Status report of

WG2 - Numerics and Dynamics

COSMO General Meeting
08-11 Sept. 2014, Eretria, Greece

Michael Baldauf (DWD)

Outline

- Targeted diffusion to avoid cold pools
- Reformulation of the divergence damping coefficient
- Code rewrite of the new fast waves solver into STELLA-version
- Summary of the Discontinuous Galerkin project
- Other work in the RK dynamical core
- Morinishi et al. (1998)-spatial discretization
- WG2 contribution to the COSMO Science plan

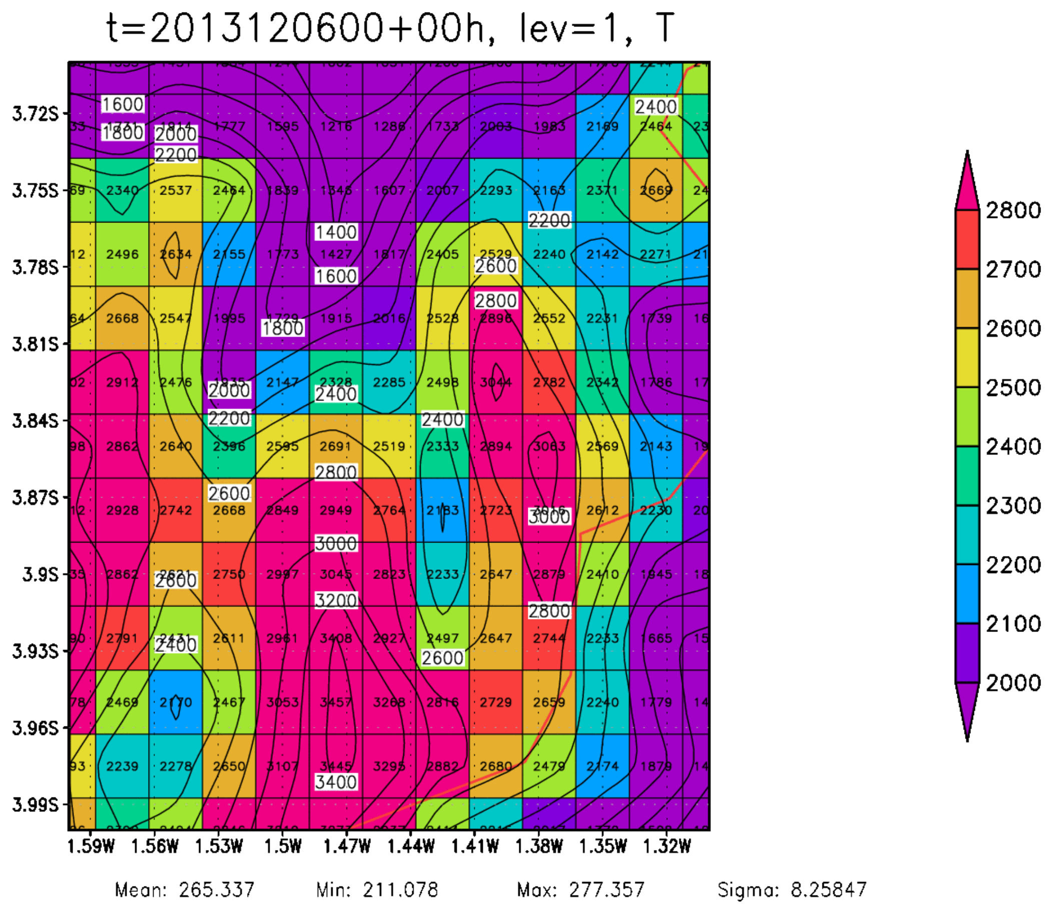
‘Targeted diffusion’ to avoid cold pools in narrow valleys

M. Baldauf (DWD)

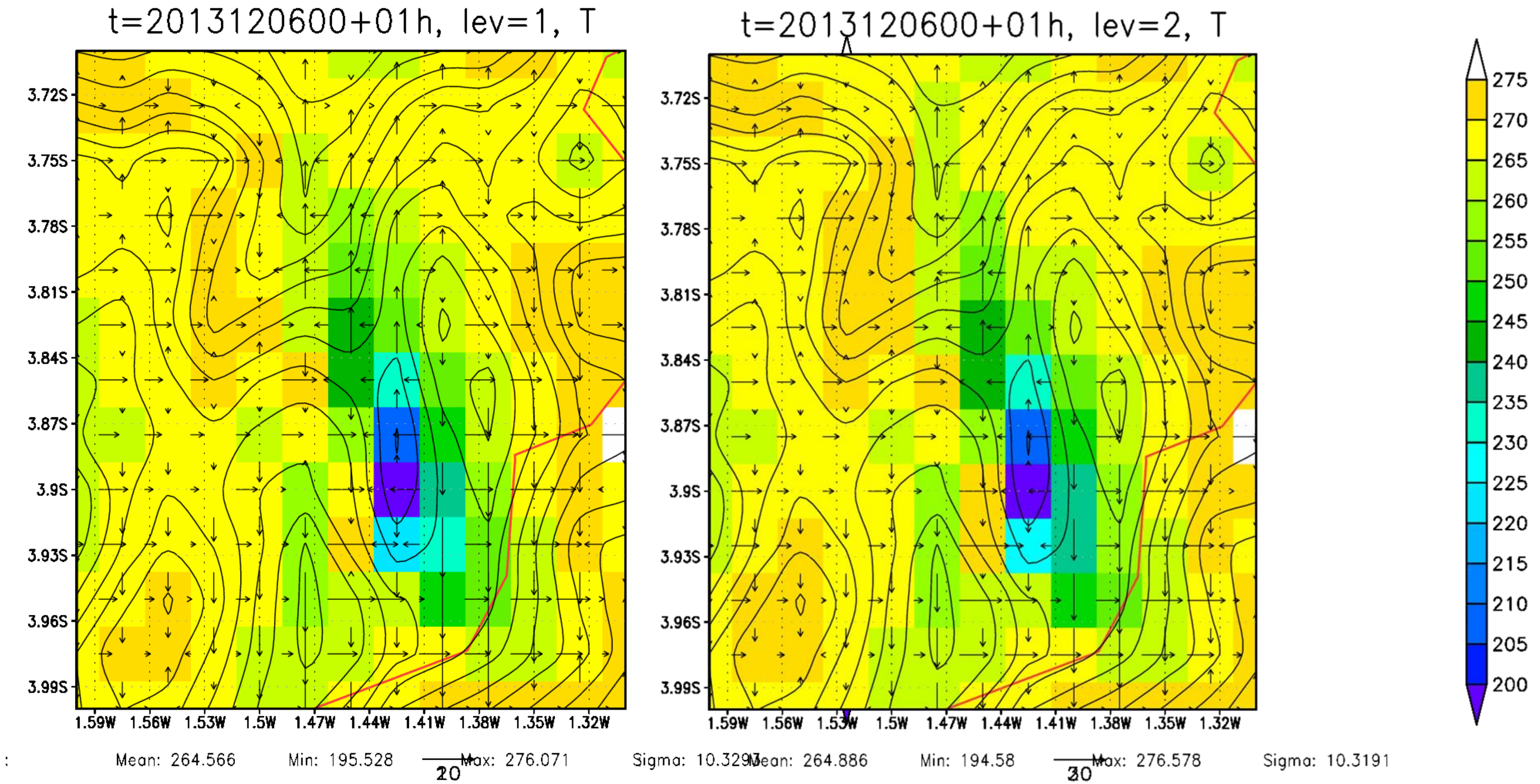
… occured in a few COSMO-DE-runs around 06 Dec. 2013 in a narrow Alpine valley and even led to a model crash in 2 EPS-members (parallel routine).

Similar ‚cold pools‘ have been reported by MeteoCH.

Orography



Problem: unrealistic strong cooling in an Alpine valley



'Targeted diffusion' to avoid cold pools in narrow valleys

these cold pools are a numerical artefact of the upwind 5th order advection scheme.

‚Targeted diffusion' (analogous to G. Zängl in ICON)

criteria: diffusion in a (near bottom) grid point, if

$$T' < \langle T'_{environment} \rangle - 10K$$

is applied only in these grid points;
reduces a cold pool very quickly and is not active later on

computation time consumption ~ 0.05%

implemented in **COSMO 5.0.2**

documentation: a short section will be included in the COSMO Sci. Doc. Part I

Reformulated divergence damping coeff. in the new fast waves solver

M. Baldauf (DWD)

Problem: model crash in a 7 km setup in the area ‚Oman', nearby Iranian mountains (‚Mekran')

Solution:
corrected version of the slope dependent reduction of the divergence damping coefficient (*Baldauf, 2013, COSMO TR*) in a staggered grid.

the divergence damping coefficient is critical for model stability →
Extensive testing in two longer running experiments at DWD:
COSMO-DE: running for 2 months and
COSMO-EU: running for 1 ½ months without problems.
Only small changes in the results.

→ contained in **COSMO 5.0.2**

documentation: not necessary, current Tech. Report No. 21 is sufficient

Divergence damping coefficient in COSMO-DE along the Alps

old version

new version

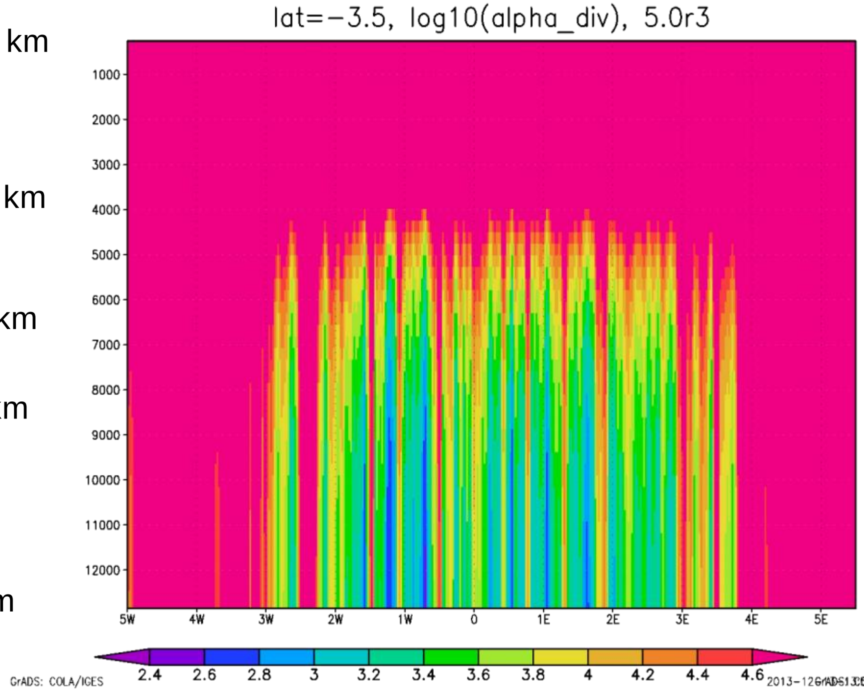
23 km

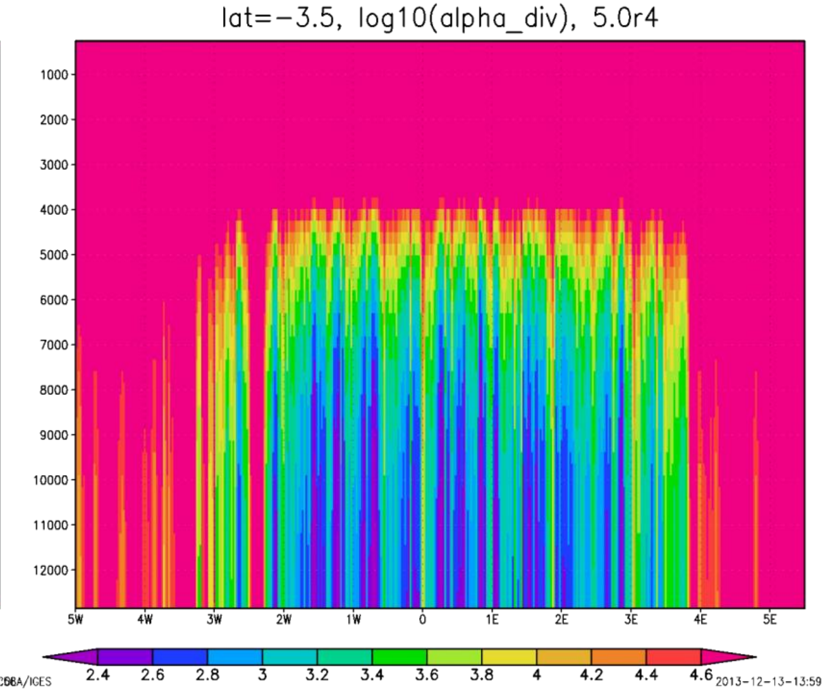
~ 10 km

~ 4 km

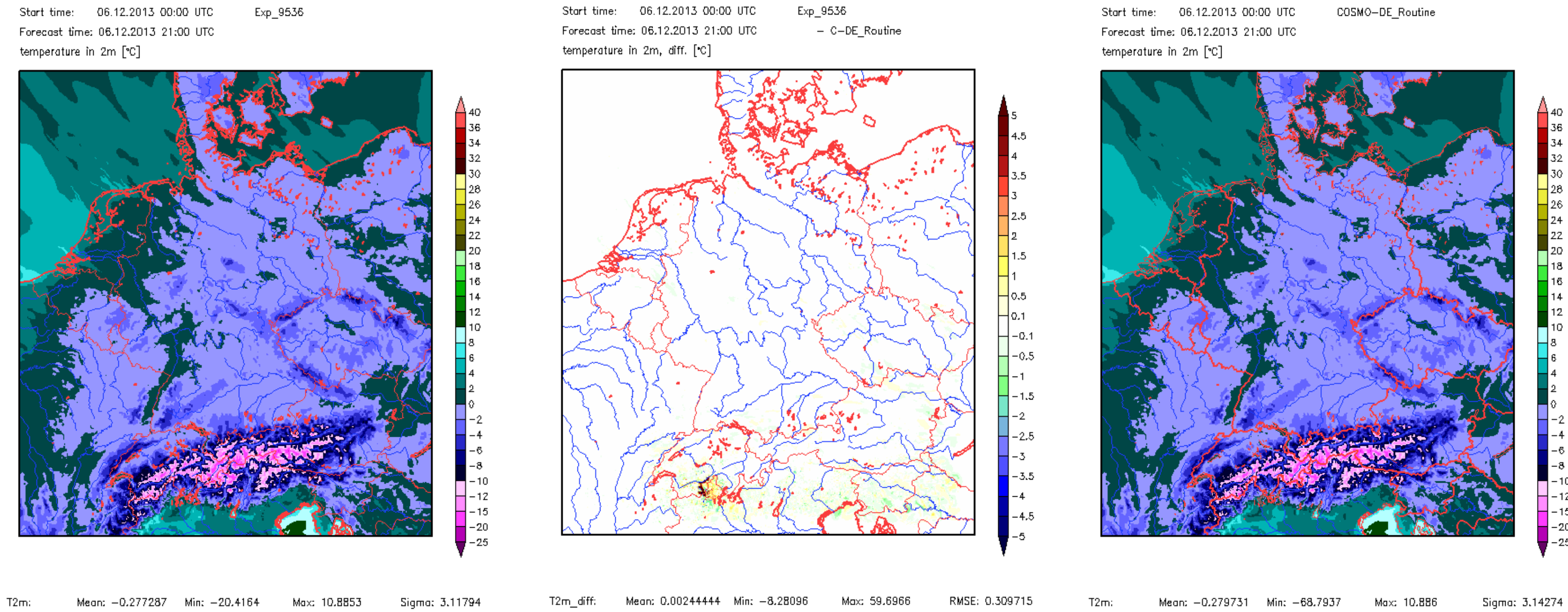
~ 2 km

0 km





Example for the influence of ‚targeted diffusion' and ‚reform. div. damping coeff'
06. Dec. 2013, 21 h forecast, T2m



Additionally: both actions do not significantly change the verification scores

Code rewrite of the new fast waves solver (COSMO 5.0) into the stencil library STELLA-version

(M. Baldauf, A. Arteaga)

Status:

- All stencils that are needed for an operational run are available:

  `FastWavesSCCalcTotalTPRho, FastWavesSCCalcDzDx, FastWavesSCInitDivDampCoeff FastWavesSCVerticalDivergenceHelper, FastWavesSCUV, FastWavesSCLHS, FastWavesSCRHS, FastWavesSCTridiag, FastWavesSCPPTP`

- all these stencils have successfully passed the unit testing framework
- putting these stencils in the right sequence (=time loop of small time steps) and implementation of the FW solver into the time integration module of the C++-dycore has been done (work by Andrea Arteaga)
- halo exchange is ready (work by Andrea Arteaga)

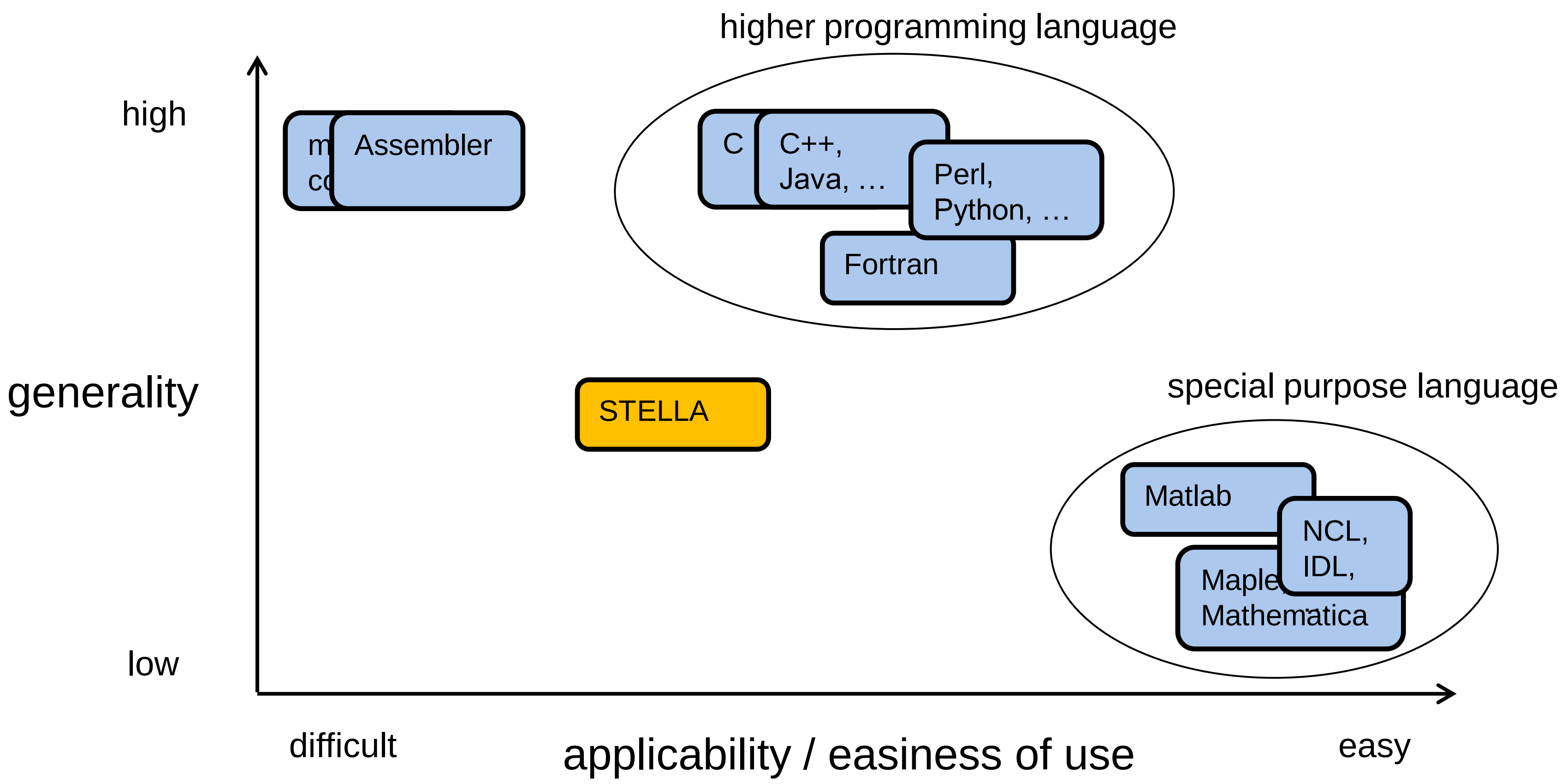
→ code rewrite has been finished

Some personal experiences …

- STELLA is doubtlessly an **impressive development** from the computational science perspective.
- During this code transfer, no errors in STELLA itself have been occured; seems to be quite **stable**
- the STELLA version of the code is needed if you want to use **GPU** based computers
- However, it is not easy to use.
  - The STELLA user **needs a lot of help** from experienced developers (many thanks to Andrea Arteaga)
    it is merely ‚pattern recognising' and ‚copy&paste' work.
  - More documentation is needed
  - Time to implement a stencil can be a factor 5-10 higher than for the similar Fortran code (means: time to transfer existing code)

- you should know the syntactical rules of **C++**; however a deeper knowledge of C++ (esp. object-orientation) is not necessarily needed
- There are several ‚syntactical' rules of STELLA you have to know; in my opinion, it is *not a library* but some sort of a **new programming language/framework**
- You have to know or be aware of several **internal rules** of STELLA, e.g.
  - 2D versus 3D fields:
    `u_sfc(i,j) = 1/2*( u(i,j,ke) + u(i-1,j,ke) )` ←→
    `ctx[u_sfc::Center()]=0.5*(ctx[u::Center()]+ctx[u::At(Offset<-1,0,0>())]);`
  - Which are the priority rules, if I define several do-methods with intersecting k-ranges:
    static void Do(Context ctx, TerrainCoordinates) { … }
    static void Do(Context ctx, KMaximum) { … }
  - ….
- → **unit testing** is very helpful and necessary!
  - But of course, this works only if a reference code (here: COSMO Fortran-code) is available.
  - Nevertheless setup of the test consumes a lot of working time (again many thanks to Andrea)
  - sometimes the Fortran code had to be adapted to run the unit test (example: `wgtfacq_u(:,:, 1:3)` → `(1:ke)` and use only `(ke-2:ke)`)

The landscape of programming languages and frameworks concerning two aspects … personal view



of course, e.g. the important dimension ‚efficiency' is not contained here

Recommendation

- from my point of view it is absolutely necessary to **keep the Fortran version** of the COSMO model instead to replace it entirely by a STELLA-version.
  - Otherwise, significant further developments of the dynamical core are *stopped!*
  - unit testing wouldn‘t be available any more
  - model development by testing via namelist-parameters
- a permanent transfer of possible new developments from the Fortran-version to the STELLA-version must be organized
  (this cannot be done by the model developers!) → Task for STC

A new dynamical core based on Discontinuous Galerkin methods

Project ‘Adaptive numerics for multi-scale flow’, DFG priority program ‘Metström’

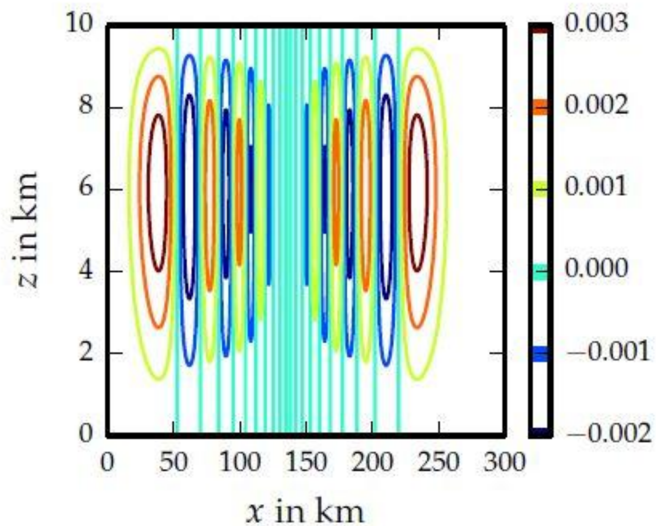
D. Schuster, M. Baldauf (DWD)

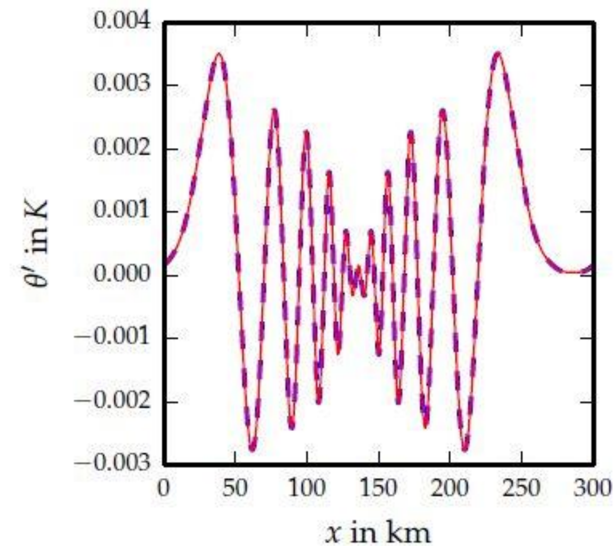
- cooperation between DWD, Univ. Freiburg, Univ. Warwick (6-year program)
    - one PhD position (2010-2014) at DWD
- goals for the DWD: new (prototype) dynamical core for COSMO with
    - high order accuracy
    - conservation of mass, momentum and energy / potential temperature
    - scalability to thousands of CPUs
    - (high grid flexibility)

□ **use of discontinuous Galerkin methods**

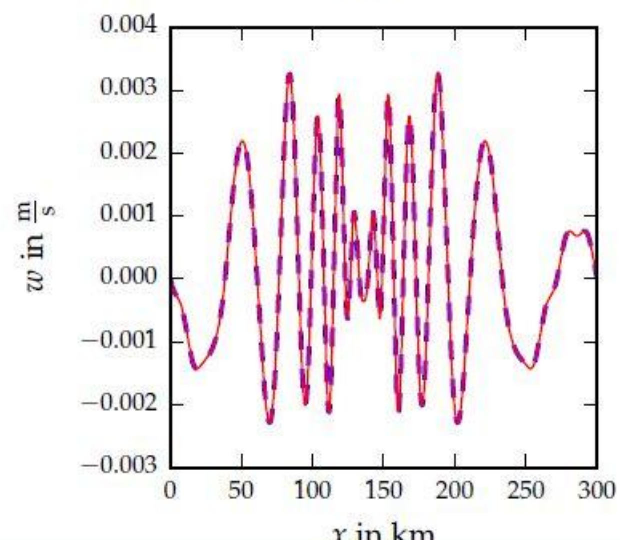
- explicit time integration (Runge-Kutta) (not efficient, of course)
- terrain following coordinates
- coupling of physical parameterisations

$\theta'(t = 30\,\mathrm{min})$

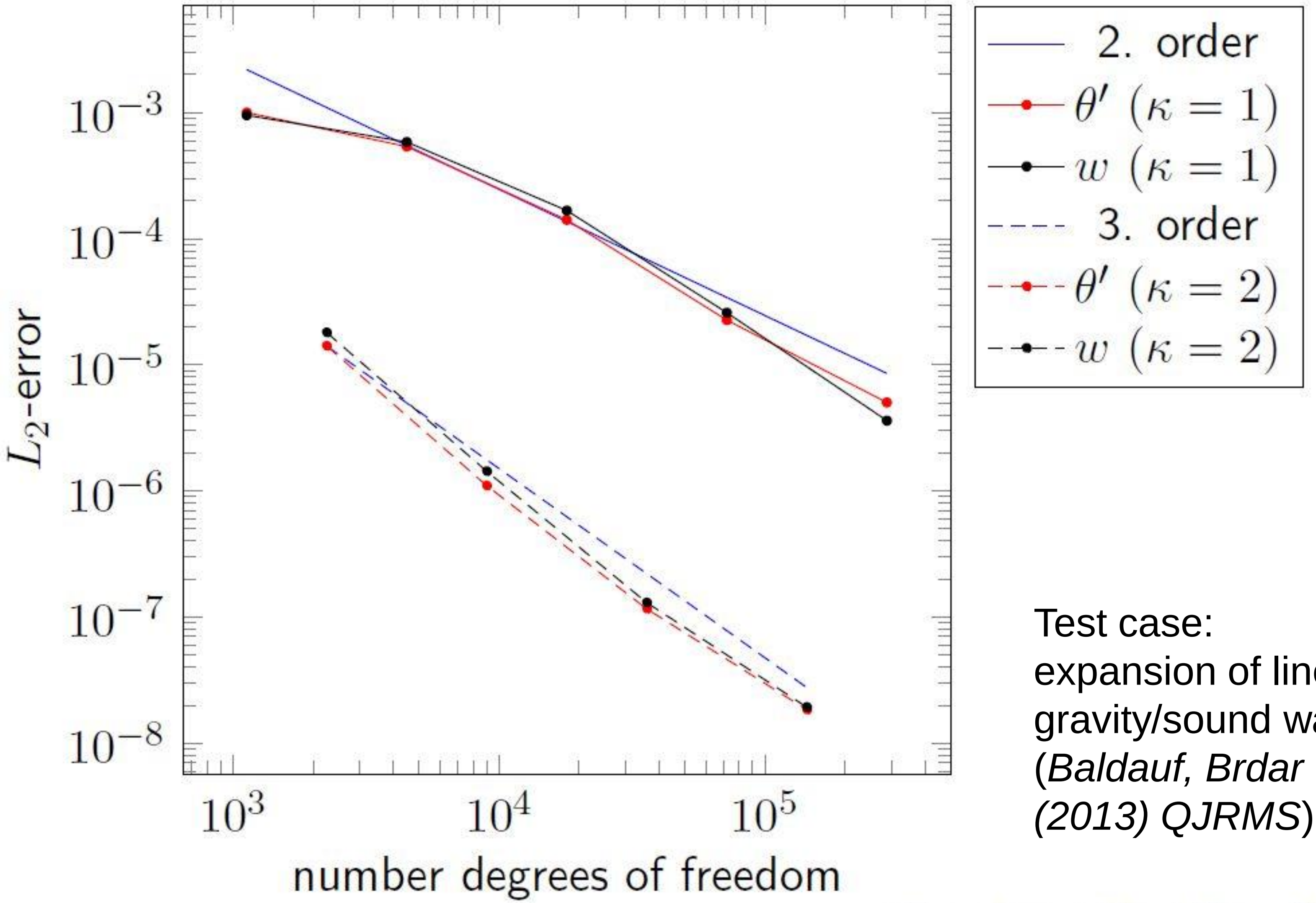




Test case:
expansion of linear gravity/sound waves
(*Baldauf, Brdar (2013) QJRMS*)

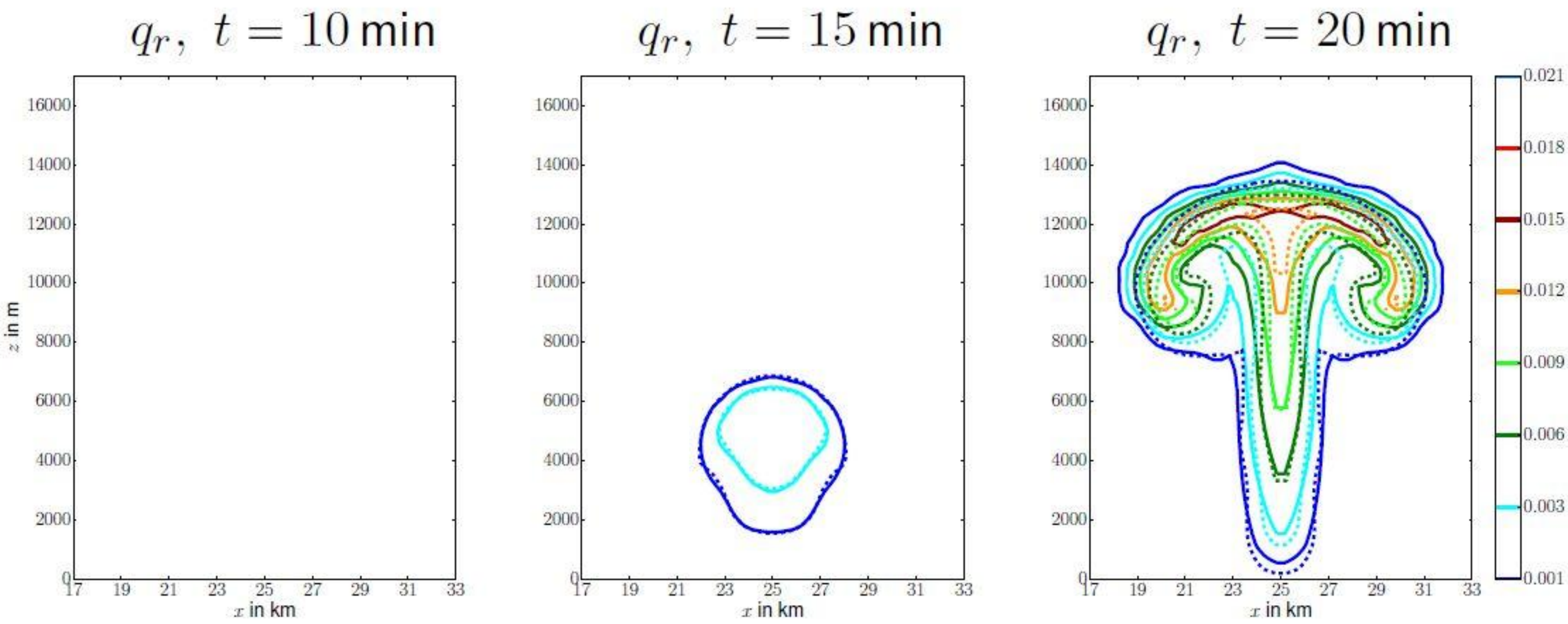


linearised solution dashed blue lines
DG-COSMO $\kappa = 3$, $\Delta x = 500\,\mathrm{m}$, red line



Test case:
expansion of linear gravity/sound waves (*Baldauf, Brdar (2013) QJRMS*)

Test case: warm bubble (*Weisman, Klemp (1982) MWR*)



COSMO dashed lines, DGCOSMO solid lines

Summary

- Discontinuous Galerkin discretization for different polynomial degrees (p=1,2,3) and RK-schemes has been implemented into COSMO
- coupling with Kessler microphysics scheme and an LES turbulence scheme (Smagorinski) has been done.
  However, physics coupling is technically more difficult than expected (physics package calls on quadrature points instead of grid points)
  By the way, similar technical problems for I/O …
- idealized tests (mountain flows, wave expansion, moist convection, …) have been performed successfully
- At least to do:
  - vertically implicit time integration scheme (strong efficiency increase needed)
  - continue physics coupling
- After finishing his PhD work, D. Schuster has found a permanent position outside of DWD → continuation of the project unclear

Other work in the dynamics … finished:

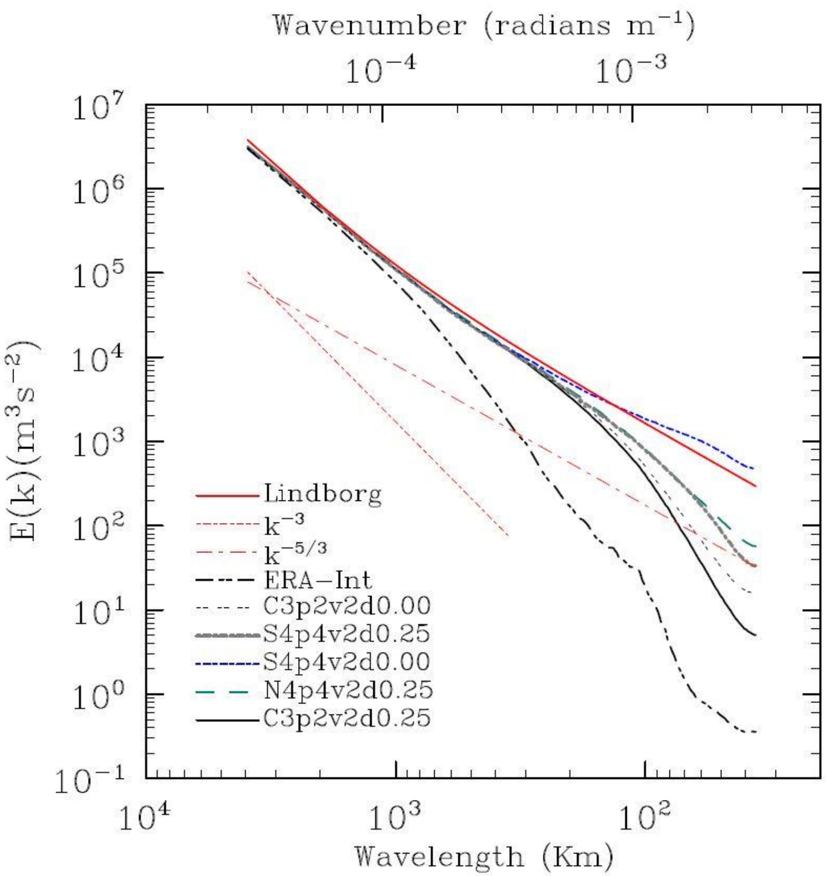
- revision of the Davies-lateral boundary relaxation (Arteaga, Baldauf, Fuhrer, Schneider)
  - ‚implicit' version' has been removed (switch `lexp_lbc` removed)
  - relaxation-coefficient at the boundary =1 → Davies relaxation always sets the correct boundary values
  - switch `crltau` (senseless before!) is replaced by `crltau_inv`
    `crltau_inv`=0 means: no relaxation
- Adaptation of the RK dynamical core (coriolis terms) for SPPT
- advection and horizontal diffusion of TKE (Blahak)
- Removal of inconsistencies (‚hacks') in the tracer module (Roches, Fuhrer)
- Cache optimizations for new fast waves solver (Baldauf)

… **currently running**:

- Revised Bott-scheme (Schneider, Bott (Univ. Bonn), Blahak (DWD)):
  NUMEX-exp. is currently running
- Adaptive time step (Smalla, Reinhard (DWD))

Morinishi et al. (1998) - spatial discretisation

A. Will, J. Ogaja (Univ. Cottbus)



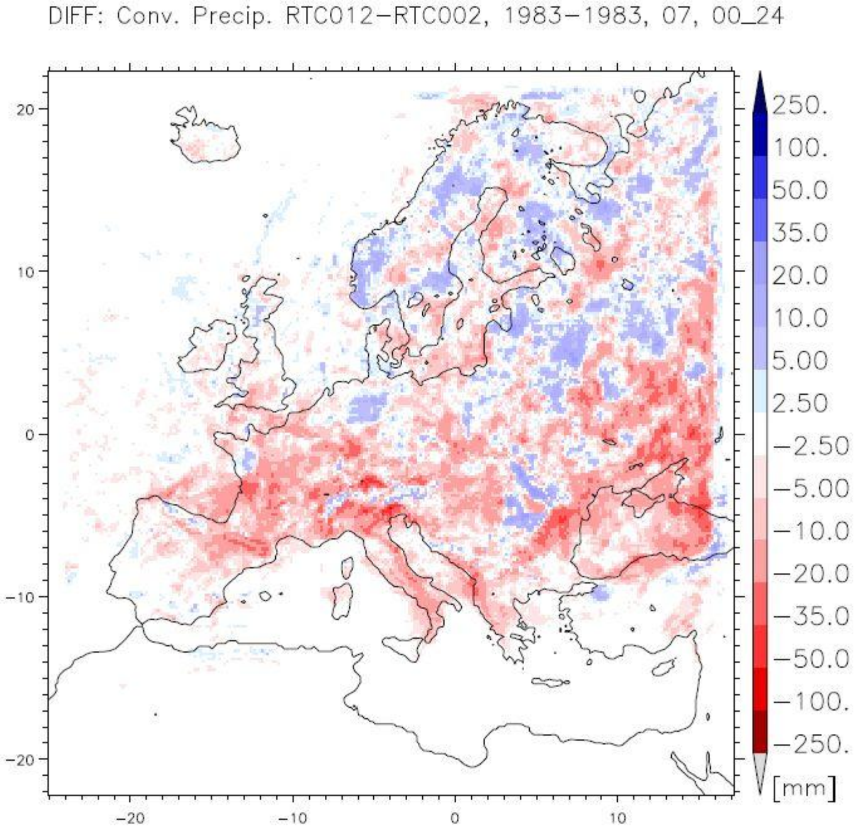
(from *Ogaja, Will, subm. to MetZ*)

main results:

- **power spectrum of kinetic energy** (here: annual (for 1979) and meridional mean for 3-6 km layer) → almost no reduction by the new scheme at small wavelengths!
- climate runs over several years stable without artificial horizontal diffusion!

Linear stability analysis of this new discretization does not show drawbacks!
(→ talk M. Baldauf in WG2 meeting)

however: strong reduction of the convective precipitation part needs a readjustment of some parameterization schemes



(c) PREC_CON

difference in convective precipitation part for month July during 1979-1983 between new scheme S4p4 and current RK dynamical core.
(from *Ogaja, Will, subm to MetZ*)

WG2/CELO meetings in COSMO year 2014

- at CIRA / Capua during 28./29. Oct 2013 (2 days)
  organized by Pier Luigi Vitagliano
  intensive discussion of the COSMO Science Plan 2014-2020
- at 20 March 2014 at DWD (during COSMO User Seminar)

WG2 publications

D. Schuster (2014): *Diskontinuierliche Galerkin-Verfahren für die operationelle Wettervorhersage*, PhD thesis, Univ. Mainz

D. Schuster, S. Brdar, M. Baldauf, A. Dedner, R. Klöfkorn, D. Kröner: *On discontinuous Galerkin approach for atmospheric flow in the mesoscale with and without moisture*, accepted by Met. Z.

M. Baldauf, O. Fuhrer, M. Kurowski, Z. Piotrowski, B. Rosa, P. Vitagliano, D. Wojcek, M. Ziemianski (2013): *The PP Conservative Dynamical Core*, COSMO Technical report no. 23

M. Baldauf, D. Reinert, G. Zängl (2014): *An analytical solution for linear gravity and sound waves on the sphere as a test for compressible, non-hydrsotatic numerical models*, QJRMS

WG2 contributions to the science plan and outlook (1)

1. Further maintenance of the RK dynamical core

- further improve ability to use the COSMO dynamical core in steep terrain ('Mahrer-option' in the new fast waves solver)
- investigate pros and cons of the 3D divergence damping
- investigate Morinishi et al. (1998)-approach
- Further general efficiency increase for cache based architectures
- implementation of additional vertical weightings outside of the fast waves solver.
- variable time steps
- option for a horizontal grid stretching
- Code rewrite of the new fast waves solver with the stencil library STELLA

high priority

WG2 contributions to the science plan and outlook (2)

2. COSMO-EULAG operationalisation (PP CELO)

→ talk by Bogdan Rosa

- general consolidation of the EULAG dynamical core formulation for NWP applications
- adjust flow at the boundaries to satisfy the integrability condition (divergence free flow)
- Use of the hybrid coordinate of COSMO should be possible, while retaining the important tensor identities of EULAG.
- Full pressure recovery
- increase of efficiency of the elliptic solver is needed, mainly by improving the preconditioner and by a possible reduction of global communications.
- possibility of using restart files.
- Code rewrite by the stencil library STELLA
- collaboration with the PantaRhei project at ECMWF

high priority

WG2 contributions to the science plan and outlook (3)

3. Investigation in new Euler solvers based on Finite volume schemes

- Investigate potential of the fully implicit dual time-stepping scheme (Jameson, 1991) (toy model)
- Discontinuous Galerkin discretisation (e.g., Cockburn, 2003) is available in a private COSMO version (basic research)
  - coupling with more physics parameterisations
  - vertically implicit scheme is needed
  - monotonic and positive definite tracer advection schemes

4. Tracer advection schemes

- improve the splitting in the Bott-scheme (Bott, 2010)
- Kaas (2008) method for a local conservative Semi-Lagrangian scheme
- transfer the current 2D-version of MPDATA to fully 3D

WG2 contributions to the science plan and outlook (4)

5. Other tasks

- Further development of the ‘z-diffusion’
- Testing of COSMO with higher model top
- implement a dynamical core test suite

6. Transition to the new model ICON

→ talk by Günther Zängl

- limited area mode of ICON
- comparison of the dynamical core of ICON with COSMO regarding accuracy, stability and efficiency according to methodology developed in the COSMO dynamical core test suite (see section 5.2.5)
- development of a quadrilateral grid version of ICON (depending on the outcome of the comparison)

high priority from ~2017

Deutscher Wetterdienst
Wetter und Klima aus einer Hand

code example:

the Fortran subroutine `calc_Z_horiz` and its corresponding part of the `FastWavesSCVerticalDivergenceHelper`-stencil

(only for demonstration; the real stencil contains more than only this subroutine)

additionally: registration of new variables in Repository files; adaptation of some header-Files

```
SUBROUTINE calc_Z_horiz ( u, v, u_sfc, v_sfc, Z_horiz )

  USE grid_metrics_utilities, ONLY: wgtfac_u, wgtfac_v

  IMPLICIT NONE

  REAL (KIND=wp), INTENT (IN)  :: u(ie,je,ke), v(ie,je,ke)
  REAL (KIND=wp), INTENT (IN)  :: u_sfc(ie,je), v_sfc(ie,je)

  REAL (KIND=wp), INTENT (OUT) :: Z_horiz(ie,je,ke1)

  REAL (KIND=wp),     ALLOCATABLE :: Z_x(:,:), Z_y(:,:)

  INTEGER :: i, j, k
  INTEGER :: istat

  ALLOCATE( Z_x (ie, je), STAT=istat)
  ALLOCATE( Z_y (ie, je), STAT=istat)

  Z_horiz(:,:,1:MAX(1,vcoord%kflat)) = 0.0_wp

  DO k=MAX(2,vcoord%kflat+1), ke

    DO j=jstart, jend
      DO i=istart-1, iend
        Z_x(i,j) =   dz_dlam(i,j,k) *                        &
          &   (           wgtfac_u(i,j,k)   * u(i,j,k  )   &
          &   + ( 1.0_wp - wgtfac_u(i,j,k) ) * u(i,j,k-1) )
      END DO
    END DO

    DO j=jstart-1, jend
      DO i=istart, iend
        Z_y(i,j) =   dz_dphi(i,j,k) * crlat(j,2) *           &
```

```
#include "StencilFramework.h"
#include "DycoreConstants.h"
#include "DycoreGlobals.h"
#include "FiniteDifferenceFunctions.h"
#include "HeightLevelFunctions.h"
#include "FastWavesSCVerticalDivergenceHelper.h"
#include "MathFunctions.h"

/**
 * Stencil function extrapolating the surface velocity
 * using a 1st order method
 */
template<typename TEnv>
struct HorizontalZComponent
{
  STENCIL_FUNCTION(TEnv)

  FUNCTION_PARAMETER(0, dz_dalpha)
  FUNCTION_PARAMETER(1, vel)
  FUNCTION_PARAMETER(2, weight)

  __ACC__
  static T Do(Context ctx)
  {
    return ctx[dz_dalpha::Center()] * (
                   ctx[weight::Center()]  * ctx[vel::Center()]
       + ((T)1.0 - ctx[weight::Center()]) * ctx[vel::At(kminus1)]
         );
  }
};

// define parameter enum
enum
{
```