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COSMO in Single Precision

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Overview

- Single precision (SP) implementation of COSMO
  $\rightarrow$Single switch to set precision: `-DSINGLEPRECISION`
- Single vs. double precision (DP):
  How precise are floats represented?
  $\rightarrow$Trade-off: precision vs. resources
- Benefits: less resources, reduced runtime (60%)
- Previous work:
  - K. Riedinger (BSc 2011): Fast wave solver runs in SP
  - J. Despraz (Intern 2012): Physics run in SP with some changes (except for radiation); SP prototype of COSMO

Floating-point numbers

- Stored in binary form: 273.15 = 0100001110001000...
- Characterized by 3 properties:
  - Sign: plus/minus
  - Exponent: order of magnitude
  - Mantissa: significant digits

	max	min	digits	precision
single	10^{38}	10^{-38}	7.2	10^{-7}
double	10^{308}	10^{-308}	16.0	10^{-16}

- Fortran: SP if not declared otherwise (compiler dependent)

COSMO: Present situation

- Runs principally in double precision
- Style guide: declare all Reals as 'ireals' (i.e. double)
  →`REAL(KIND=ireals) :: x`
  →`x = 0.5_ireals * y`
  →`var_r = REAL(var_i,ireals)`
- Problem: many `_ireals` missing →many SP Reals
  →Additional +60% `_ireals` in 72/131 files
- Undeclared Reals introduce physically random noise
  →Relative magnitude 1E-7

Steps towards single precision

1. Add all missing ireals declarations
   →Changes results of all runs (inevitably)
   →Only changes having significant effects in DP

2. Various local changes
   - Add epsilons to some divisions to prevent division by zero
     →e.g. `x = y / MAX(z,repsilon)`
   - Adapt some epsilons
     →e.g. `zepclc = MAX(1.0E-8_ireals,rprecision)`
   - Optimize some formulas
     →e.g. `a**4/b**3` →`a*(a/b)**3`

3. Mixed precision implementation of radiation
   →Some routines don't work in SP (`inv_th/so, coe_th/so`)
   →Major part of radiation always runs in DP

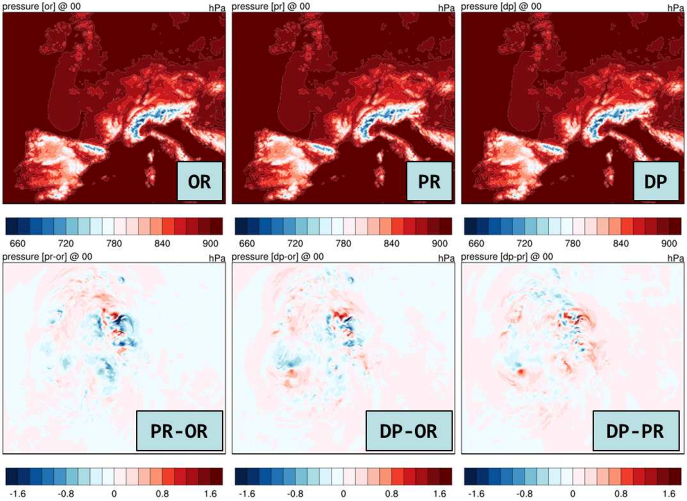
Sensitivity experiments

- Validation of code changes (COSMO-4.26)
- Setup of COSMO-7 for +72h lead time
- Main code versions:
  - Original version 4.26 (OR)
  - Modified code in double precision (DP)
  - Modified code in single precision (SP)
- Two sets of experiments:
  - Perturbation $\rightarrow$validate DP
  - Single precision $\rightarrow$validate SP

Perturbation experiments: Overview

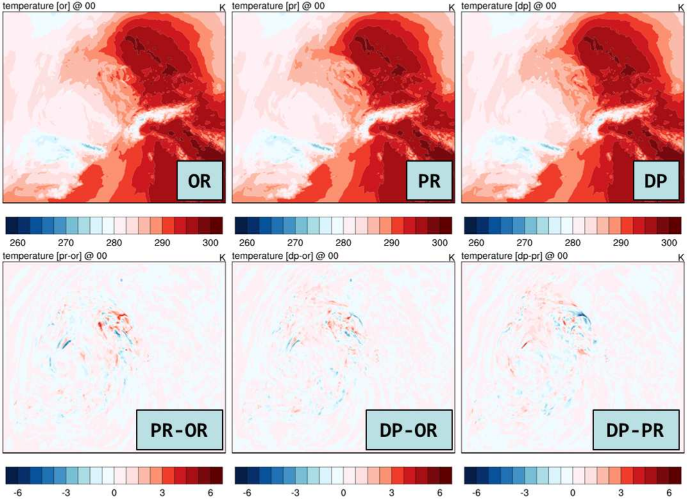
- Aim:
  - Validate new code in DP
- Hypothesis:
  - Differences DP-OR only due to additional ireals
  - Missing ireals equivalent to random perturbations
- Method:
  - Create code with random perturbations (PR)
    $\rightarrow$Relative magnitude $1E-7$
    $\rightarrow$Added to all fields every time step
  - Compare 72h runs of OR, PR, and DP

Perturbations experiments: P @ 72h



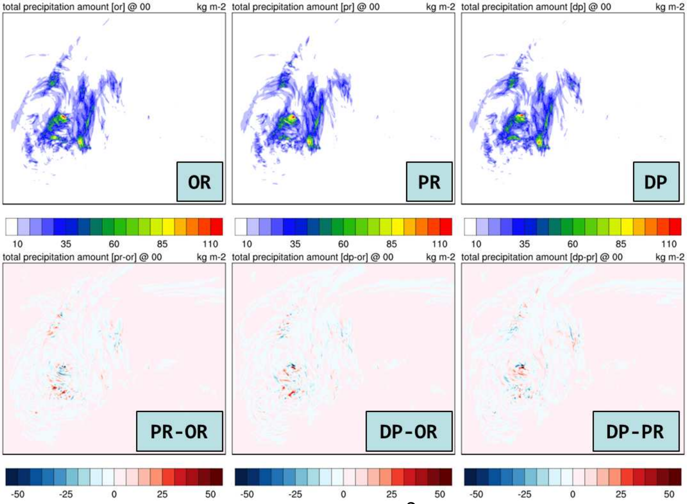
$\pm 1.6 hPa$

Perturbations experiments: T @ 72h



$\pm 6.0K$

Perturbations experiments: Prc @ 72h

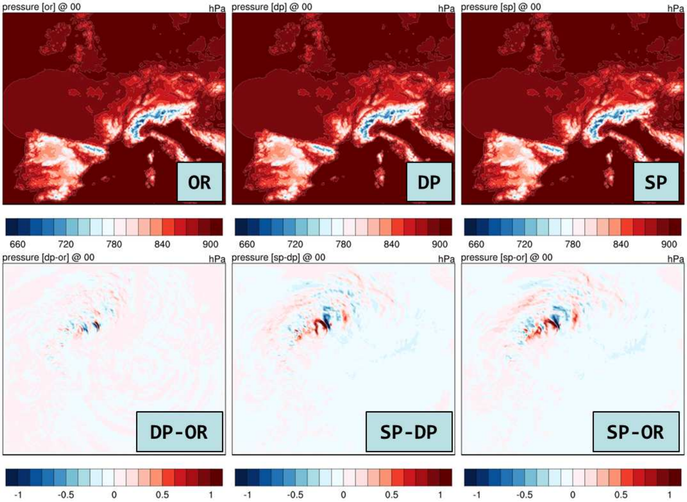


$\pm 50.0 kgm^{-2}$

Single precision experiments: Overview

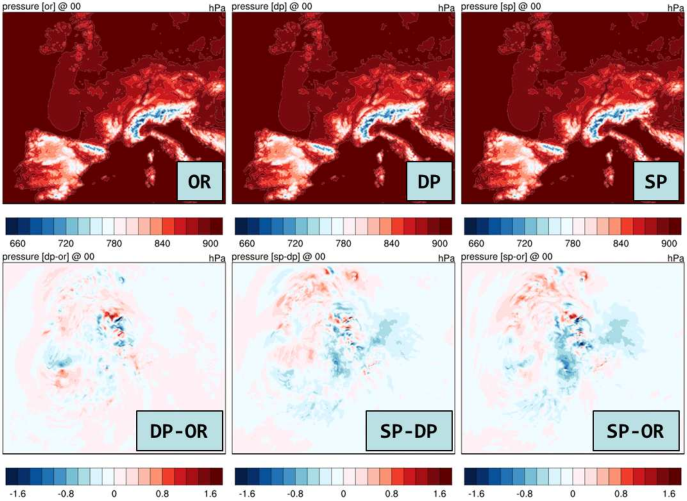
- Aim:
  - Validate new code in SP
- Method:
  - Compare 72h runs of OR, DP, and SP

Single precision experiments: P @ 12h



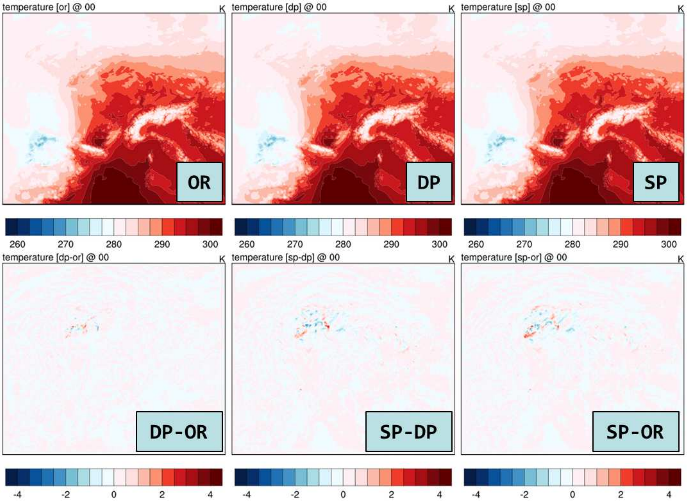
$\pm 1.0 hPa$

Single precision experiments: P @ 72h



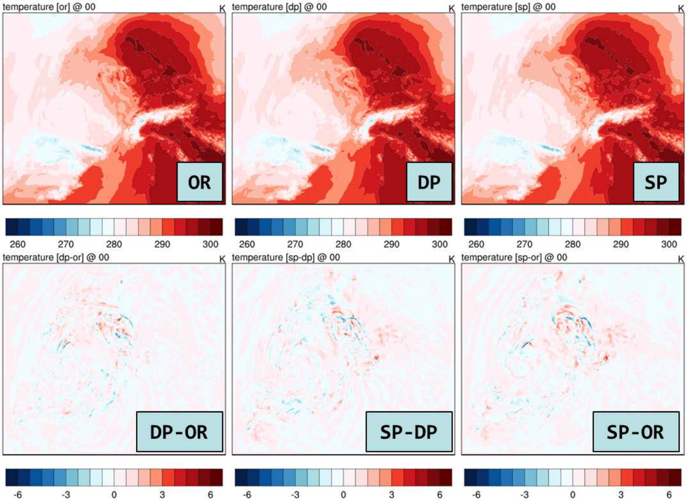
$\pm 1.6 hPa$

Single precision experiments: T @ 12h



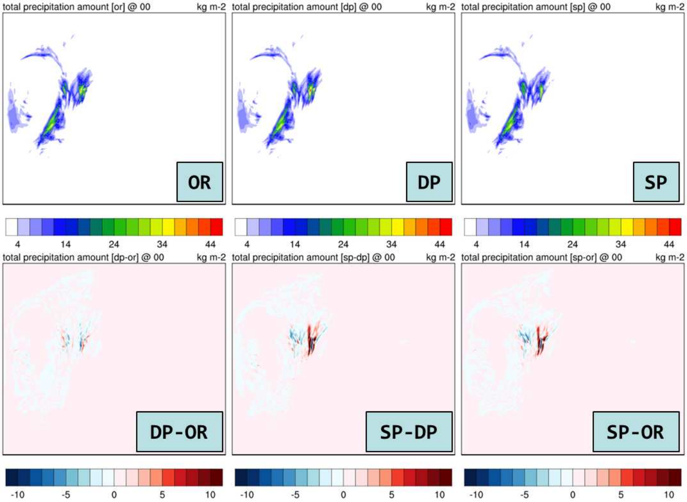
$\pm 4.0K$

Single precision experiments: T @ 72h



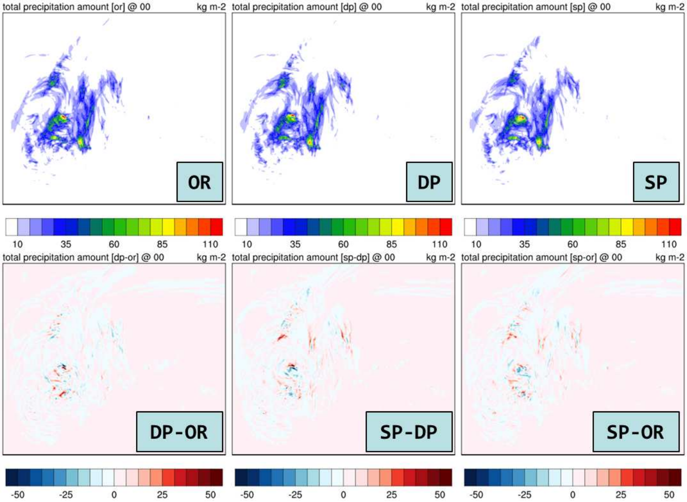
$\pm 6.0K$

Single precision experiments: Prc @ 12h



$\pm 10.0 kgm^{-2}$

Single precision experiments: Prc @ 72h



$\pm 50.0 kgm^{-2}$

Sensitivity experiments: Results

- Perturbation:
  - Deviations DP-OR and PR-OR comparable
- Single precision:
  - After 12h deviations SP-OR clearly larger than DP-OR
  - After 72h deviations SP-OR comparable to DP-OR
- Conclusions:
  - DP: should be able to fully replace OR
  - SP: should be good enough for many applications
- Code ready for validation against observations

Verification: Overview

- Comparison to observations (ground stations and sounding)
- Setup: COSMO-2, lead up to +120h (soundings: +72h)
- One summer and one winter month
- Result: same skill as OR (both in DP and SP)
- Caution: large deviations might not show up in verification
  - Thunderstorms in summer (both DP-OR and SP-OR)
  - Snow-bug: huge anomalies only seen as small deviations

$\rightarrow$Look at plots at the slightest suspicion

Verification: Timings

- Mean relative runtime of verification runs:

100.0%	OR	Original code (reference)
102.0%	DP	Modified code in double precision
60.2%	SP	Modified code in single precision
56.2%	SPi	SP without `-Kieee`
55.9%	SPf	SP with `-Mfprelaxed`

- DP slightly slower than OR (mainly radiation)
- SP drastically faster: runtime reduced to 60%
  $\rightarrow$even faster with aggressive optimization

Summary and Outlook

- Successfully implemented precision switch in COSMO-4.26
- Only major part not running in SP is radiation
  →Must partly run in DP (mixed precision implementation)
- Verification: same skill as original code in both DP and SP
- Runtime reduced to 60% in SP (COSMO-2 setup)
- Next steps:
  - COSMO-5.0 in single precision
  - Bring changes back into official COSMO version
  - Test SP implementation on GPU →timings

Q&A

Precision in Fortran

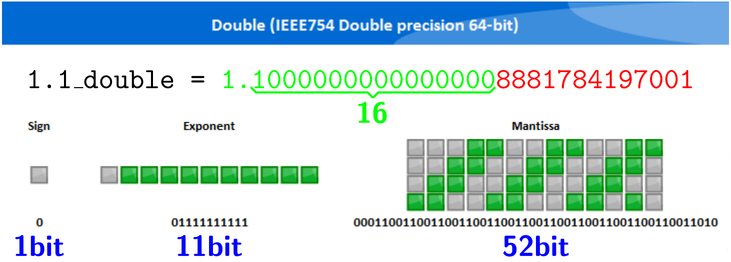
- Undeclared floats introduce random noise (10^{-7} rel. to 1)
- COSMO: `_ireals`; soon: `_wp` (working precision)

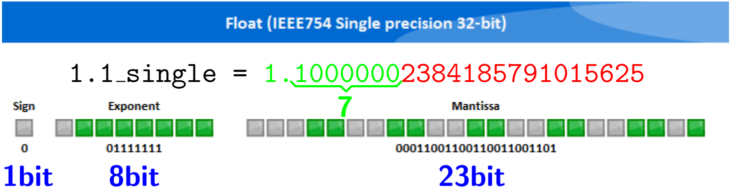
```fortran
PROGRAM sample
  IMPLICIT NONE
  INTEGER,PARAMETER :: sp = 4 ! single precision
  INTEGER,PARAMETER :: dp = 8 ! double precision
  REAL(KIND=sp)     :: single_sp
  REAL(KIND=dp)     :: double_dp, double_sp, double_no

  double_dp = 1.1_dp ! correctly declared as double
  single_sp = 1.1_sp ! correctly declared as single
  double_sp = 1.1_sp ! wrongly declared as single
  double_no = 1.1    ! missing declaration

  print*, 'double_dp',double_dp             ! =>  double_dp   1.1000000000000001
  print*, 'single_sp',single_sp             ! =>  single_sp   1.1000000
  print*, 'double_sp',double_sp             ! =>  double_sp   1.1000000238418579
  print*, 'double_no',double_no             ! =>  double_no   1.1000000238418579
END PROGRAM sample
```

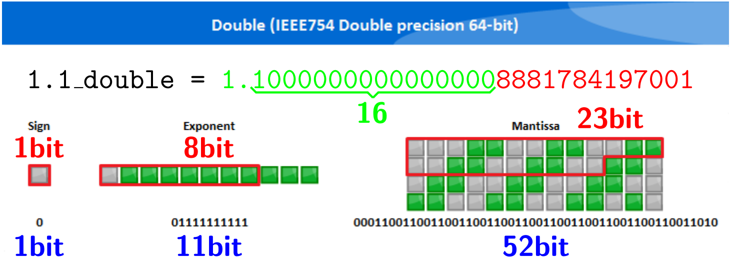
Single vs. double precision

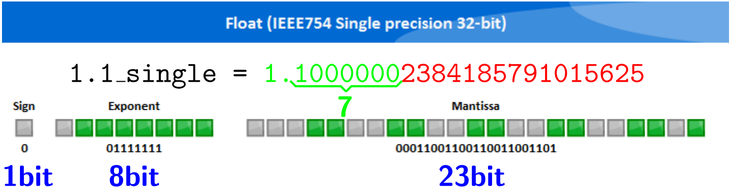




source: www.binaryconvert.com

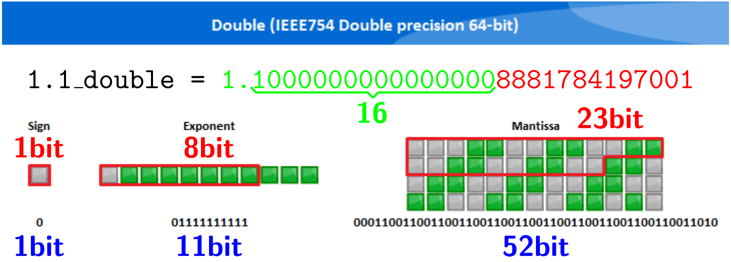
Single vs. double precision

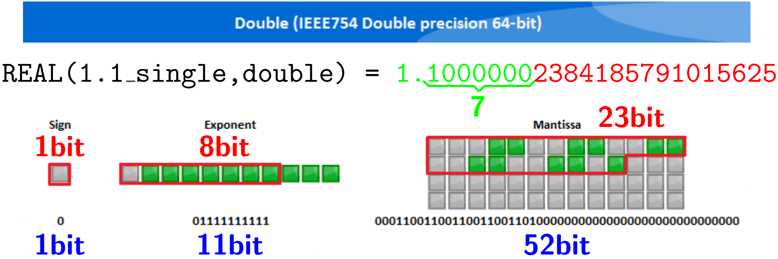




source: www.binaryconvert.com

Single vs. double precision





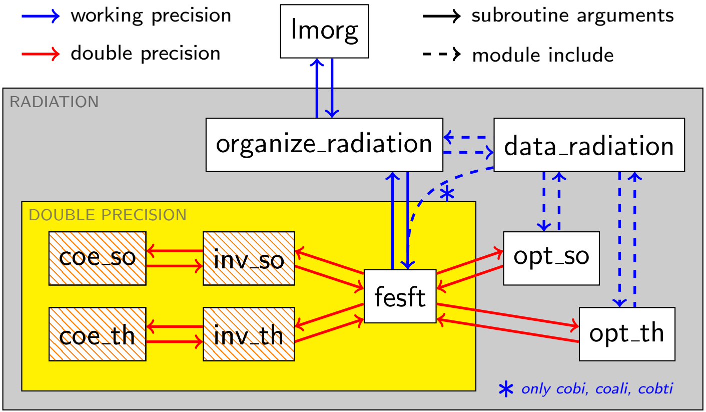
source: www.binaryconvert.com

Ireals declarations: Summary

- Missing _ireals declarations added by script
- Overall +60% _ireals in 72/131 files
- Majority spread over 2/3 of src-files

	nf	nf*	nold	del	del%	del%*
src_*	60	43	6276	4299	68.5	81.9
data_*	27	4	791	1141	144.3	967.0
rest	44	25	3026	682	22.5	26.6
total	133	72	10093	6122	60.7	76.2

nf	total number of files	del	number of _ireals added (delta)
nf*	number of changed files	del%	relative delta (all files)
nold	initial number of _ireals	del%	relative delta (only changed files)



working precision
double precision
lmorg
subroutine arguments
module include
RADIATION
organize_radiation
data_radiation
DOUBLE PRECISION
coe_so
inv_so
coe_th
inv_th
fesft
opt_so
opt_th
* only cobi, coali, cobti