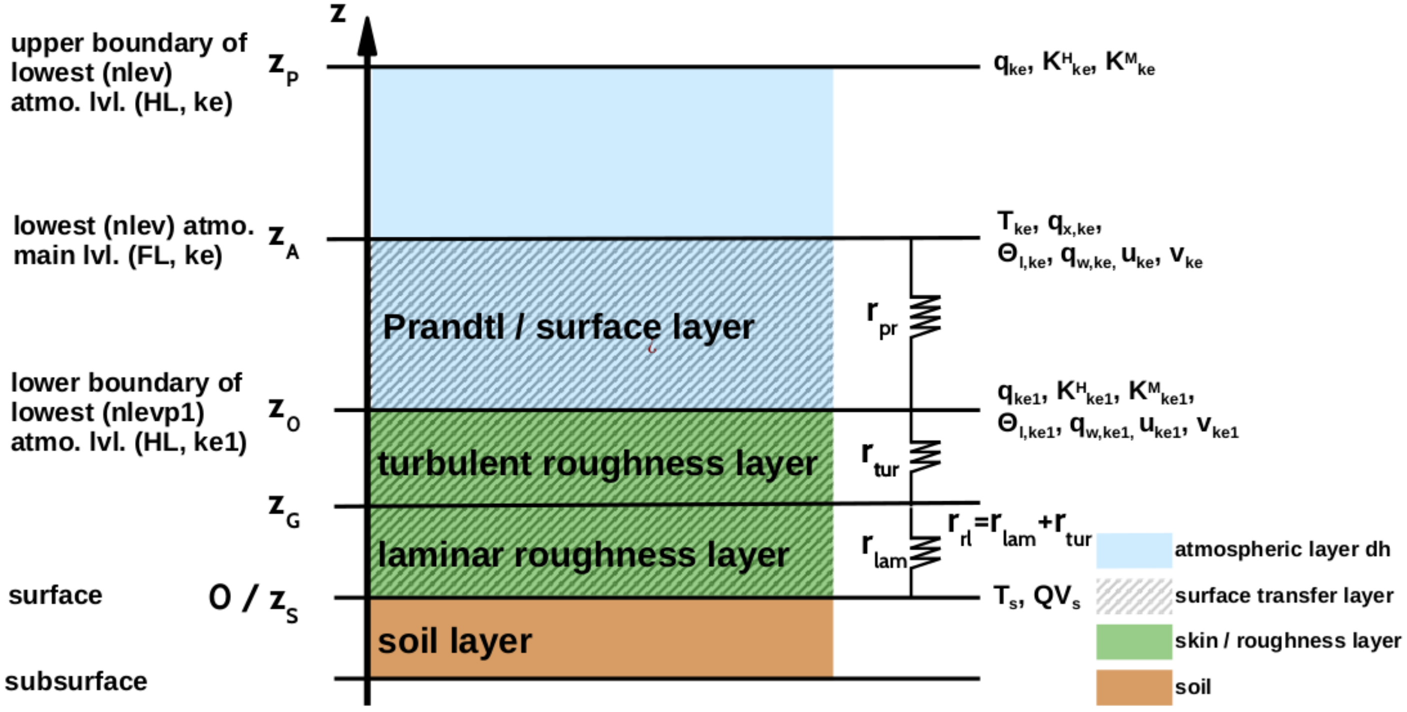
$$C_M = \underset{\text{COSMO/ICON}}{=} \frac{tvm}{|v_h|} = \frac{K^M_{ke1}}{r^M_{tot} \cdot |v_h|} \underset{\text{CLM}}{=} \frac{1}{\hat{r}^M_{tot} \cdot |v_h|}$$

$$C_{q,\theta} = \underset{\text{COSMO/ICON}}{=} C_H = \frac{tvh}{|v_h|} = \frac{K^H_{ke1}}{r^H_{tot} \cdot |v_h|} \underset{\text{CLM}}{=} \frac{1}{\hat{r}^{q,\theta}_{tot} \cdot |v_h|}$$

COUPLING STRATEGY

Turbtrans transfer scheme

Structure of Surface Transfer Layer



TKE at lowermost model layer

$$\frac{\partial q^2}{\partial t} = 2K^M\left[\left(\frac{\partial \bar{u}}{\partial z}\right)^2 + \left(\frac{\partial \bar{v}}{\partial z}\right)^2\right] - 2K^H\frac{g}{\bar{\theta}_v}\left(A_\theta \frac{\partial \bar{\theta}}{\partial z} + A_{q_w}\frac{\partial \overline{q_w}}{\partial z}\right) - 2\frac{q^3}{\alpha_{MM}\lambda}$$

Temperature at lowermost model layer

$$\frac{\partial \theta_l}{\partial z} = \frac{\theta_{l,ke} - \theta_{l,ke1}}{r^H_{pr}} \qquad \theta_{ke1} = (1 - tfh)\cdot\theta_{ke} + tfh\cdot\theta_s \qquad tfh = \frac{r^H_{pr}}{r^H_{tot}}$$

Resistances

$$r^\varphi_{XY} = \int_X^Y \frac{dz}{K^\varphi_{XY}(z)} \qquad K^\varphi_{XY}(z) = \lambda u^\varphi_x \qquad u^\varphi_h = q_h S^\varphi_h + \frac{k^\varphi}{\kappa z_h}$$

Sublayers

- Prandtl layer: Transport velocity scale u' is assumed to be linear with height
- Turbulent roughness layer: Transport velocity scale is assumed to be constant
- Laminar roughness layer: The velocity scale component of u‘ vanished

PERFORMANCE

ICON + CLM