ACTIVITY PERFORMED AT CIRA WITHIN THE FRAME OF PP-CDC

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OUTLINE

- Motivations and goals
- Basic concepts
- Test cases
- Conclusions

COSMO WG2
Prioritary Project
Conservative Dynamical Core

Goals:

To get a dynamical core with explicit conservation properties: (mass, energy, ..)

To improve capability of the model to work in steep terrain

Motivations:

Conservation of mass, momentum, energy are fundamental principles

Grid size < 3km requires explicit simulation of diabatic processes and steeper slopes

THE ACTIVITY IS FOCUSED ON TWO OBJECTIVES:

- **Test spatial schemes based on Finite Volumes in (ρ, ρ<u>U</u>, ρe) variables set**
- **Test a time integration scheme(*) to be implemented in COSMO**

A CODE FOR IDEALIZED TESTS (CONSOL) WAS INITIALLY DEVELOPED, BASED UPON FINITE VOLUMES AND DUAL TIME STEPPING (DTS)

DTS HAS BEEN IMPLEMENTED IN COSMO, KEEPING ORIGINAL SPATIAL SCHEME. CURRENTLY IN PRELIMINARY TESTING PHASE

(*) Jameson, A., 1991: *Time Dependent Calculations Using Multigrid,with Applications to Unsteady Flows Past Airfoils and Wings.* AIAA Paper 91–1596

MATHEMATICAL FORMULATION

$$\frac{\partial}{\partial t}\int_{\Omega}\underline{W}\,dV + \oint_{\partial\Omega}\underline{\underline{F}}\cdot\underline{n}\,dS = \int_{\Omega}\underline{B}\,dV$$

$$\underline{\boldsymbol{W}} = \begin{bmatrix}\rho' \\ \rho u \\ \rho v \\ \rho w \\ \rho e\end{bmatrix} \quad \underline{\boldsymbol{F}}_x = \begin{bmatrix}\rho u \\ \rho u^2 + p' \\ \rho uv \\ \rho uw \\ \rho uh\end{bmatrix} \quad \underline{\boldsymbol{F}}_y = \begin{bmatrix}\rho v \\ \rho uv \\ \rho v^2 + p' \\ \rho vw \\ \rho vh\end{bmatrix} \quad \underline{\boldsymbol{F}}_z = \begin{bmatrix}\rho w \\ \rho uw \\ \rho wv \\ \rho w^2 + p' \\ \rho wh\end{bmatrix} \quad \underline{\boldsymbol{B}} = \begin{bmatrix}0 \\ 0 \\ 0 \\ \rho' g_z \\ \rho \underline{U}\cdot\underline{g}\end{bmatrix}$$

$$p = p_0 + p' \qquad \underline{U} = (u, v, w) \qquad p = (\gamma - 1)\rho\left(e - \frac{1}{2}U^2\right)$$

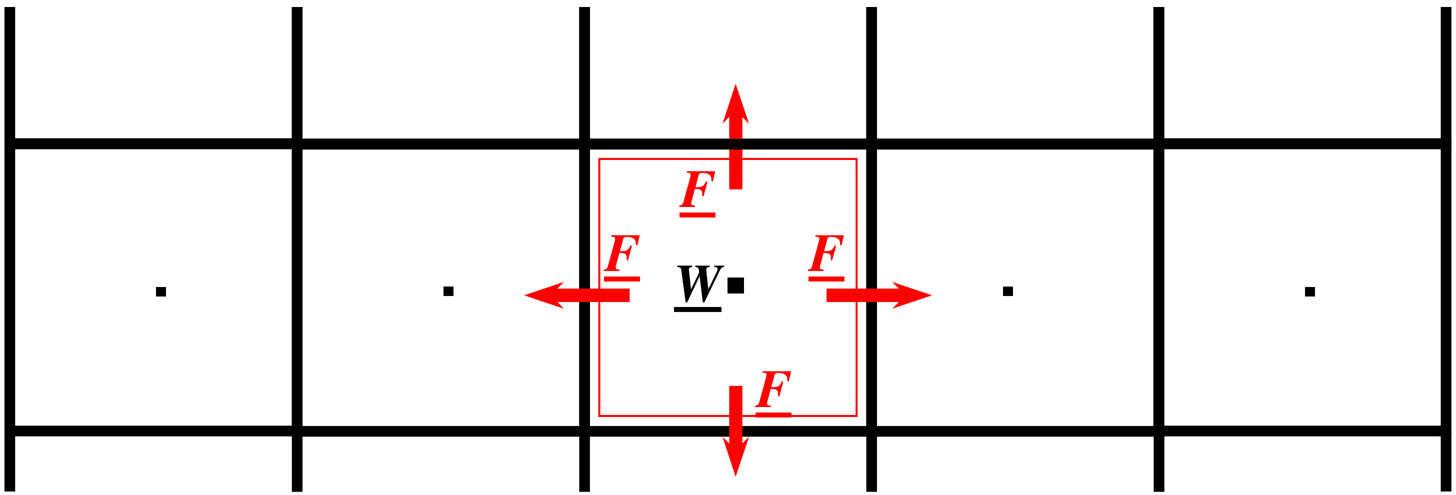
$$\rho = \rho_0 + \rho'$$

$$p_{0_z} = g\rho_0 \qquad h = e + \tfrac{p}{\rho}$$

conservation of mass, momentum and total energy are physical fundamental principles

SPATIAL DISCRETISATION

- Integral form allows discontinuities in the flow field
- Finite Volumes approach
- Conservation laws applied to each sub-domain (cell)
- Variables stored at cell centers
- Fluxes approximated at cell face centers
- Artificial dissipation and diffusion in flux form
- No constraints for cells shape and size (clustering)



DUAL TIME STEPPING

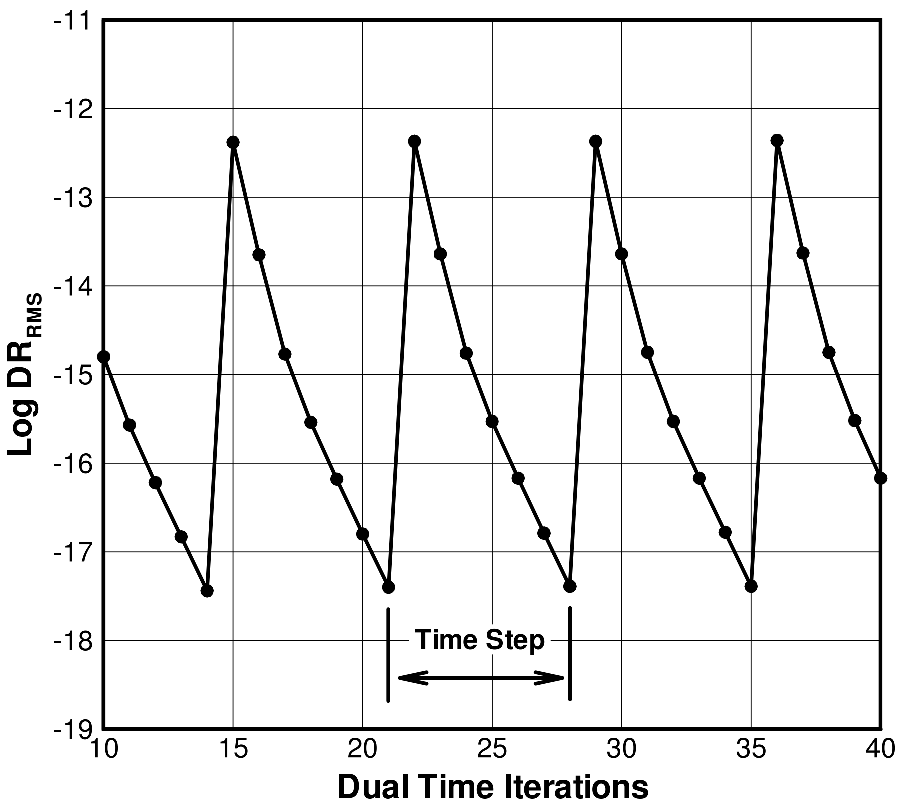
$$\partial \underline{W}^{new}/\partial\tau + \tfrac{1}{2}(3\underline{W}^{new} - 4\underline{W}^{now} + \underline{W}^{now-1})/\Delta t + R(\underline{W}^{new}) = 0$$

add a pseudo-time τ derivative to the unsteady equation
advance the solution in τ until the residual of the unsteady equation is negligible

iterations in τ are performed by explicit Runge-Kutte scheme
convergence acceleration techniques can be adopted without loss of time accuracy: residual averaging, local time stepping, multigrid

formulation is A-stable and damps the highest frequency
very large physical time step Δt can be used

DUAL TIME STEPPING

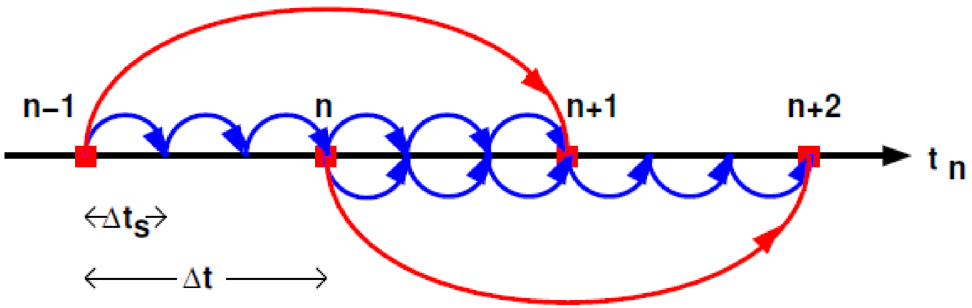


Example of time integration with DTS:
a norm of the residuals of mass transport equations is monitored

TIME INTEGRATION

CURRENT TIME INTEGRATION SCHEME IN COSMO IS A Time-Splitting Method (*)

It is based on 3 stages RK (or Leap-Frog) for the large time steps and modified Crank-Nicholson for the small time steps

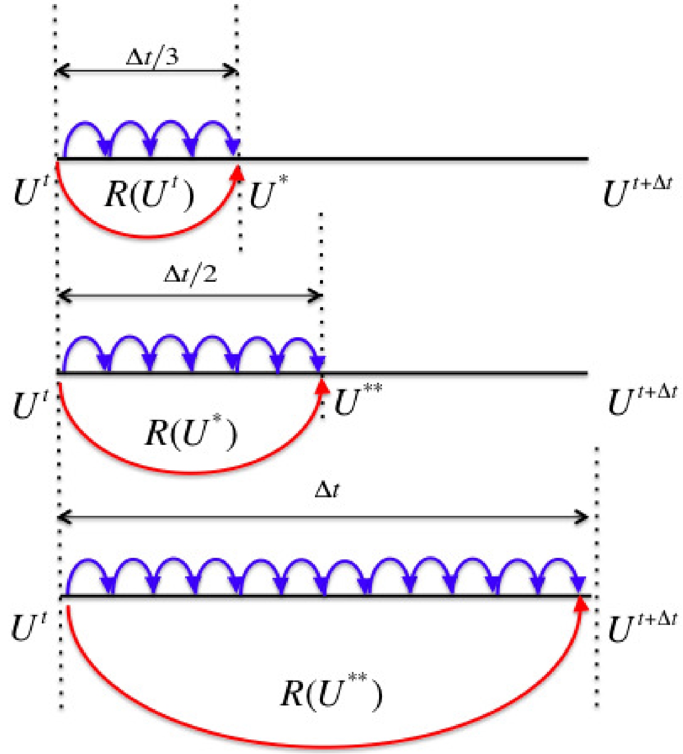


The Klemp-Wilhelmson time splitting algorithm, based on Leap-Frog for large time step

(*) Wicker, L.J., and Skamarock, W.C., 2002: *Time-Splitting Methods for Elastic Models Using Forward Time Schemes.* Mon.Wea.Rev. **130,** 2088-2097

Runge-Kutta 3 stages time iterations in COSMO

- variables are re-computed advancing in physical time with two different time steps.



The Klemp-Wilhelmson time splitting algorithm, based on Runge-Kutta 3 stages for large time step

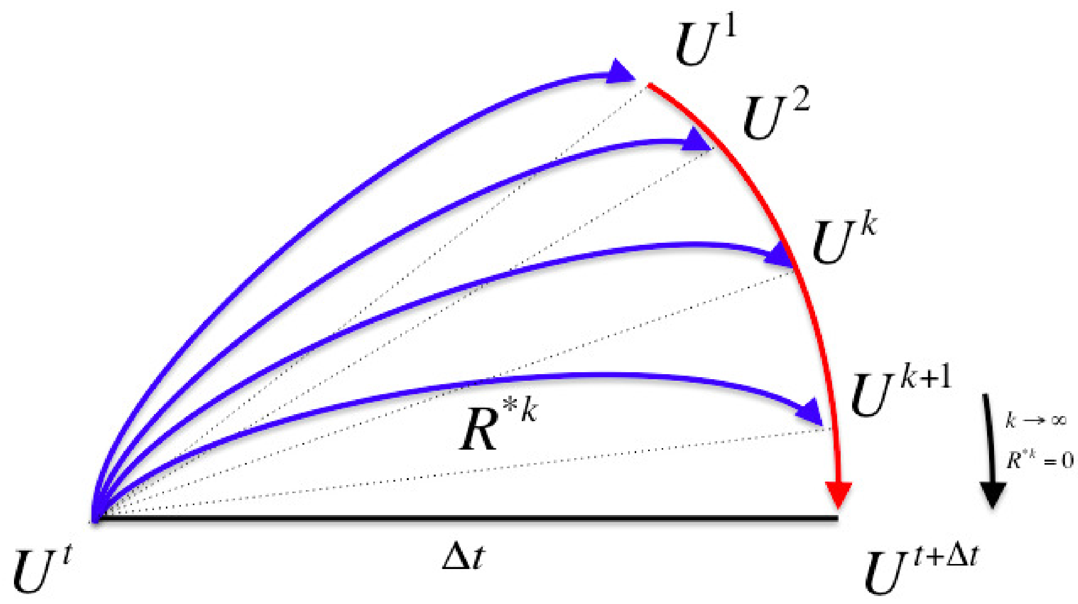
TIME INTEGRATION WITH DTS

- variables are re-computed until a physical time step is converged within a given accuracy

- instead of a number of small steps for three RK stages, a number of (multi)stages

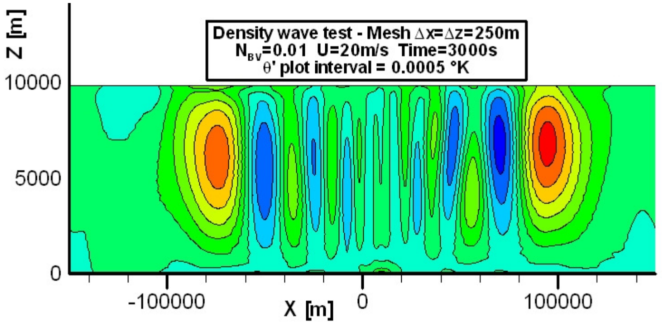
- acceleration techniques non time accurate are allowed: residuals averaging, preconditioning, local time stepping, multigrid

Dual time iterations

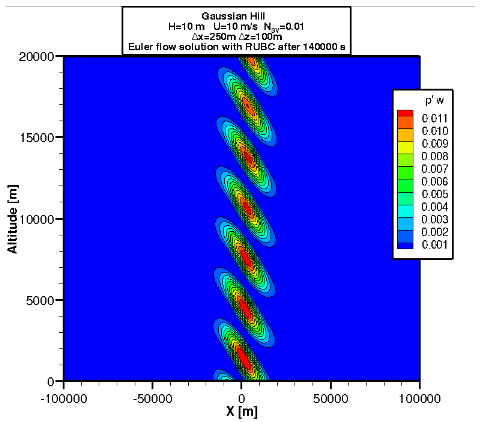


Convergence toward time t+Δt

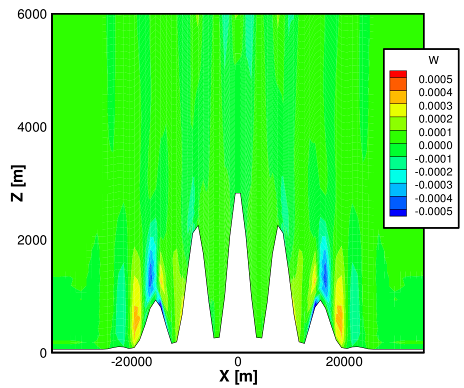
IDEAL TEST CASES PERFORMED WITH CONSOL



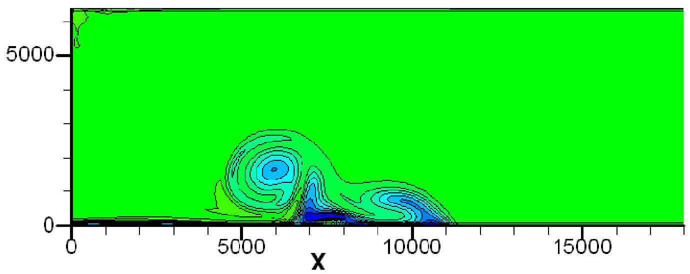
INERTIA-GRAVITY WAVE



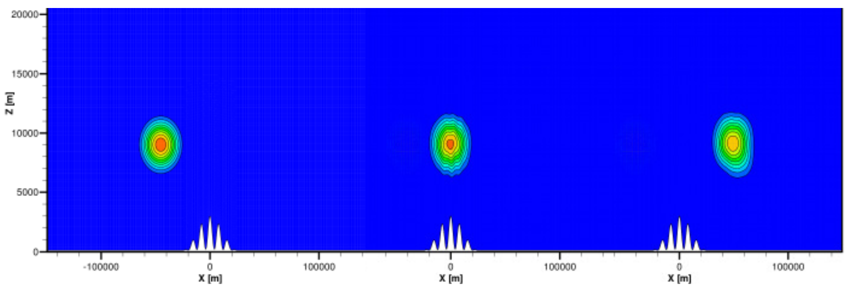
GAUSSIAN HILL



ATMOSPHERE AT REST



DENSITY CURRENT

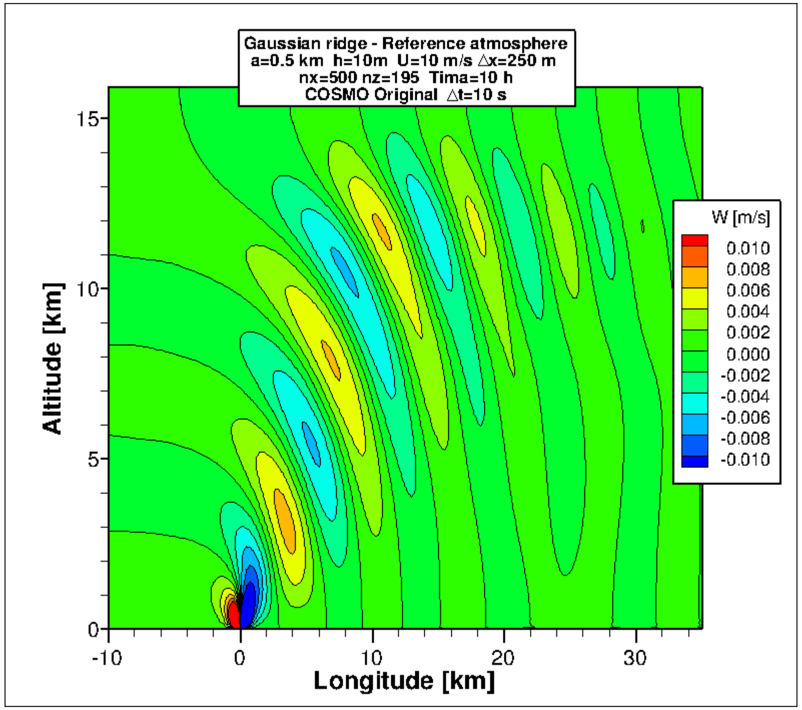


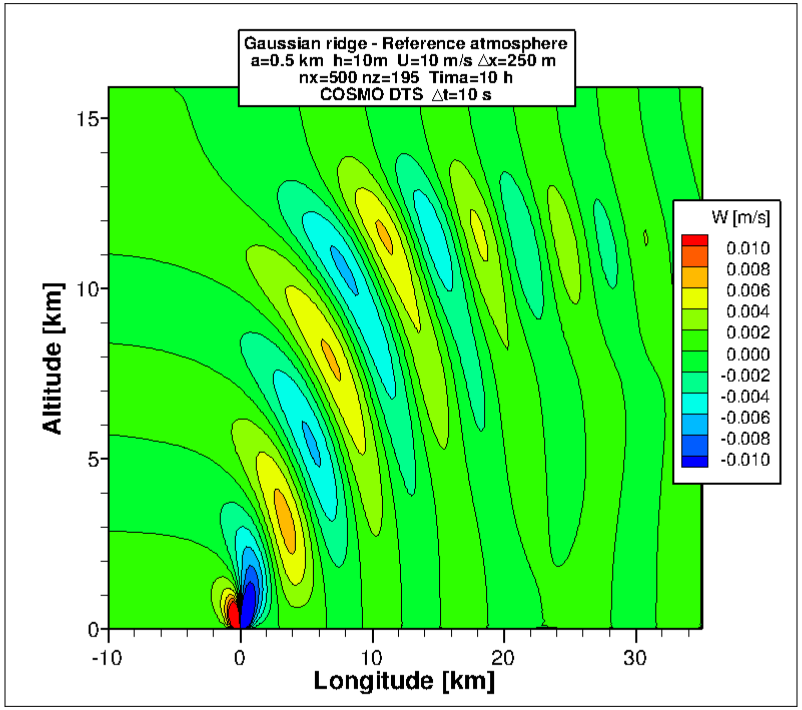
TRANSPORT OF CONSERVED QUANTITY

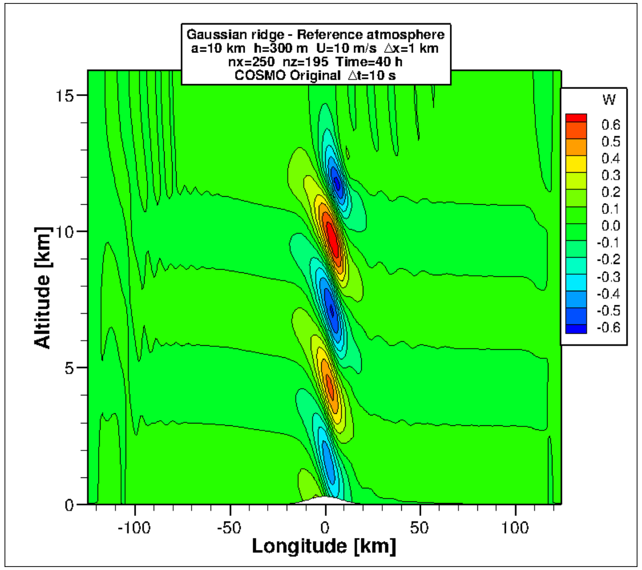
IMPLEMENTATION OF DTS IN COSMO

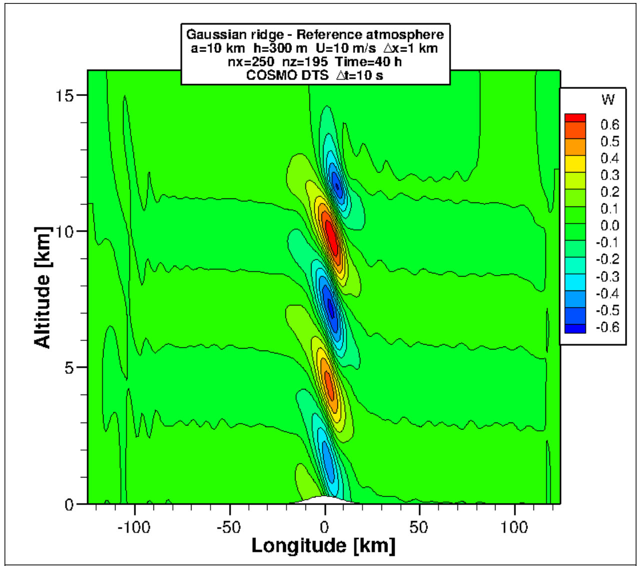
- Test code in development
- Limited intervention on original COSMO
- Major modifications in 2 subroutines only
- COSMO data structure not modified
- Currently only initial tests with idealised cases

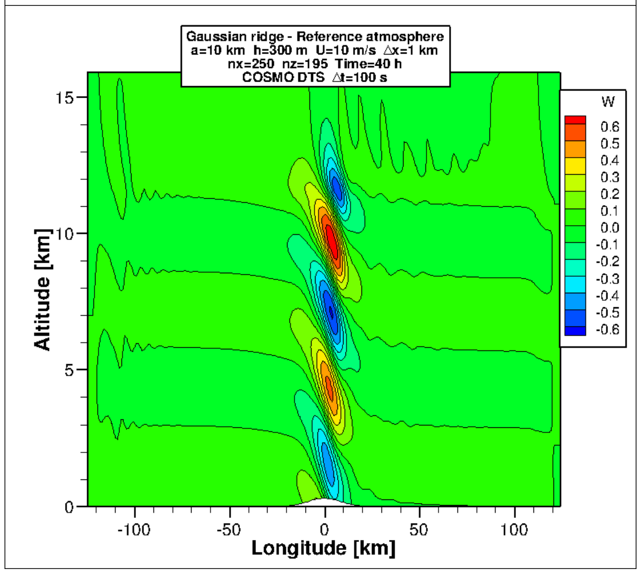
COMPARISON RK3 vs DTS
Gaussian ridge h=10 m a=0.5 km





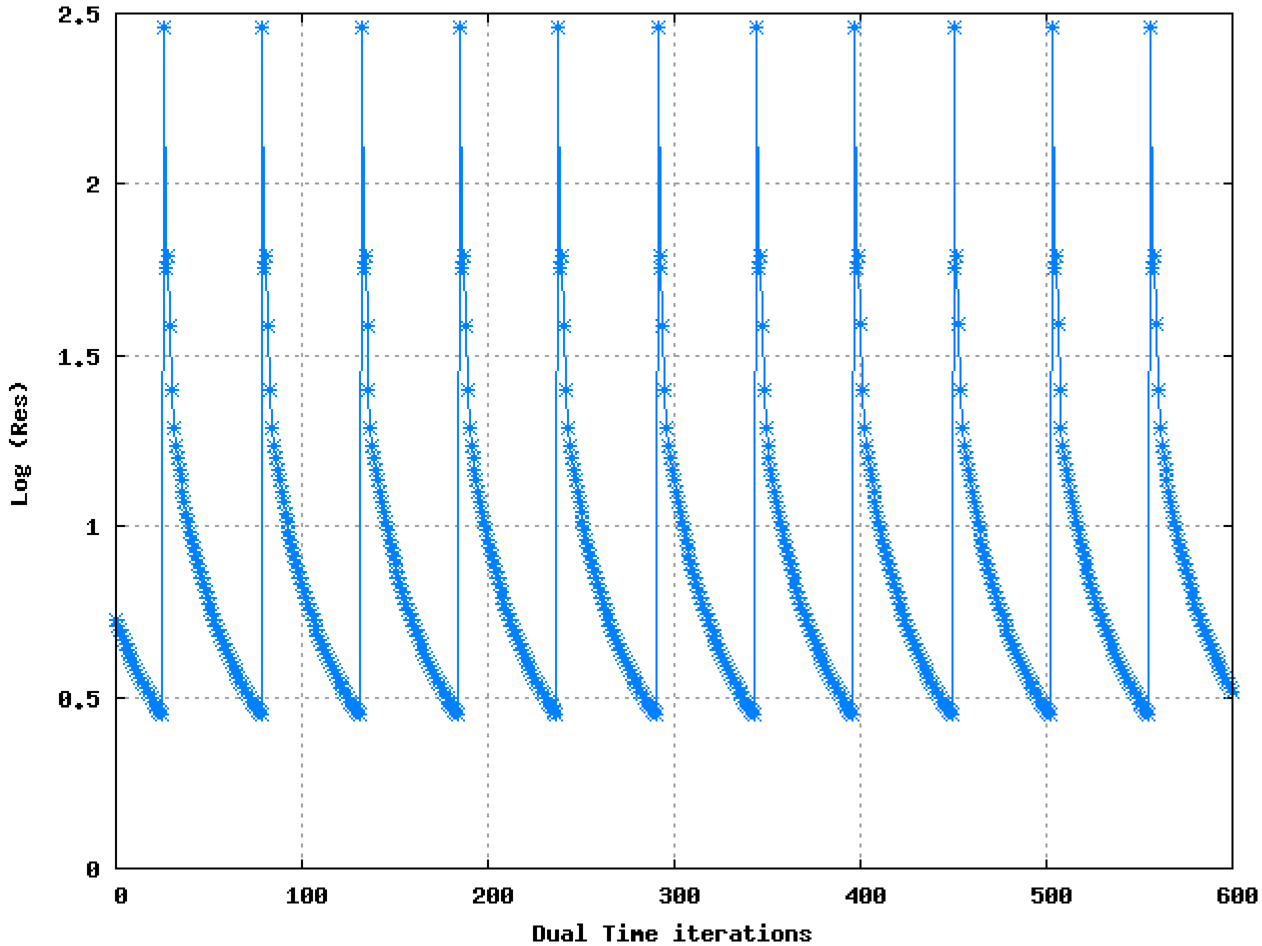






COMPARISON RK3 vs DTS
Gaussian ridge h=300 m a=10 km

DTS Gaussian ridge h=300 m a=10 km
Δx=1 km dt=100 s



CONCLUSIONS (1)

- FV and DTS implemented in CONSOL can simulate the test cases
- DTS works with a wide range of time steps
- II order spatial schemes (cell center) require denser mesh
- Specific treatment of pressure gradient term could improve accuracy

CONCLUSIONS (2)

- DTS implemented in COSMO works with some ideal test cases
- Results are comparable with original COSMO version
- Larger time steps can be achieved
- More work is required to evaluate efficiency and accuracy