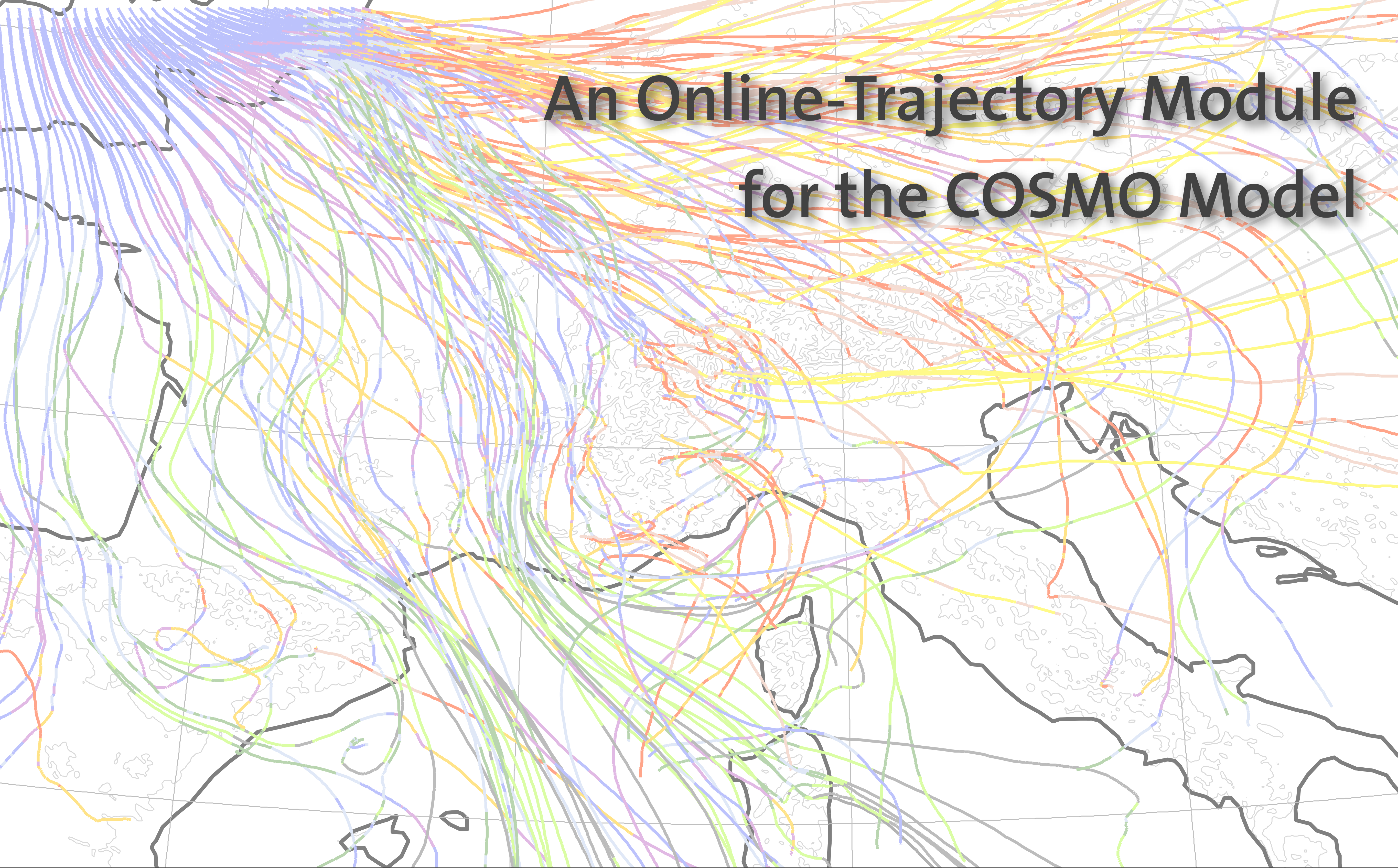

An Online-Trajectory Module for the COSMO Model

Annette K. Miltenberger [1], Stephan Pfahl [1] and Heini Wernli [1]

[1] *Institute for Atmospheric and Climate Science, ETH Zurich*

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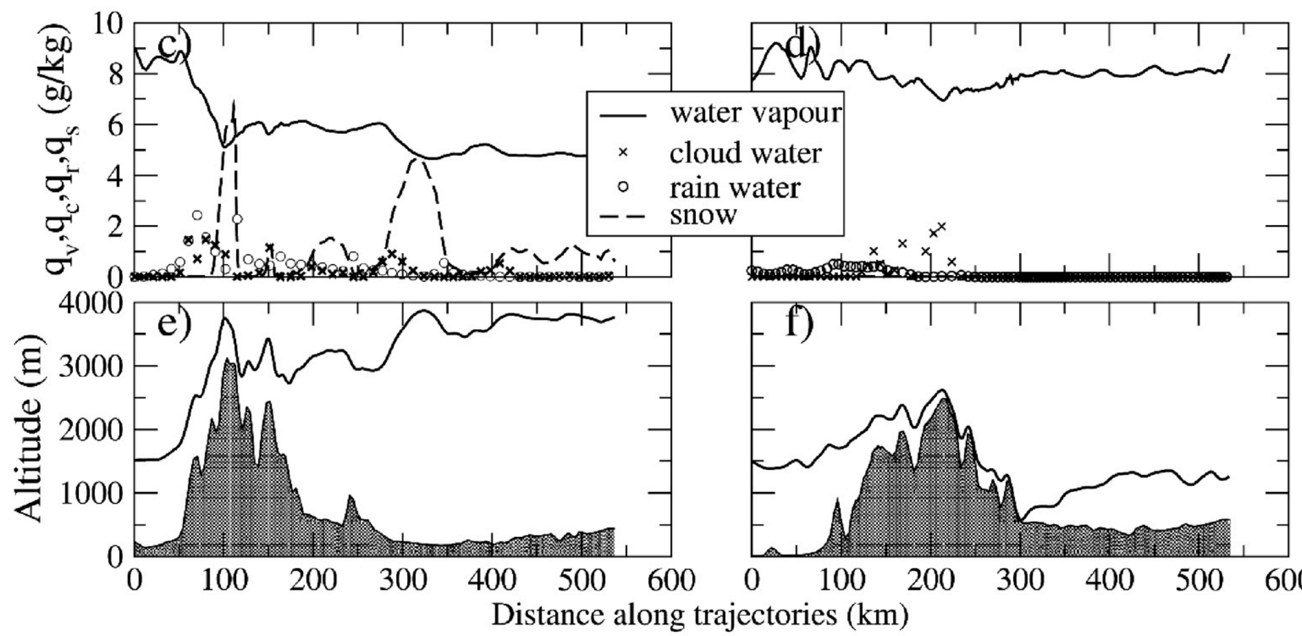
ETH
Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

the Lagrangian approach

the Lagrangian approach

Föhn - air mass transformation & precipitation

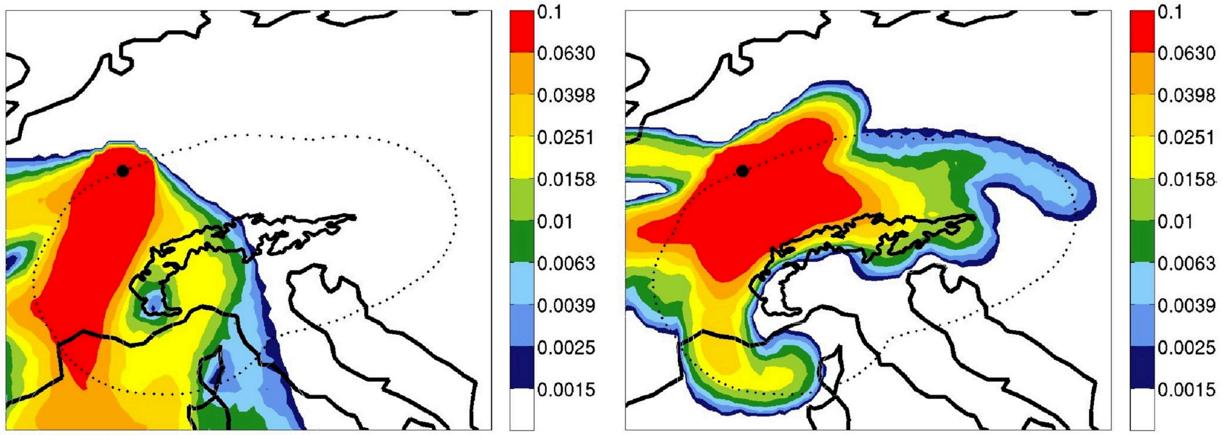
(Smith et al., 2003)



the Lagrangian approach

Orographic blocking

(Master thesis Alexandre Roch, 2011)



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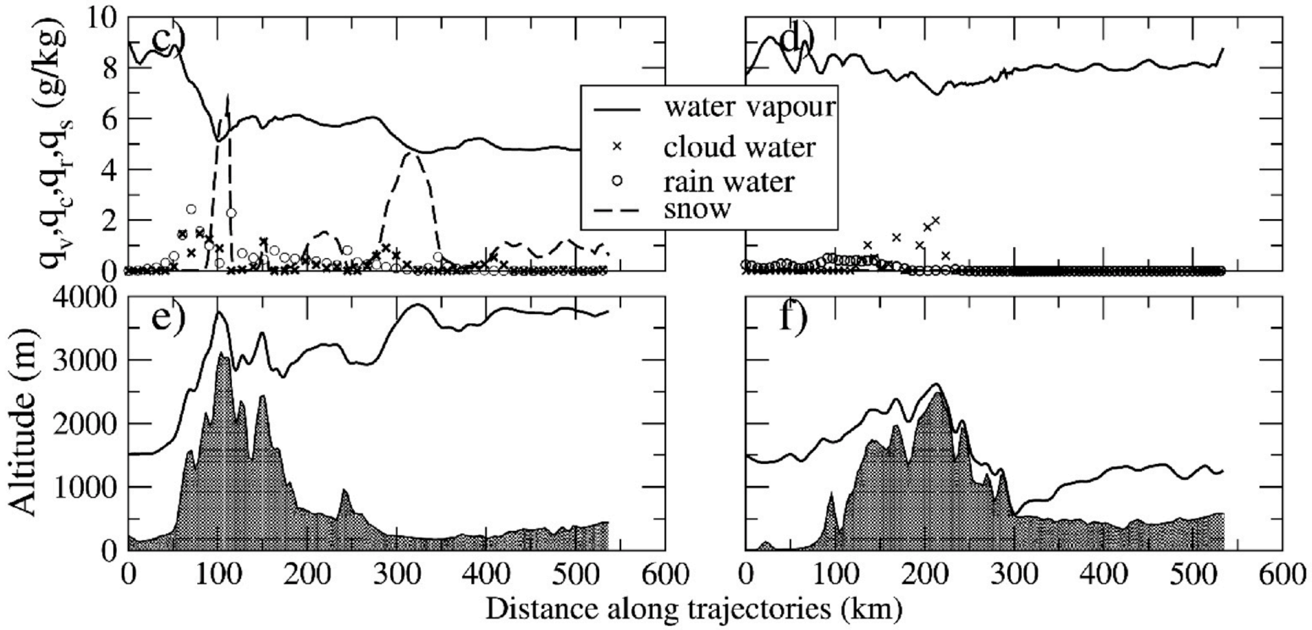

the Lagrangian approach

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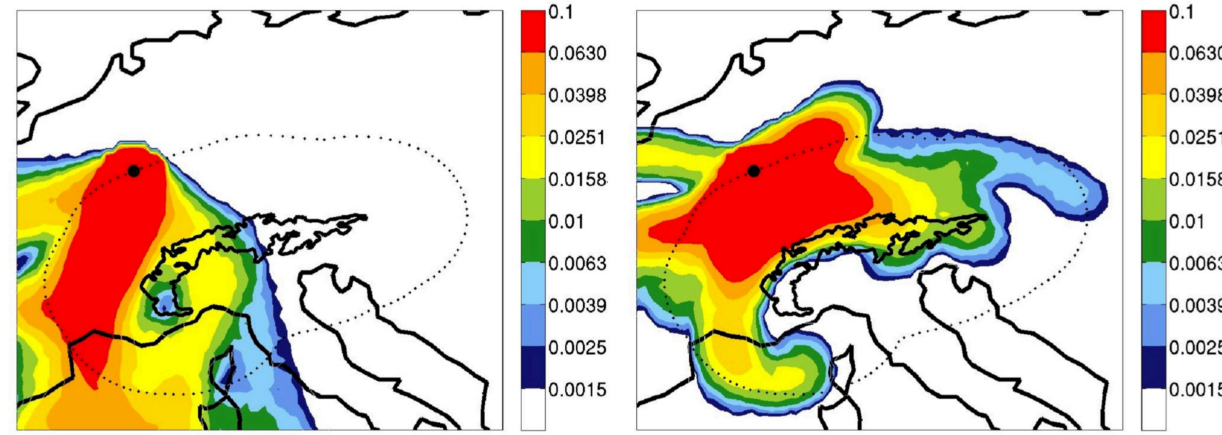
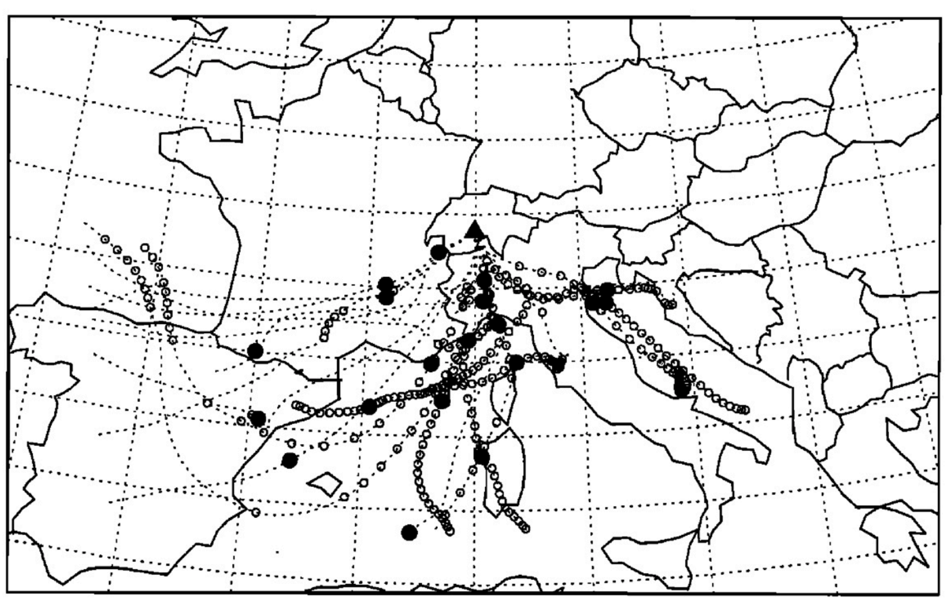


Trace gas variability at Jungfraujoch
(Forrer et al., 2000)



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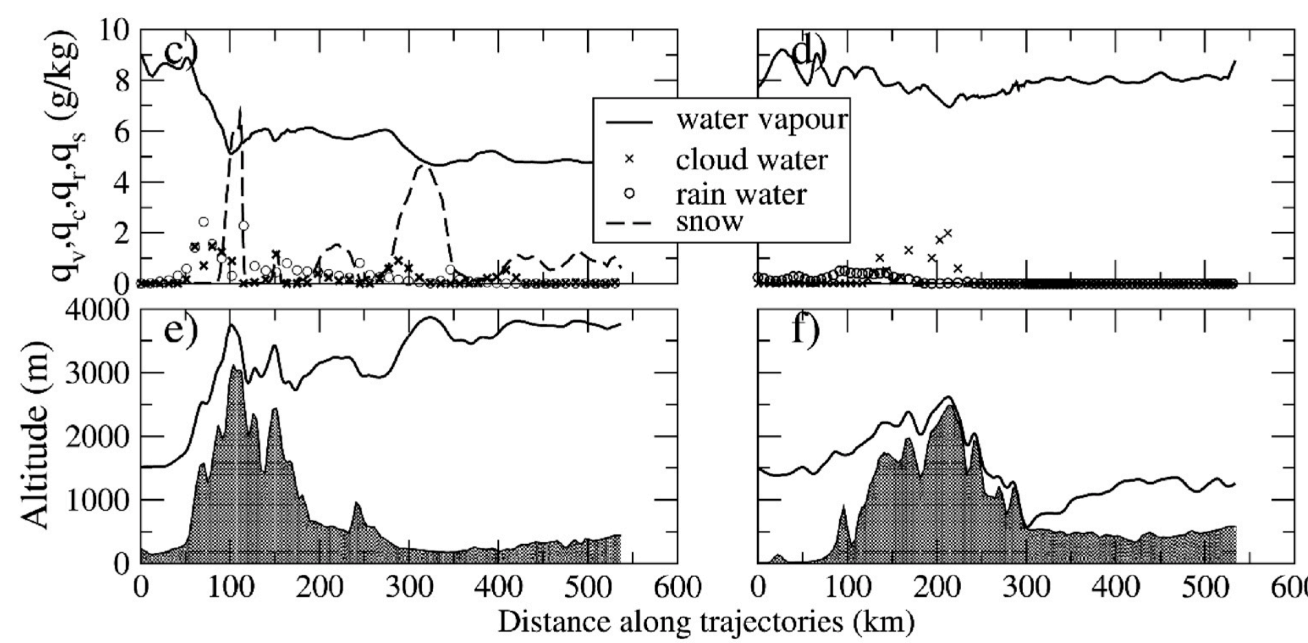
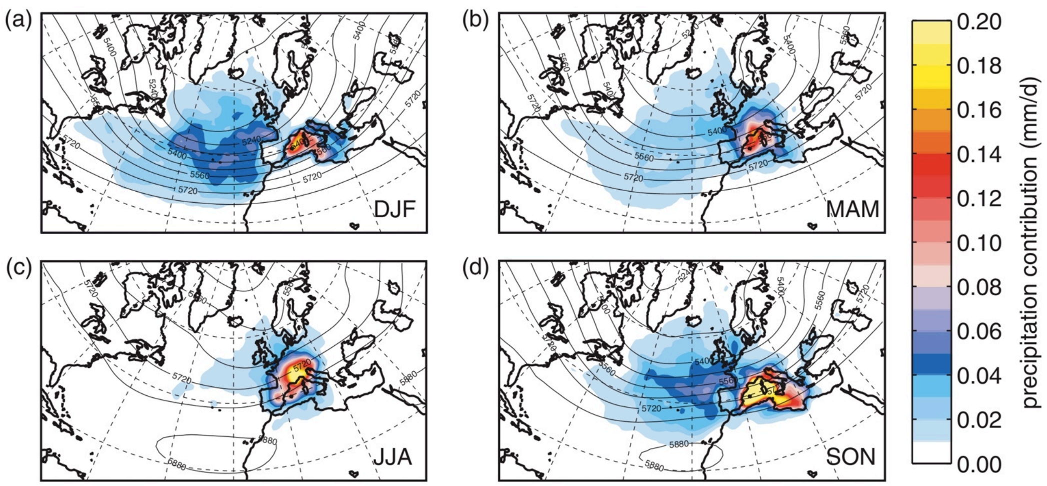


the Lagrangian approach

Moisture sources for Alpine precipitation
(Sodemann and Zubler, 2010)



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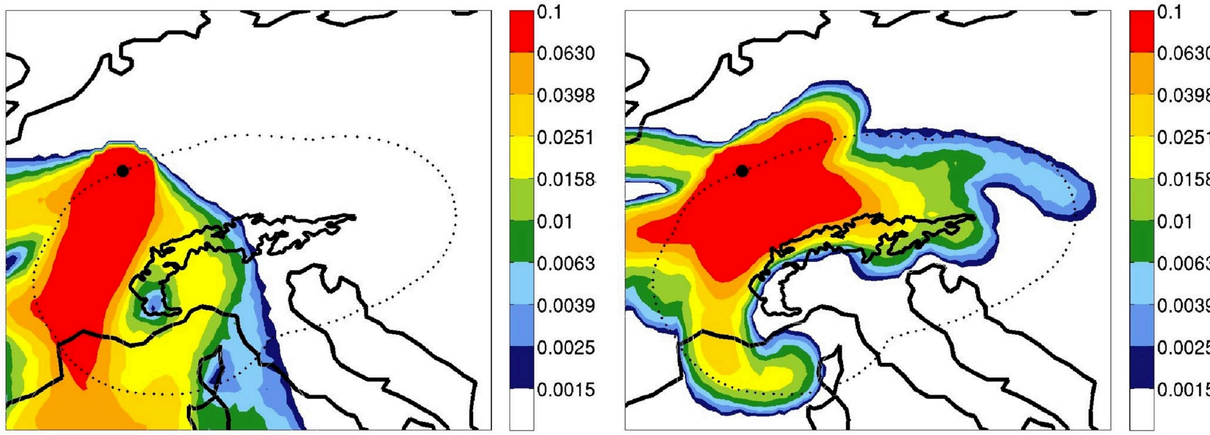

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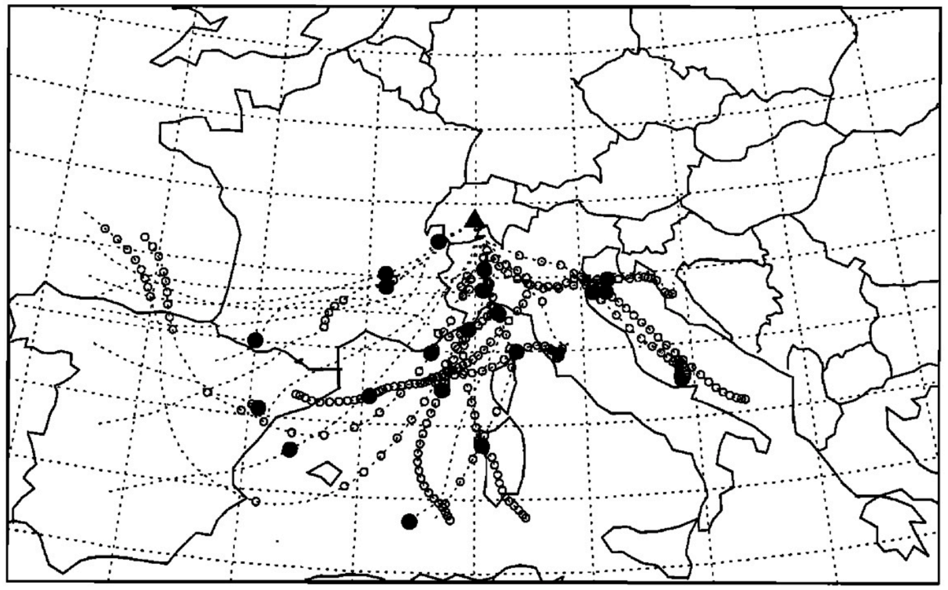

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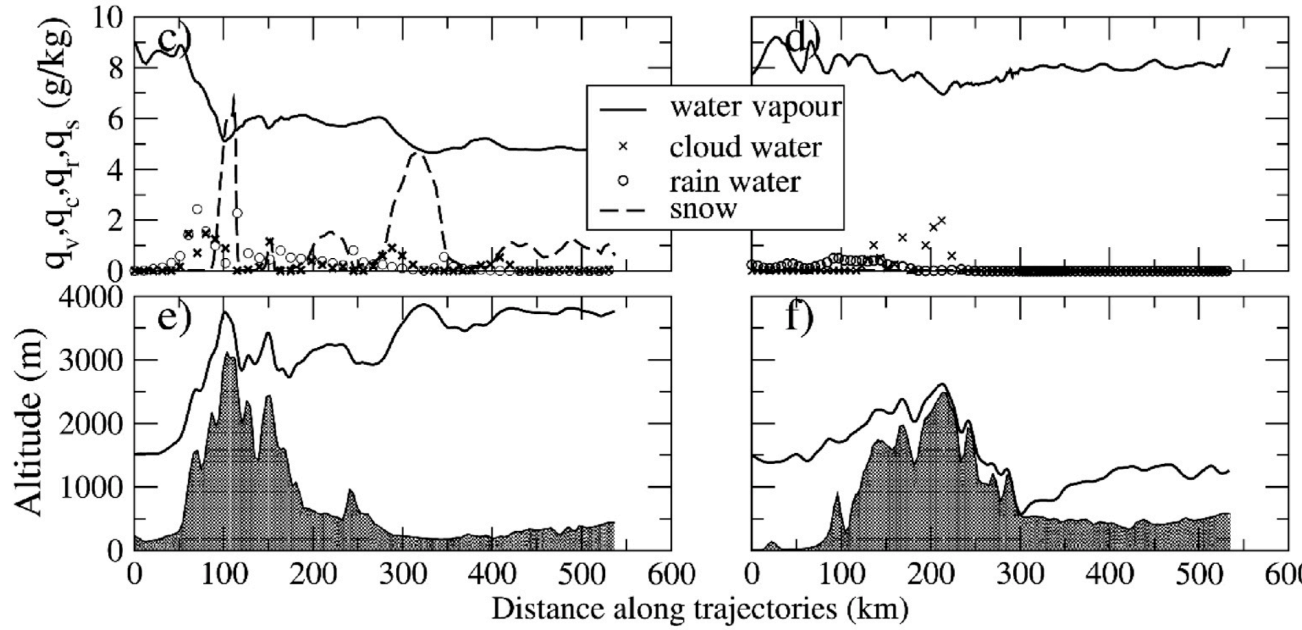

error sources for numerical solution of **trajectory equation** $\frac{D\boldsymbol{x}}{Dt} = \boldsymbol{u}(\boldsymbol{x},t)$ (Stohl, 2003)

(i)	wind field errors	:	the NWP model system
(ii)	starting position errors	:	...
(iii)	truncation error	:	Pettersen scheme: ~ Δt_{traj}^2 trajectory integration
(iv)	interpolation error	:	Δt of model output and Δx of NWP model

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(i) wind field errors : the NWP model system

(ii) starting position errors : ...

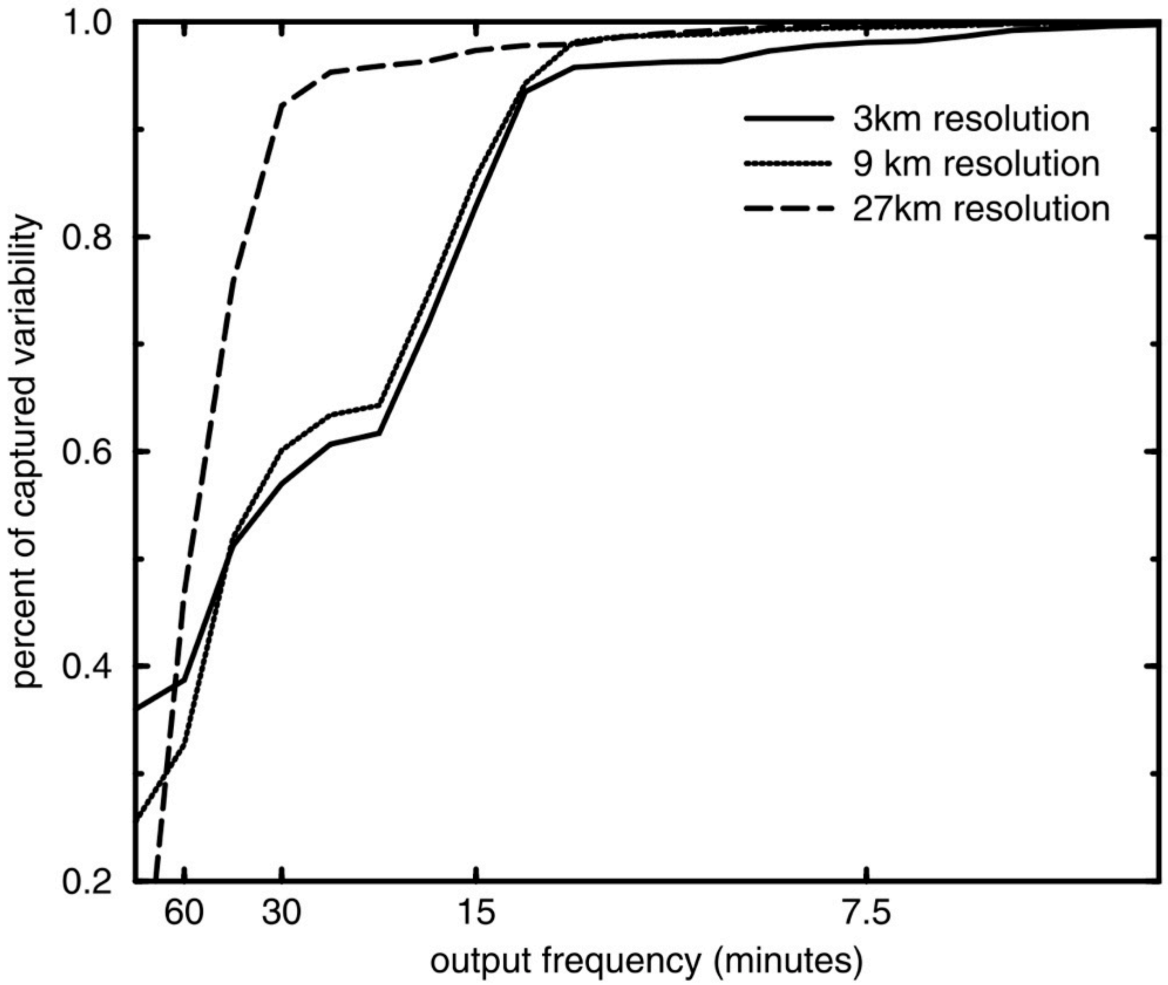
(iii) truncation error **!!!** : Pettersen scheme: ~ Δt_{traj}^2 trajectory integration

(iv) interpolation error **!!!** : Δt of model output and Δx of NWP model

>> Compute trajectories during the integration of the NWP model (online trajectories)

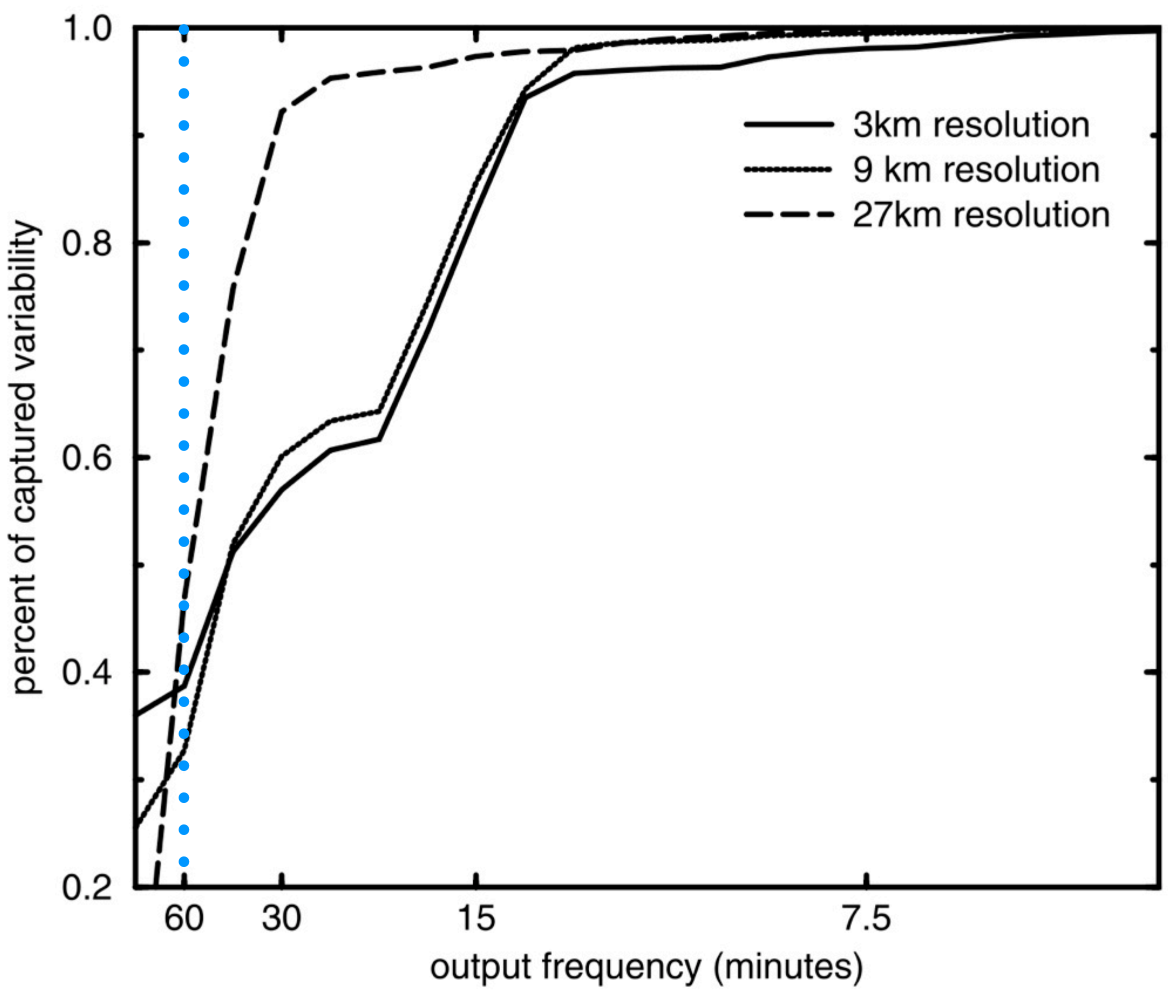
+ minimal truncation error
+ minimal temporal interpolation error

the Lagrangian approach



Grell et al. (2004)

the Lagrangian approach



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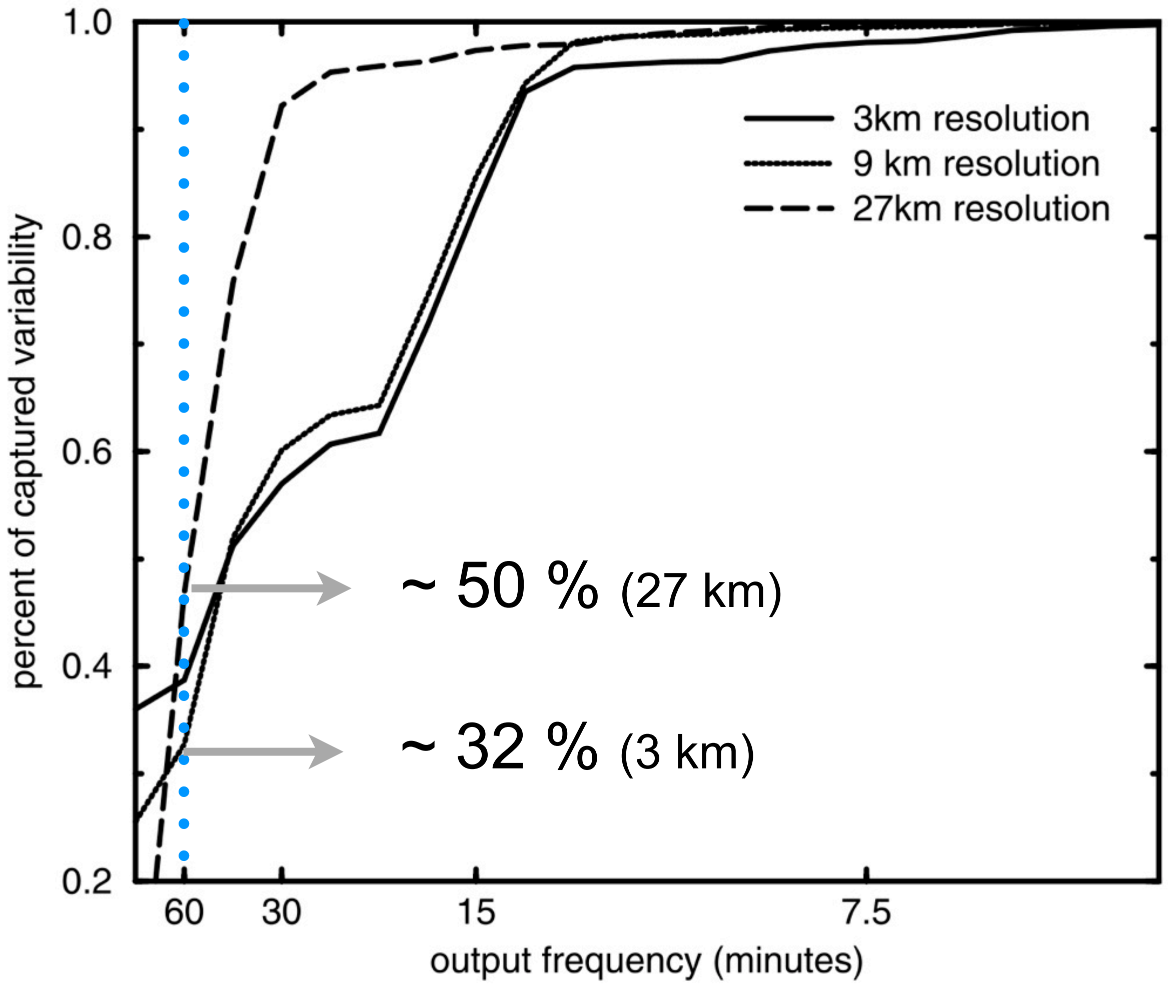

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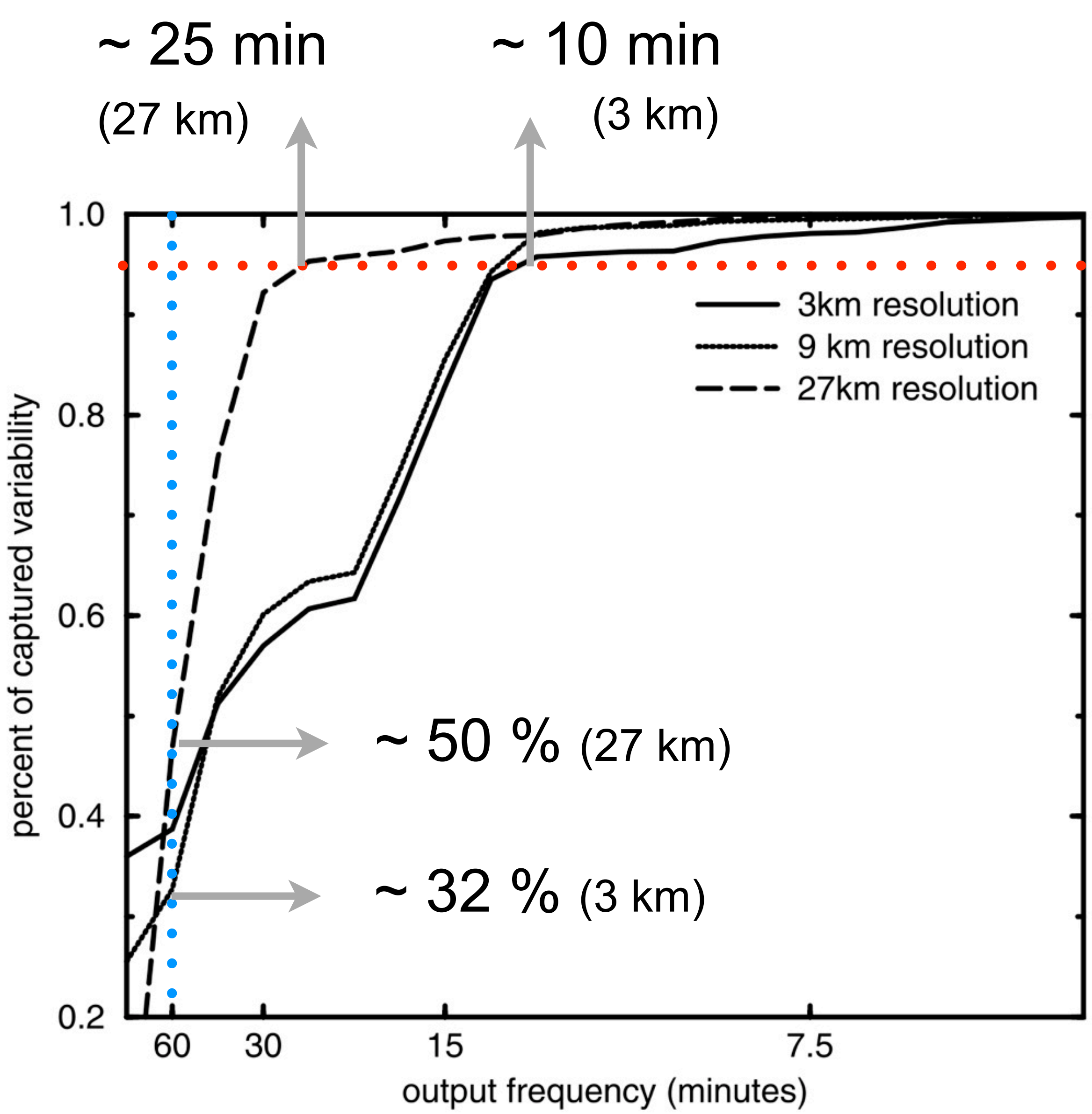

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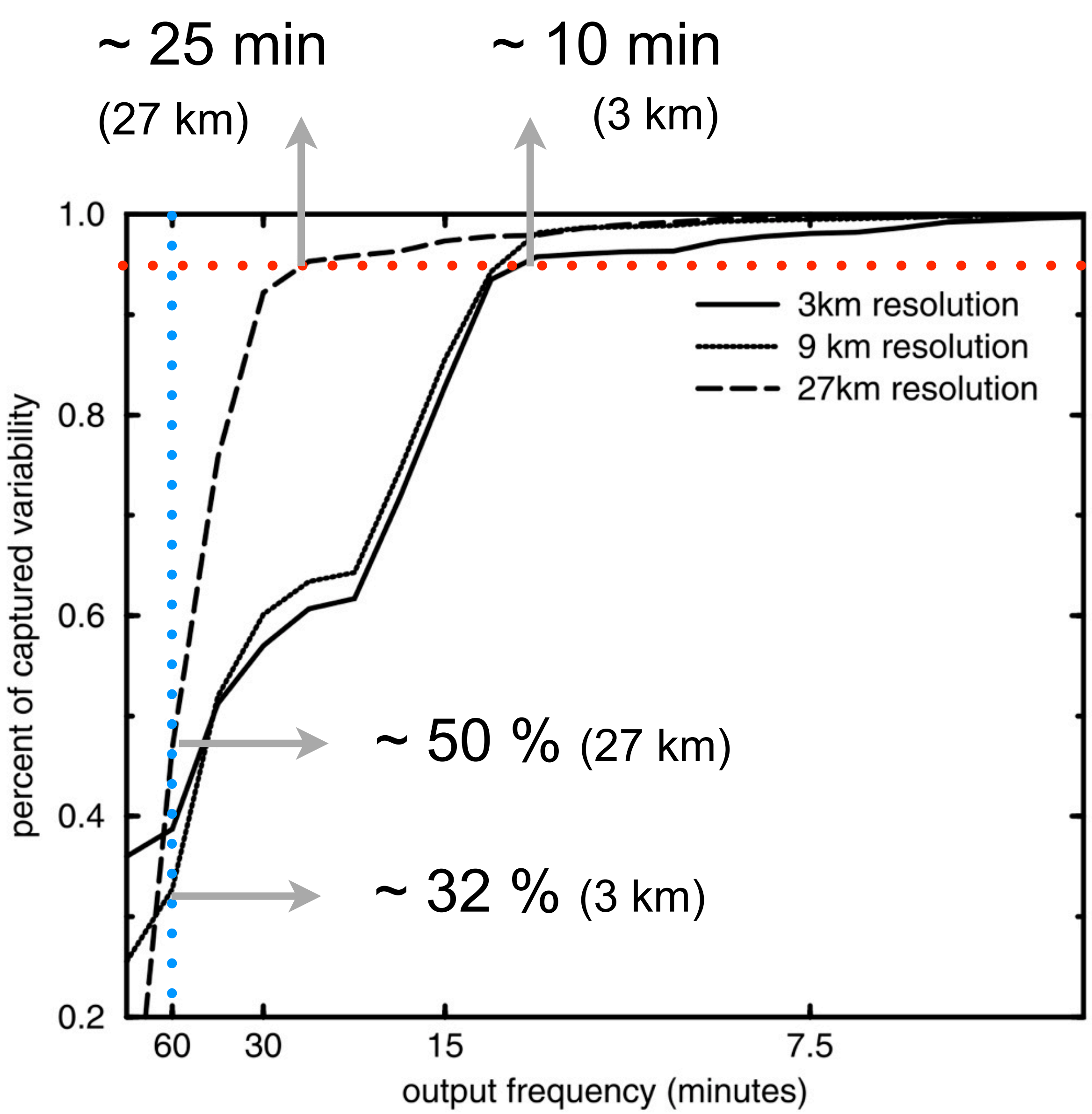
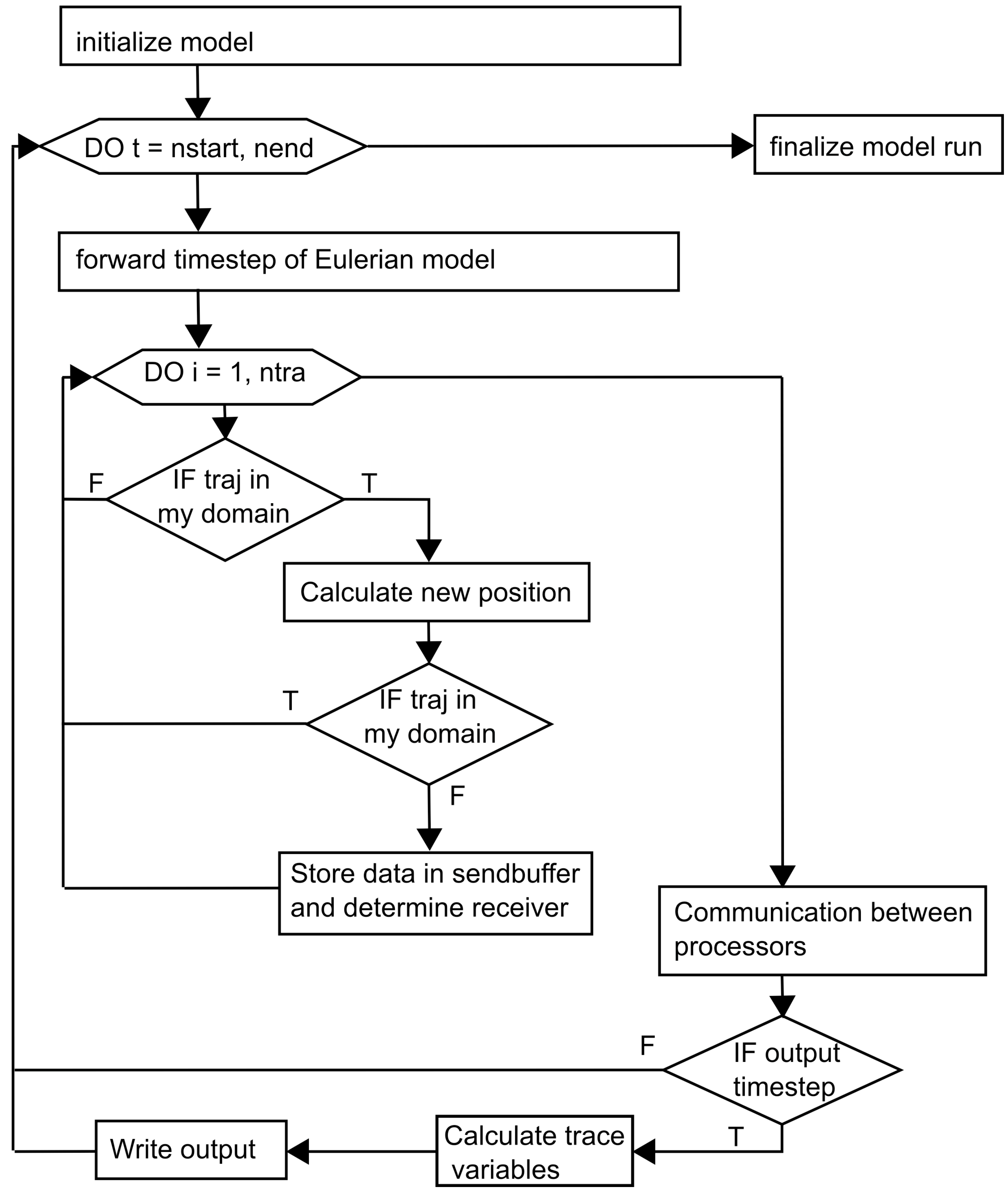


Grell et al. (2004)

- balance between spatial and temporal resolution required
- need of high temporal resolution of trajectories for high resolution NWP


initialize model
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Calculate new position
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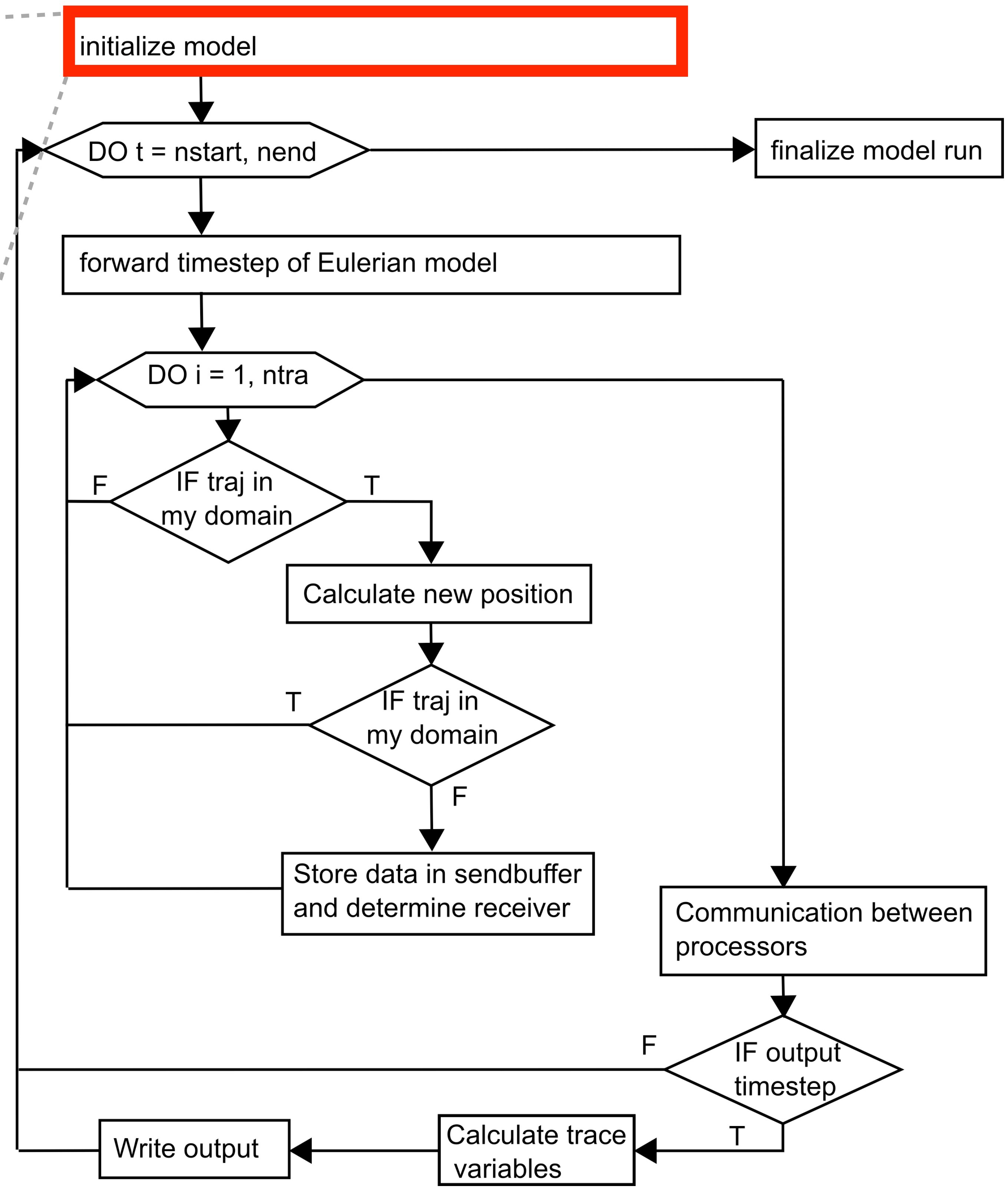
F
Store data in sendbuffer and determine receiver
Communication between processors
IF output timestep
F
T
Calculate trace variables
Write output

I. Initialization



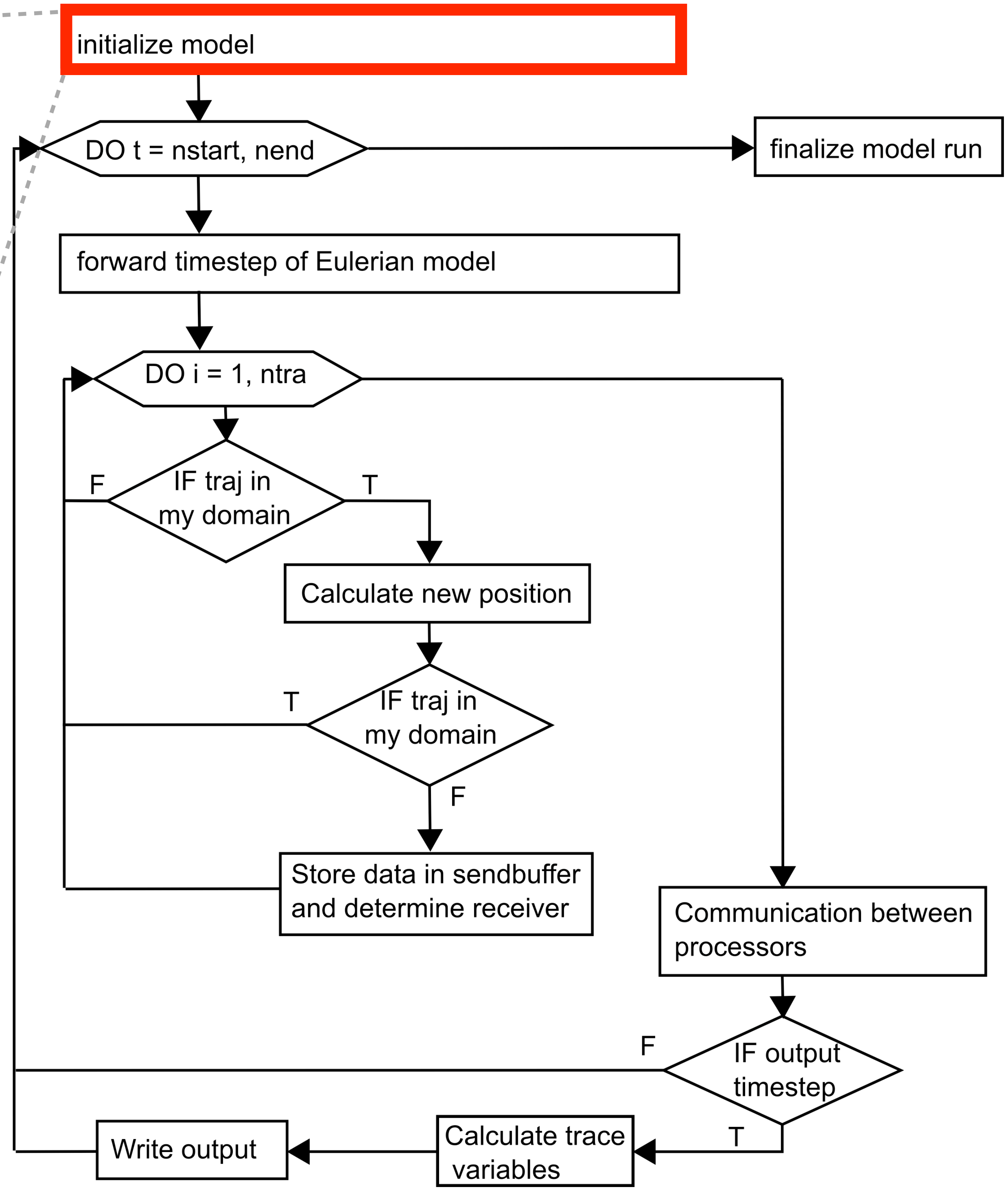
I. Initialization

& RUNCTL

ltraj = true,

& TRAJCTL

ltraj_init = 1,



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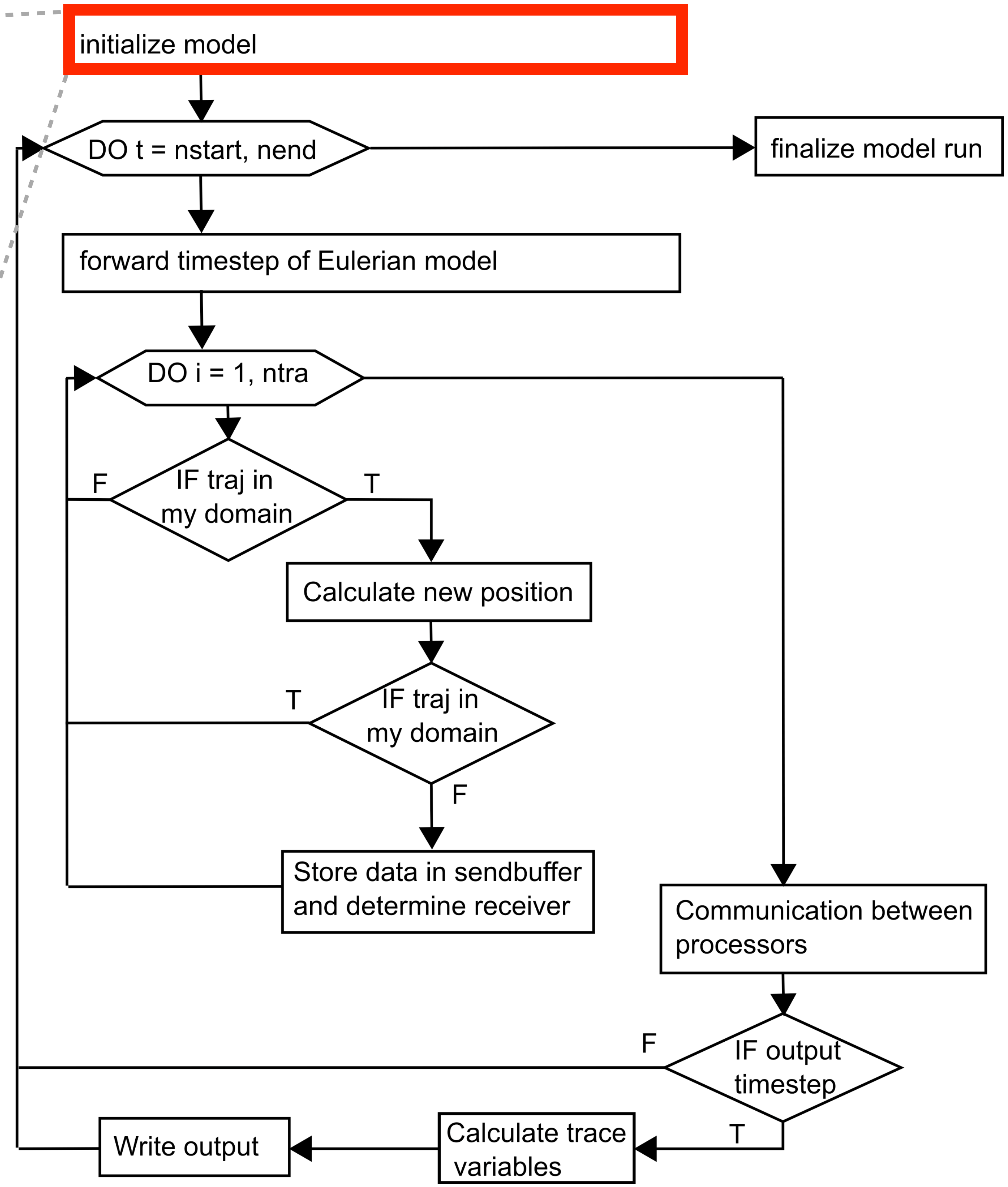
1: user specified starting times

2: starting with fixed temporal interval

(always same location, only namelist)

3: times and starting points via startfile



I. Initialization

& RUNCTL

ltraj = true,

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ltraj_init = 1,

lstartf = true,

start_reg = lon1, lon2, lat 1, lat2, z1, z2,

traj_inittime = 0,

dt_traj = 20,

numit = 3,

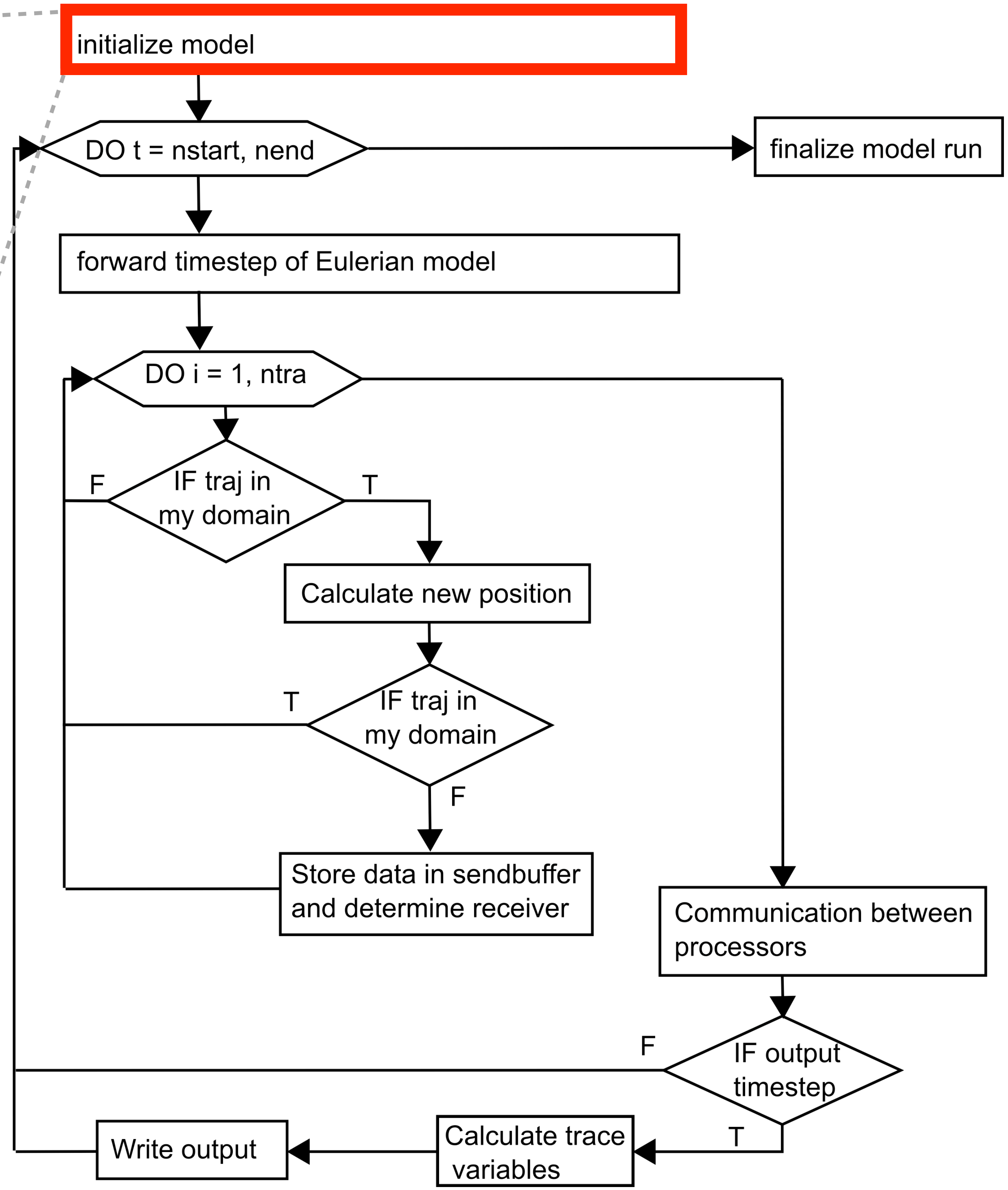
ljump = true,

ntrace = 2,

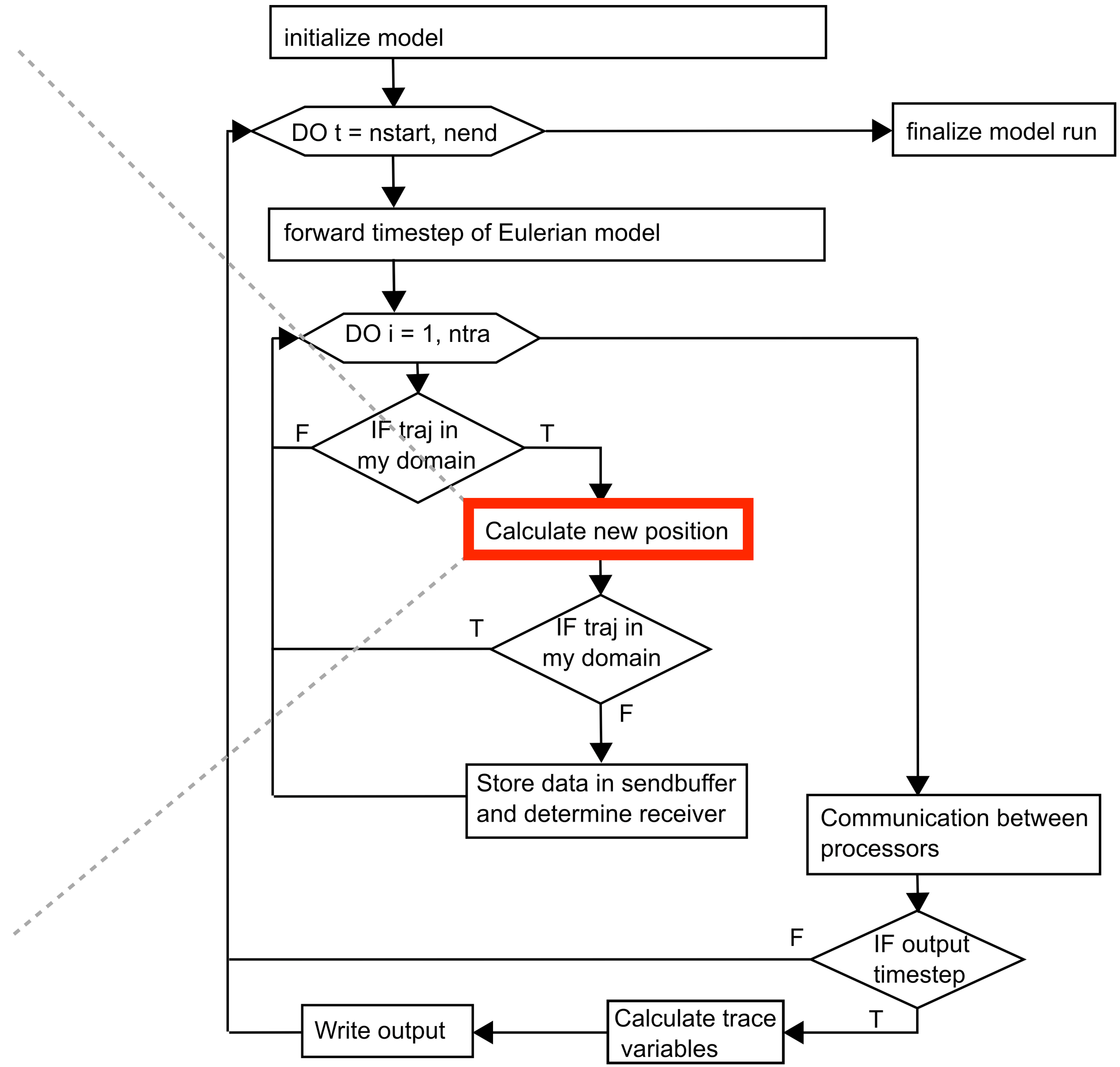
...

& TRACEVAR

trace_var = 'T', 'P'



II. Integration of Trajectory Eq.



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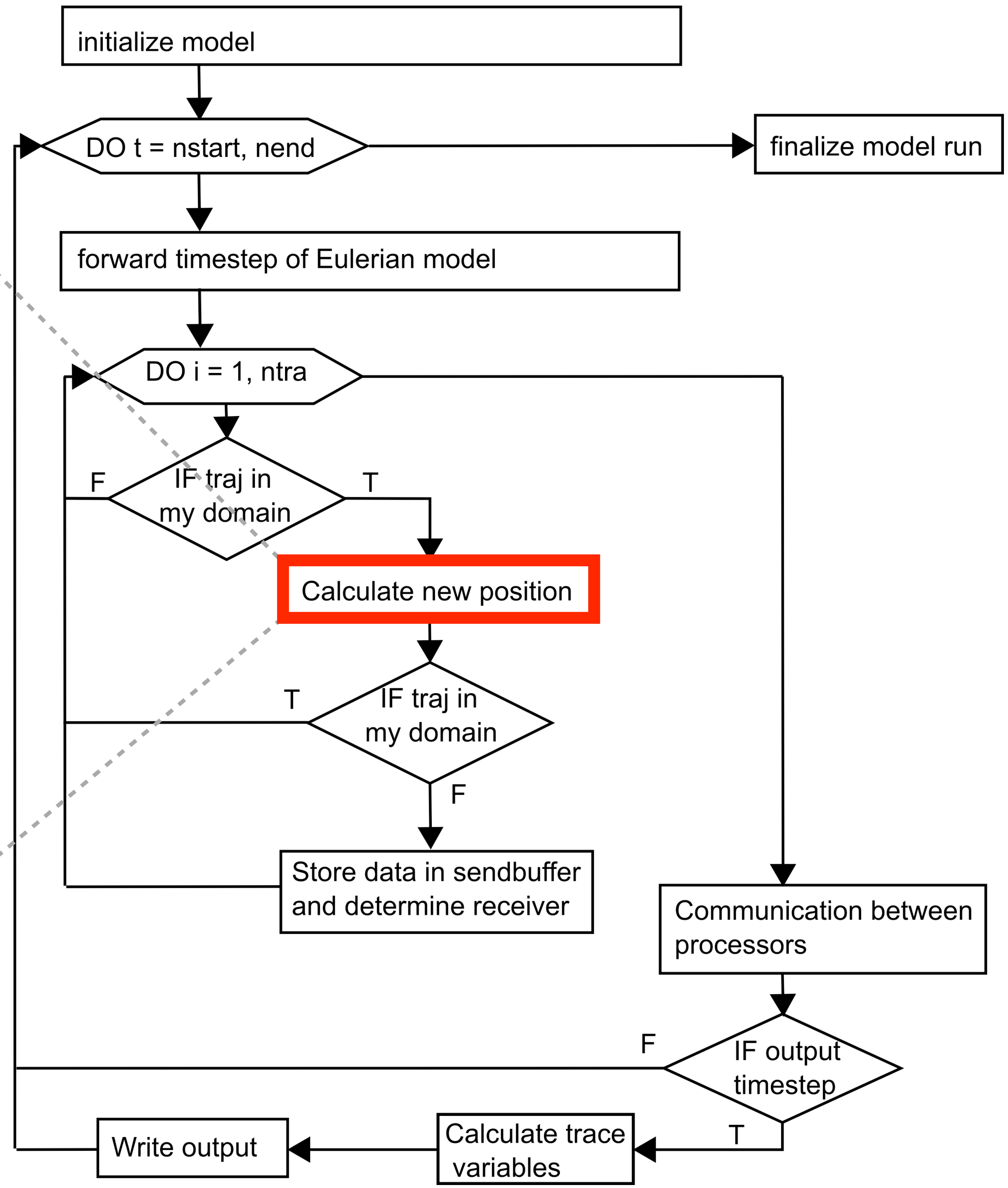
- iterative Euler forward timestep (Petterssen scheme)

$$\boldsymbol{x}_1(t_1) \approx \boldsymbol{x}(t_0) + \Delta t \boldsymbol{u}(\boldsymbol{x}, t_0)$$

$$\boldsymbol{x}_2(t_1) \approx \boldsymbol{x}(t_0) + \frac{1}{2}\Delta t(\boldsymbol{u}(\boldsymbol{x}, t_0) + \boldsymbol{u}(\boldsymbol{x}_1, t_1))$$

$$\ldots$$

$$\boldsymbol{x}_n(t_1) \approx \boldsymbol{x}(t_0) + \frac{1}{2}\Delta t(\boldsymbol{u}(\boldsymbol{x}, t_0) + \boldsymbol{u}(\boldsymbol{x}_{n-1}, t_1))$$



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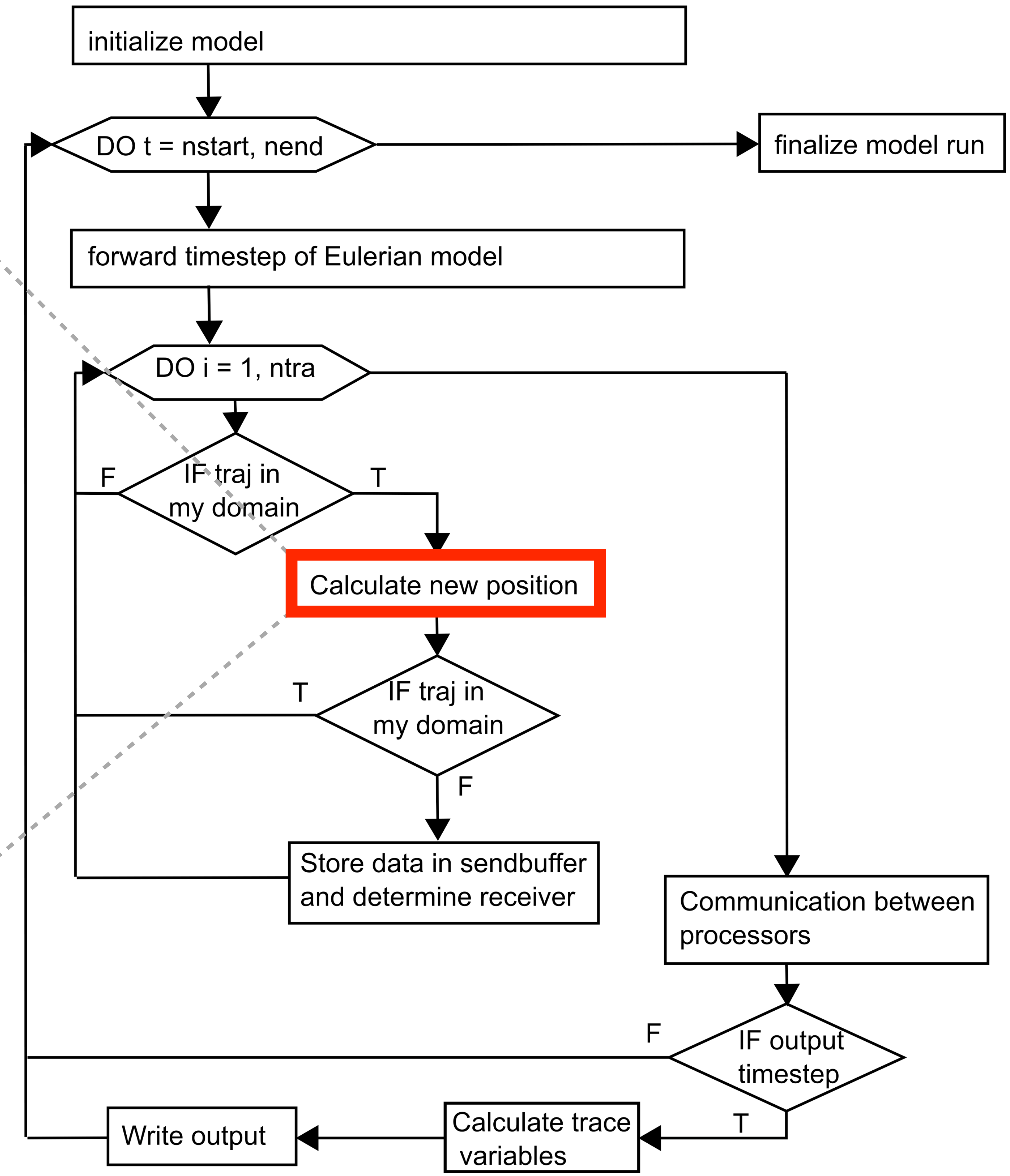
- second order scheme



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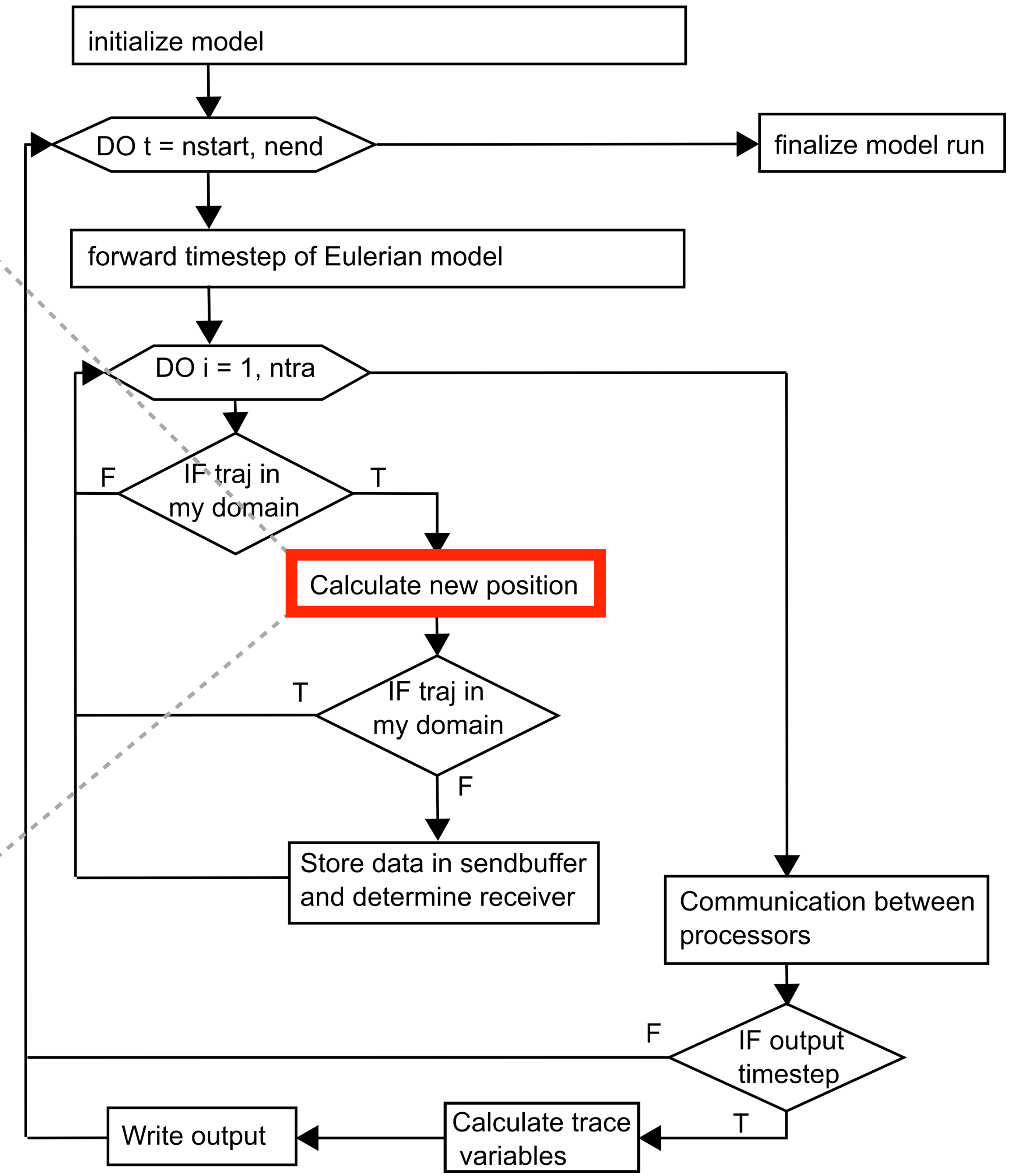

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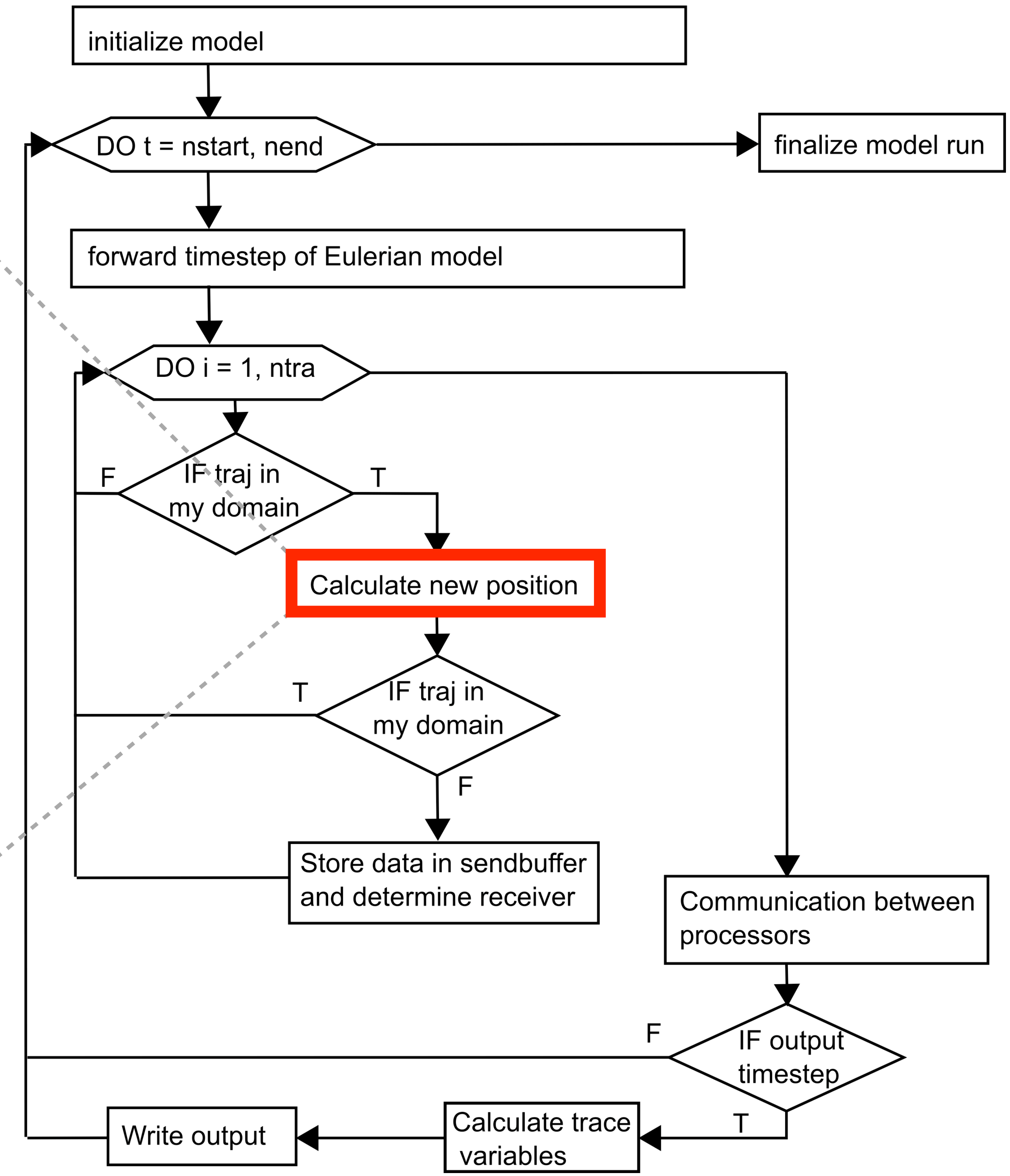
- linear spatial 3D interpolation of **u**



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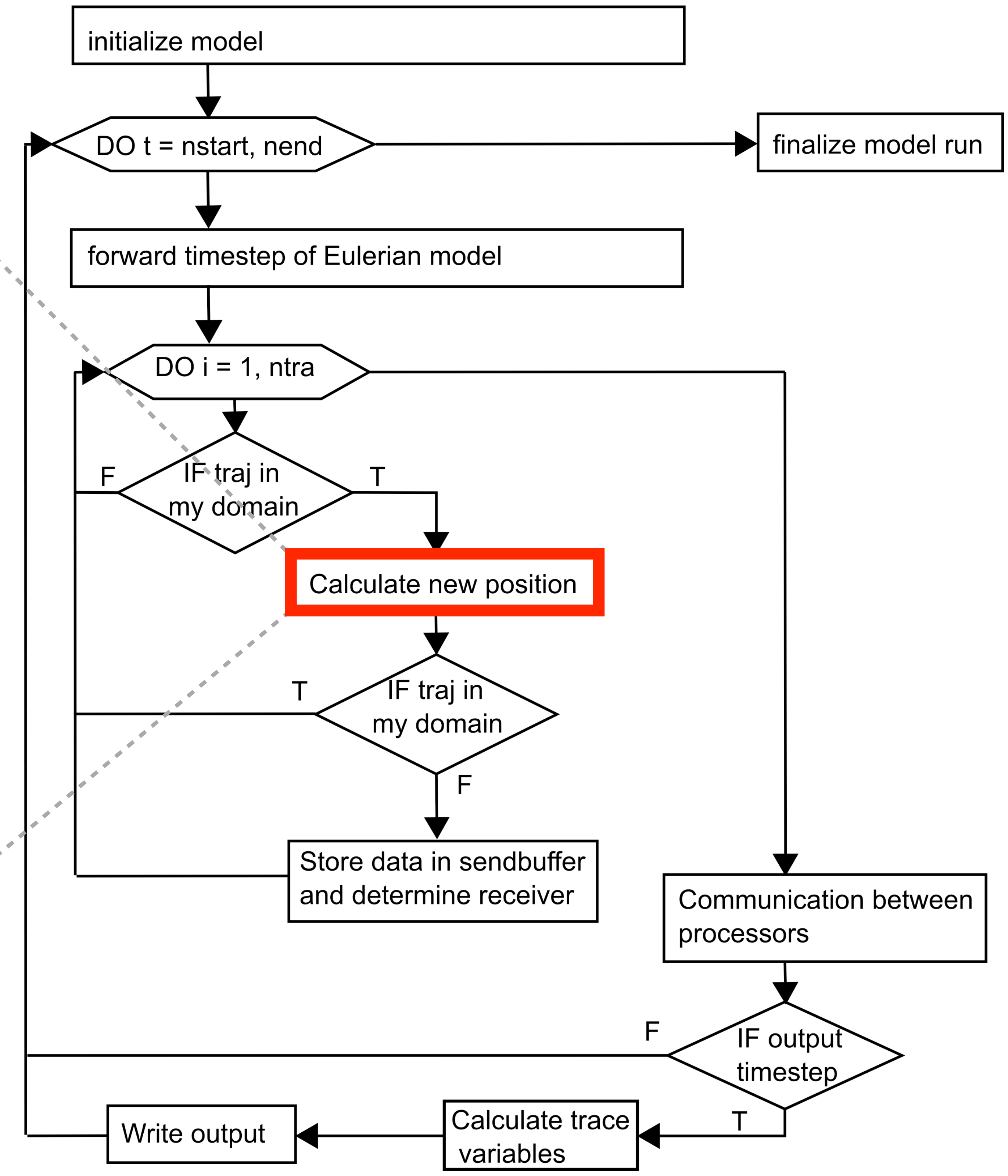
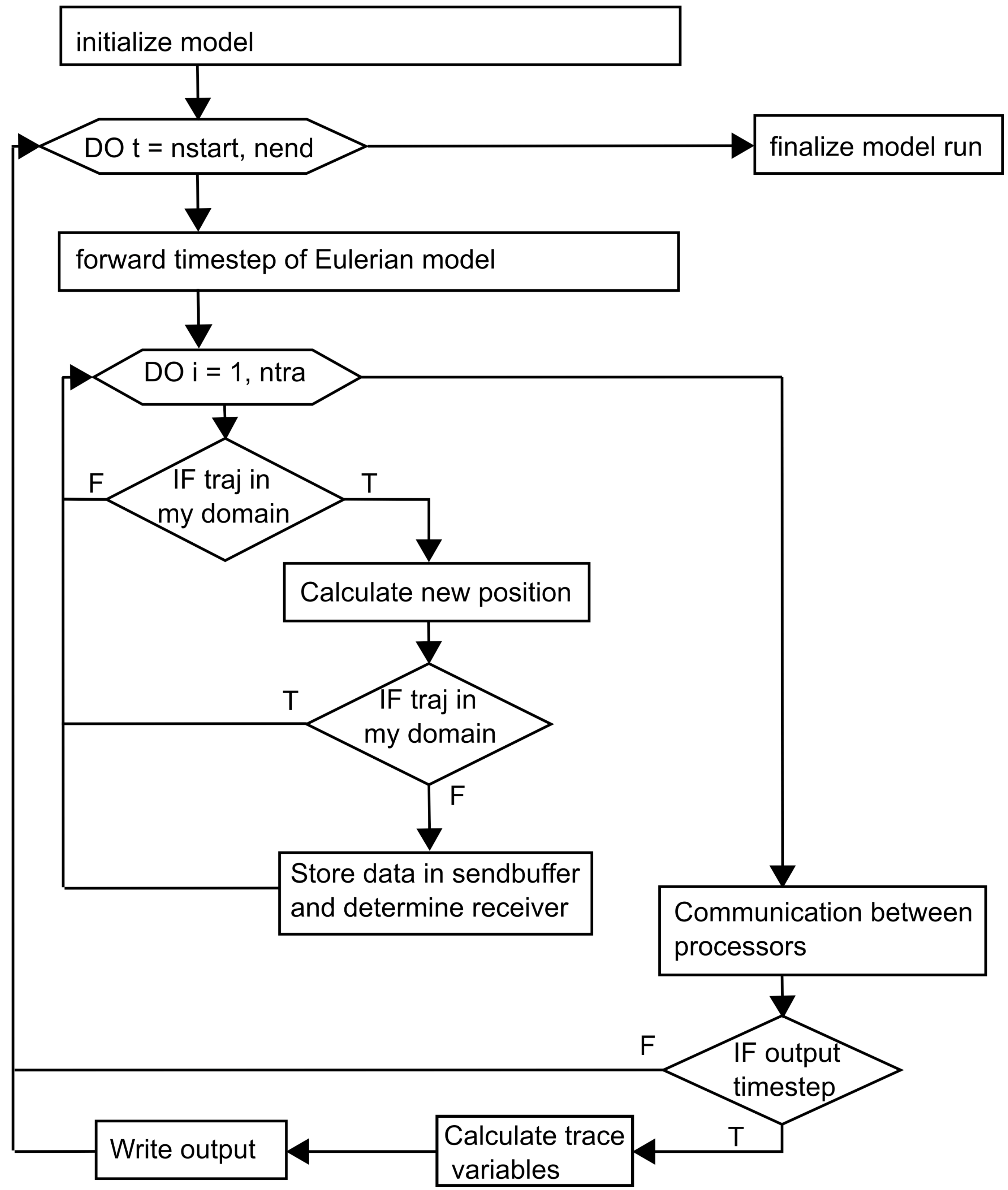
- jump flag

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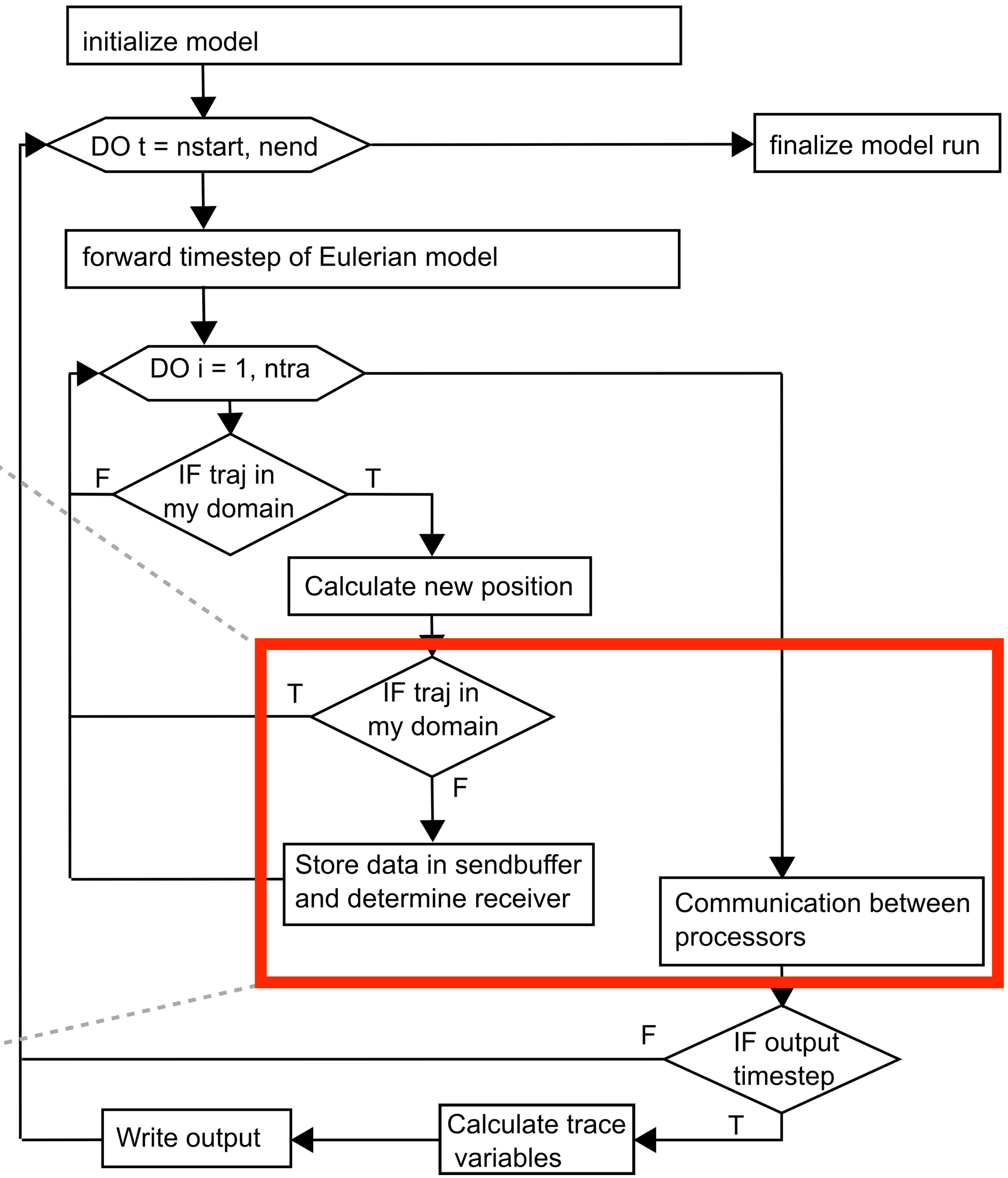
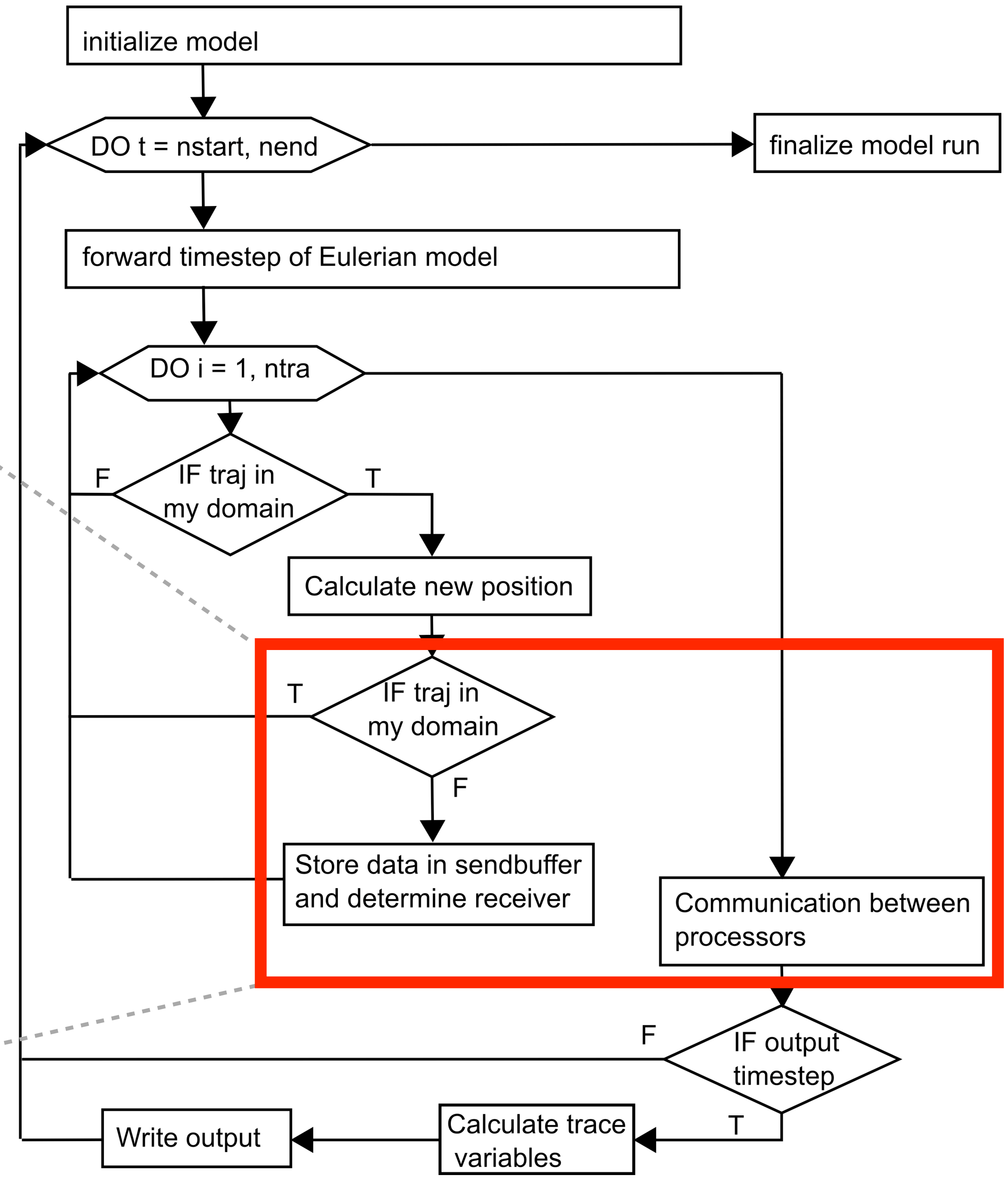


III. Communication

- fixed spatial domain decompositon
- trajectories pass between domains



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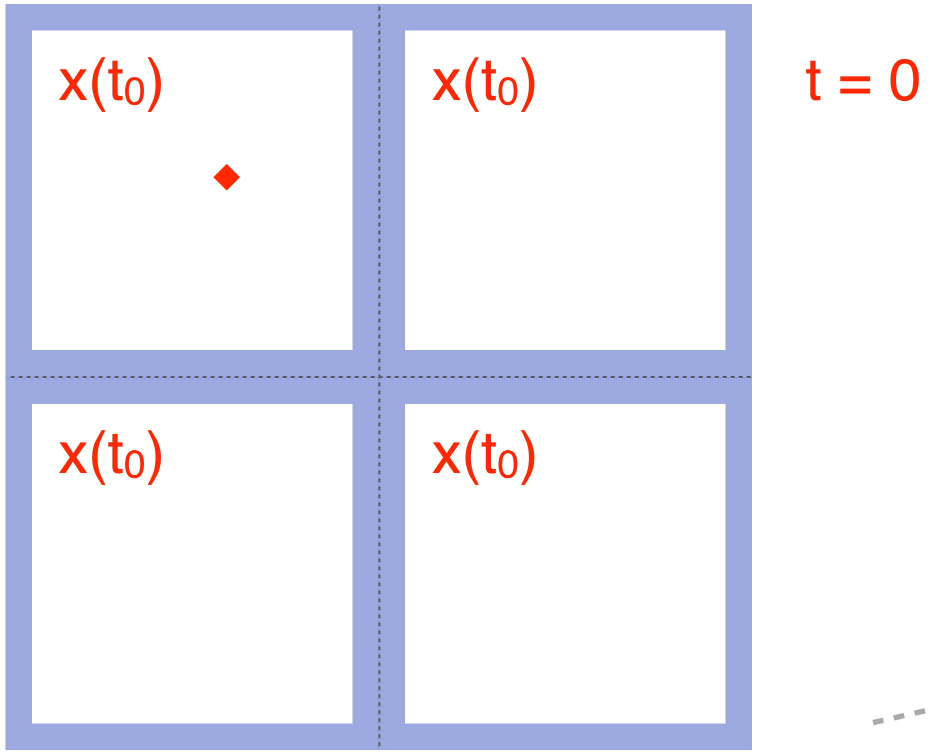

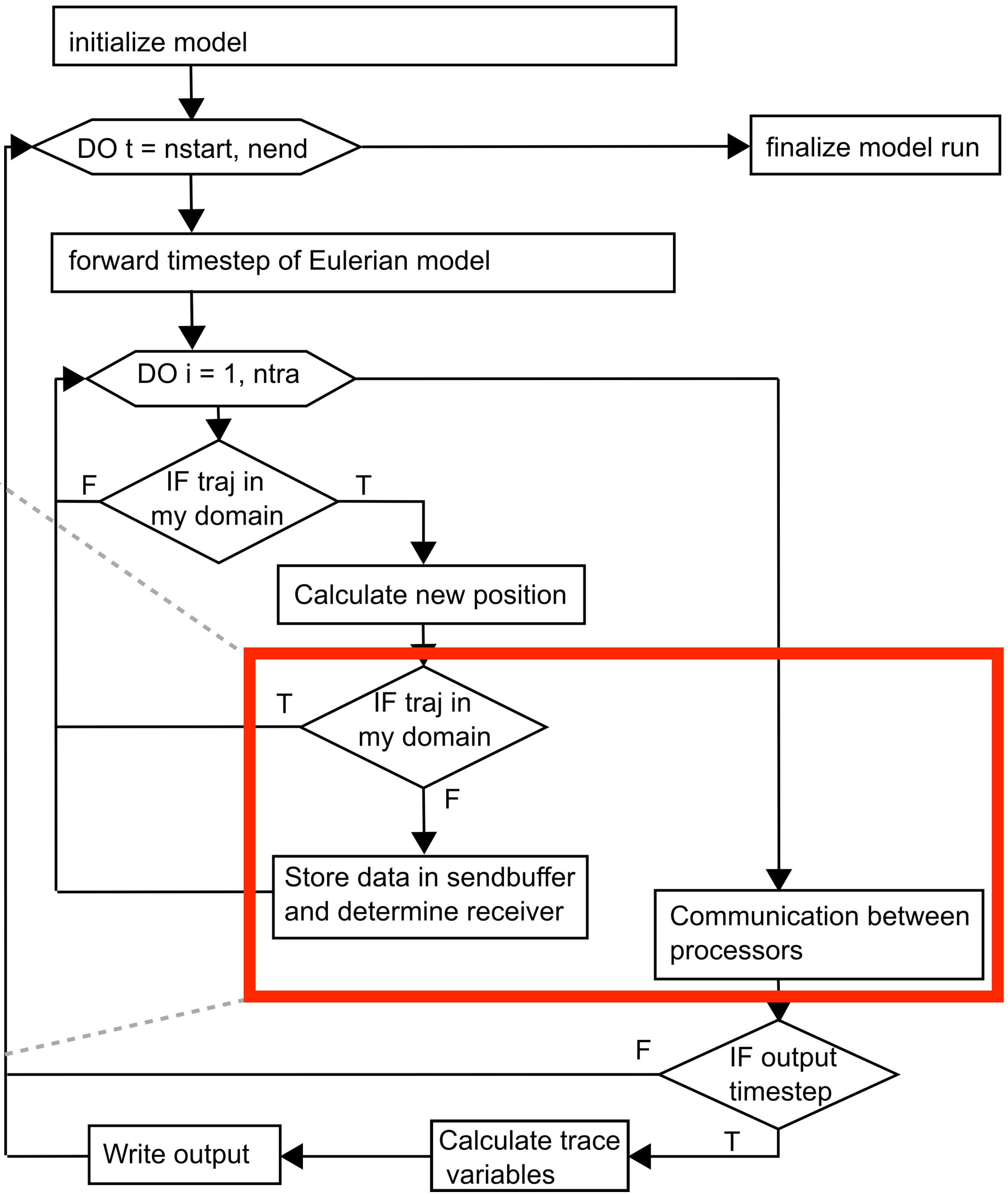

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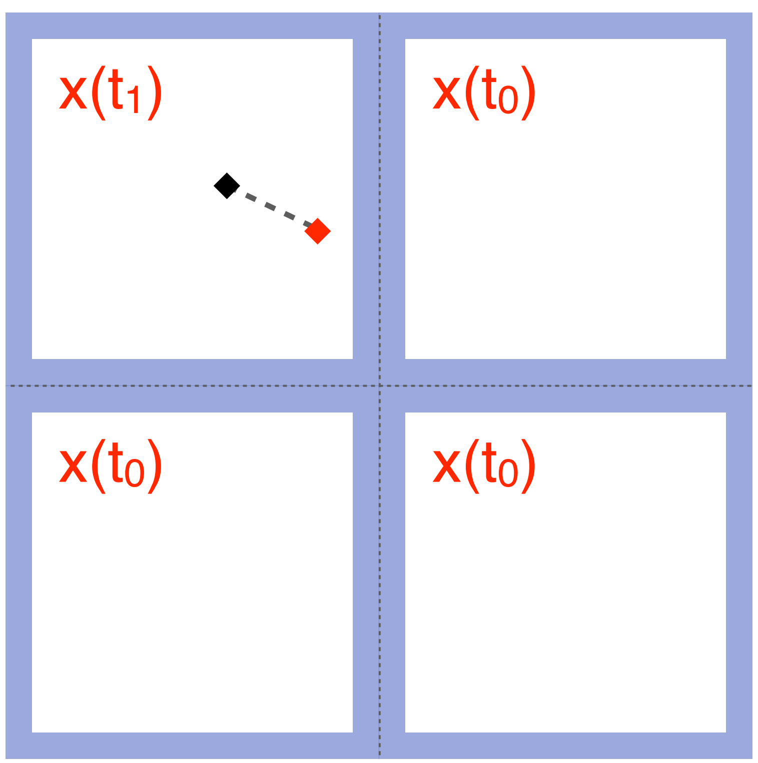
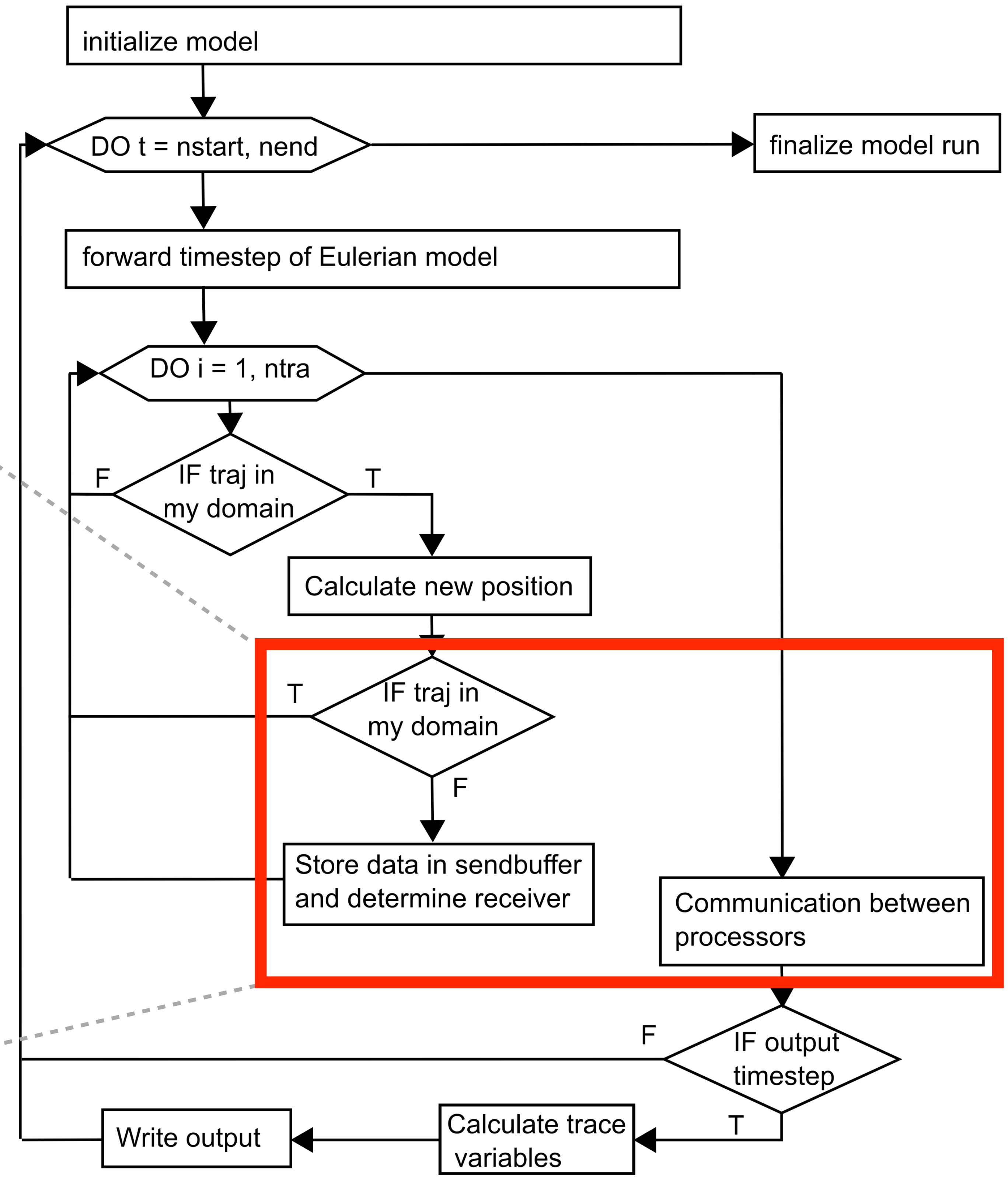


t = 0
t = 1



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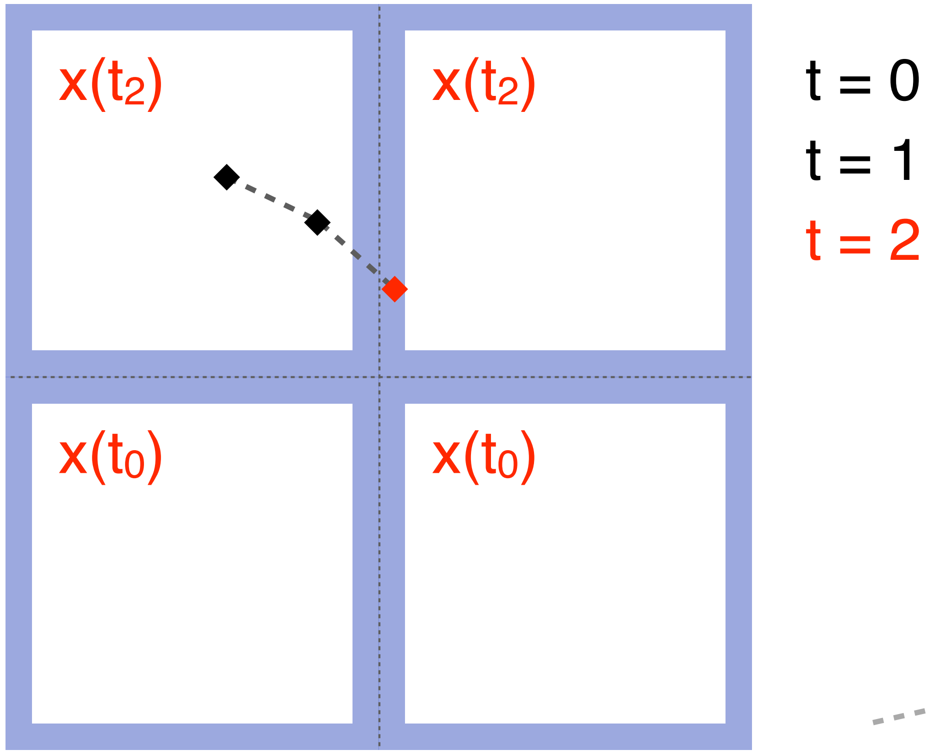

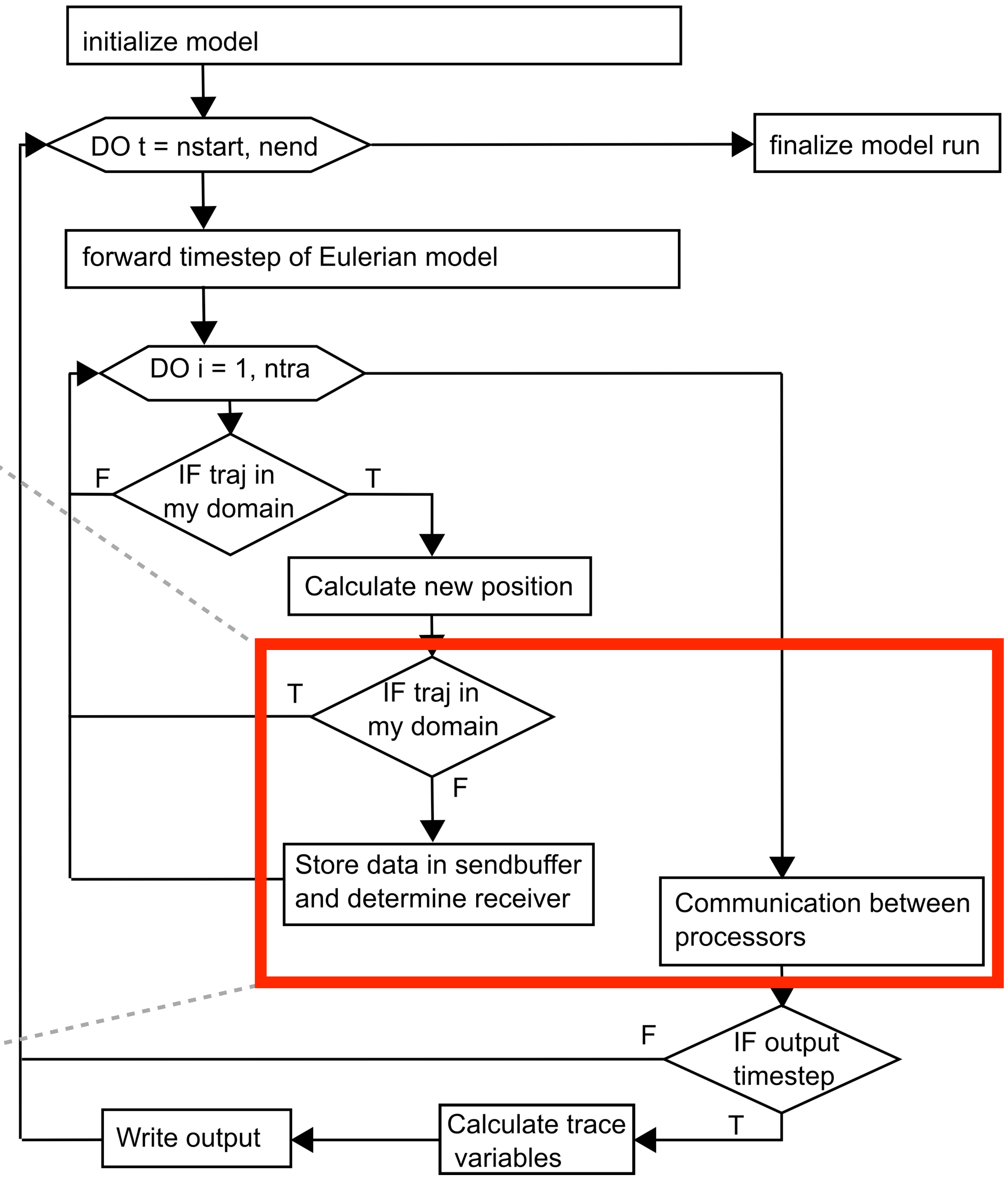

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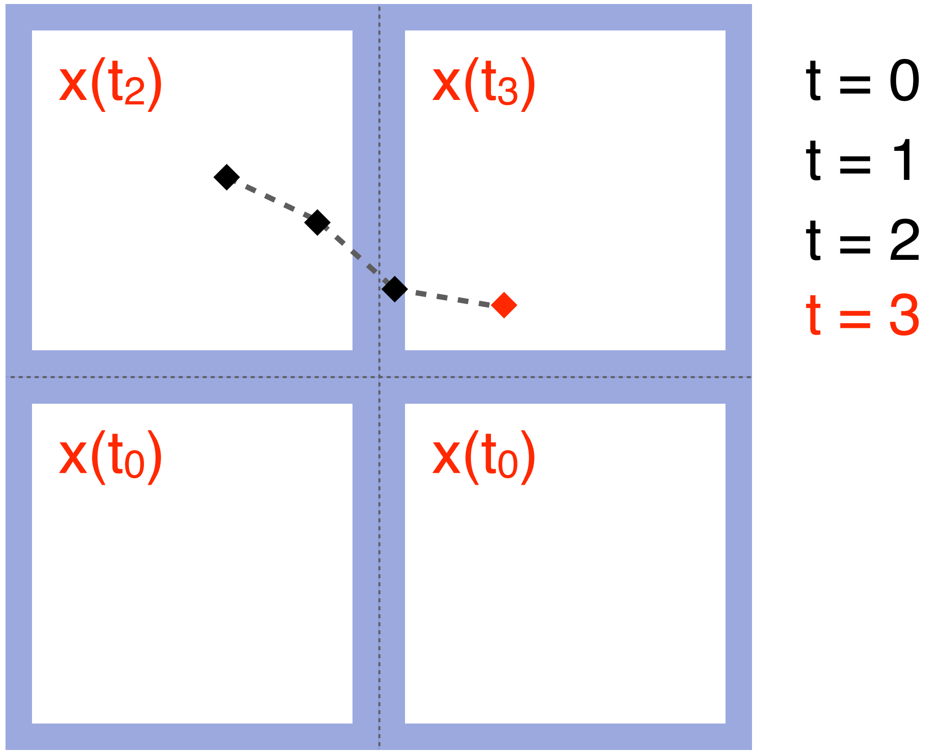

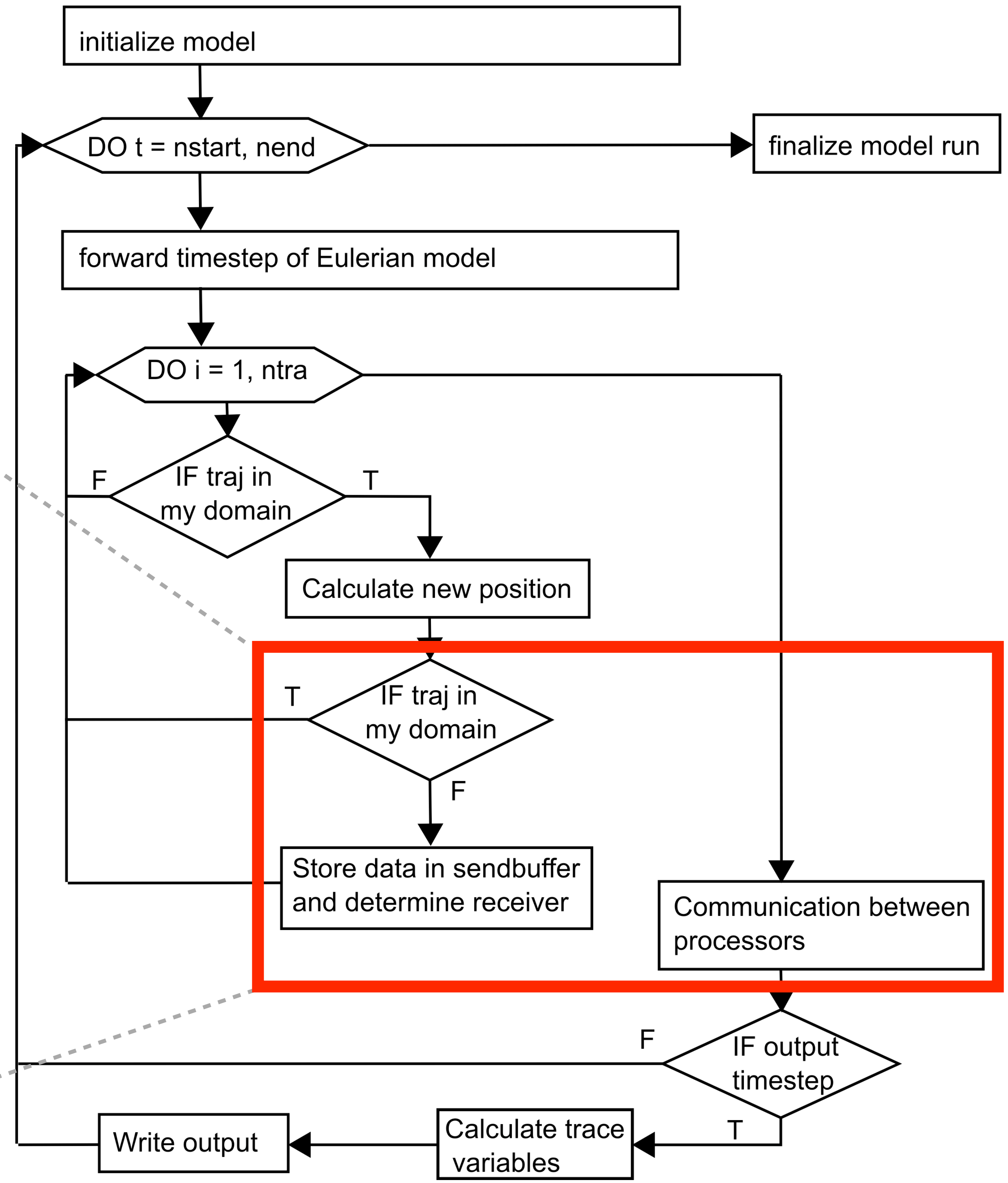

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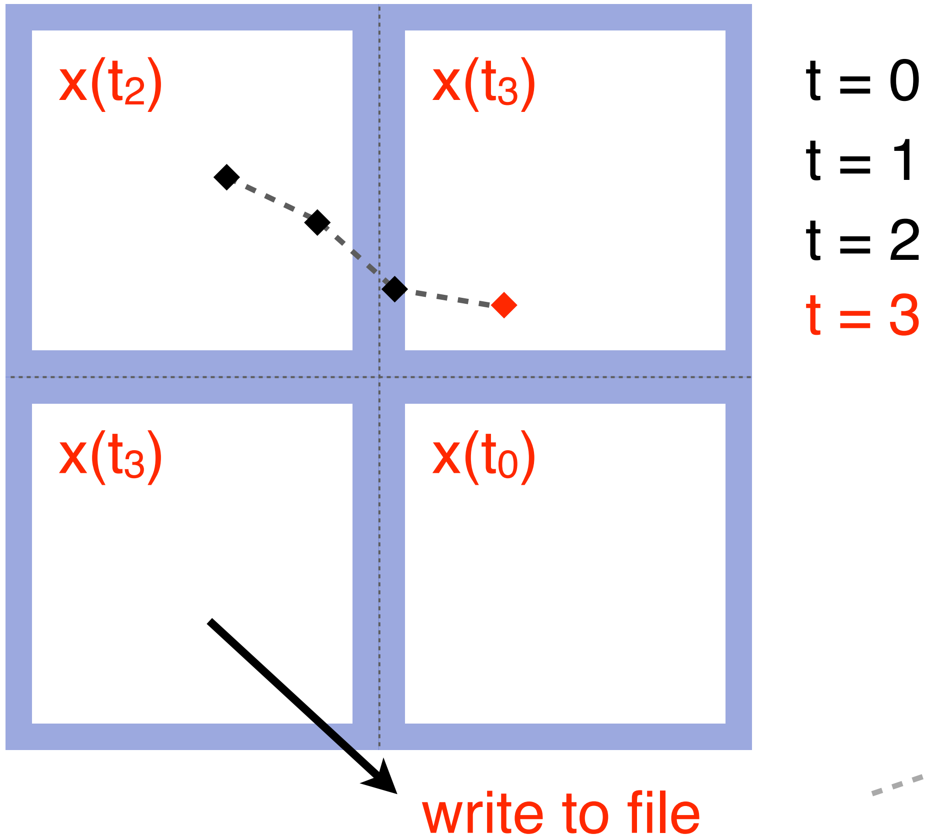

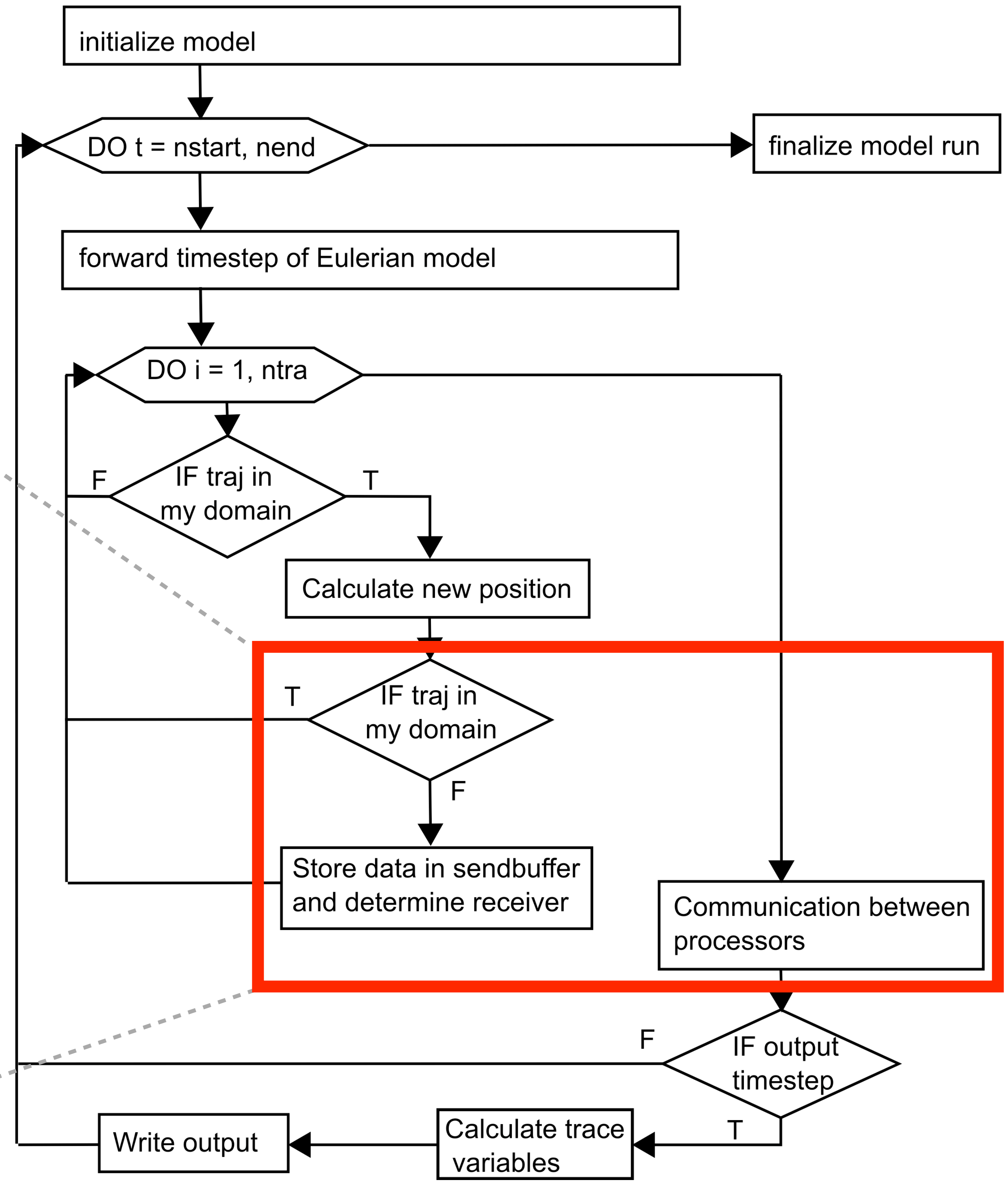

an alpine foehn event: 25 - 27 July 1987

- case study of north foehn on 26 July 1987

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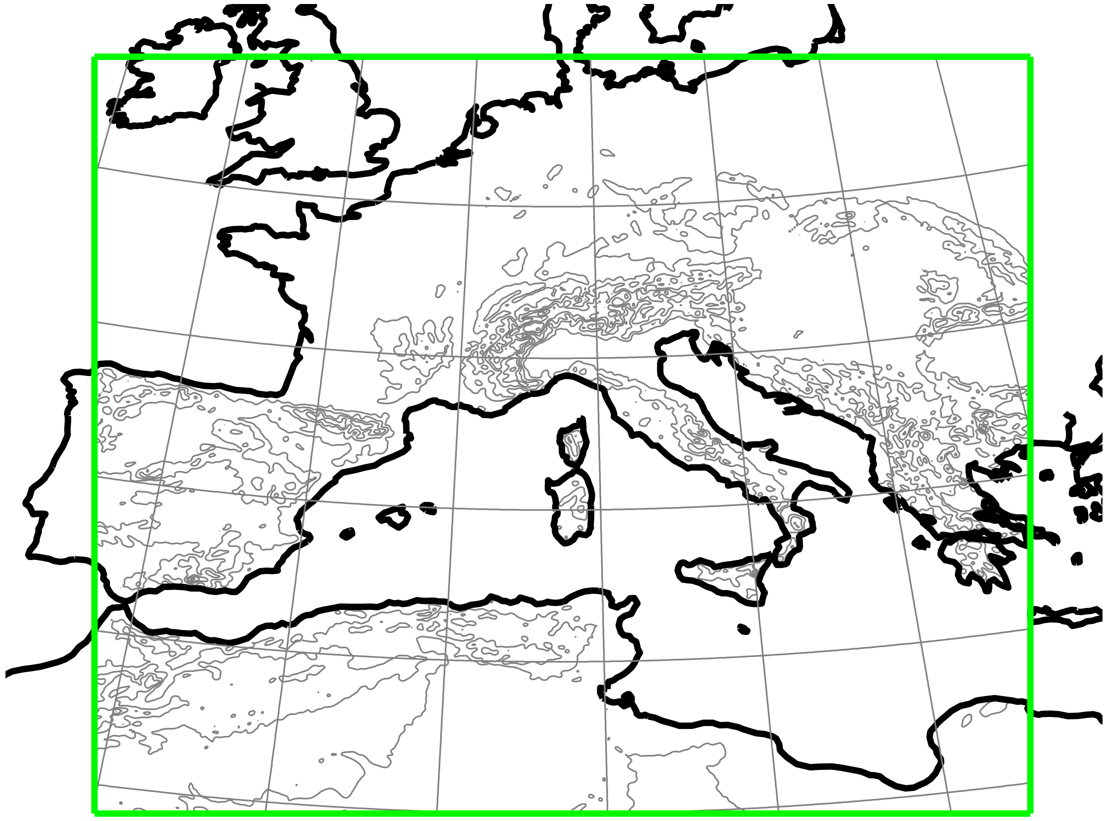
- COSMO 4.17 with two-moment microphysics
(Seifert and Beheng 2006)

horizontal resolution	14 km	7 km	2.2 km
vertical resolution	40	40	60
timestep	40 s	40 s	20 s
convection param.	full	ful	shallow
BC / IC	ERA40	ERA40	7km



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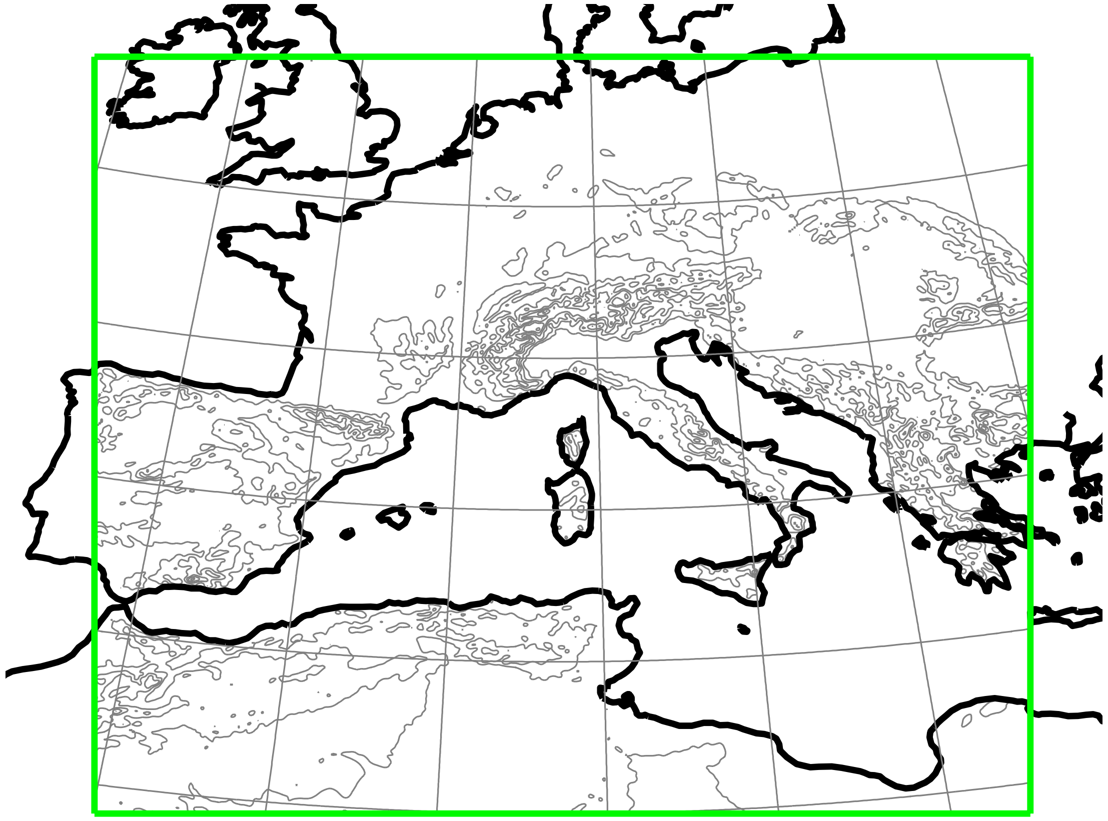
  (Wernli and Davies 2006)
  - based on 6-, 3- and 1-hourly COSMO output
  - jump flag



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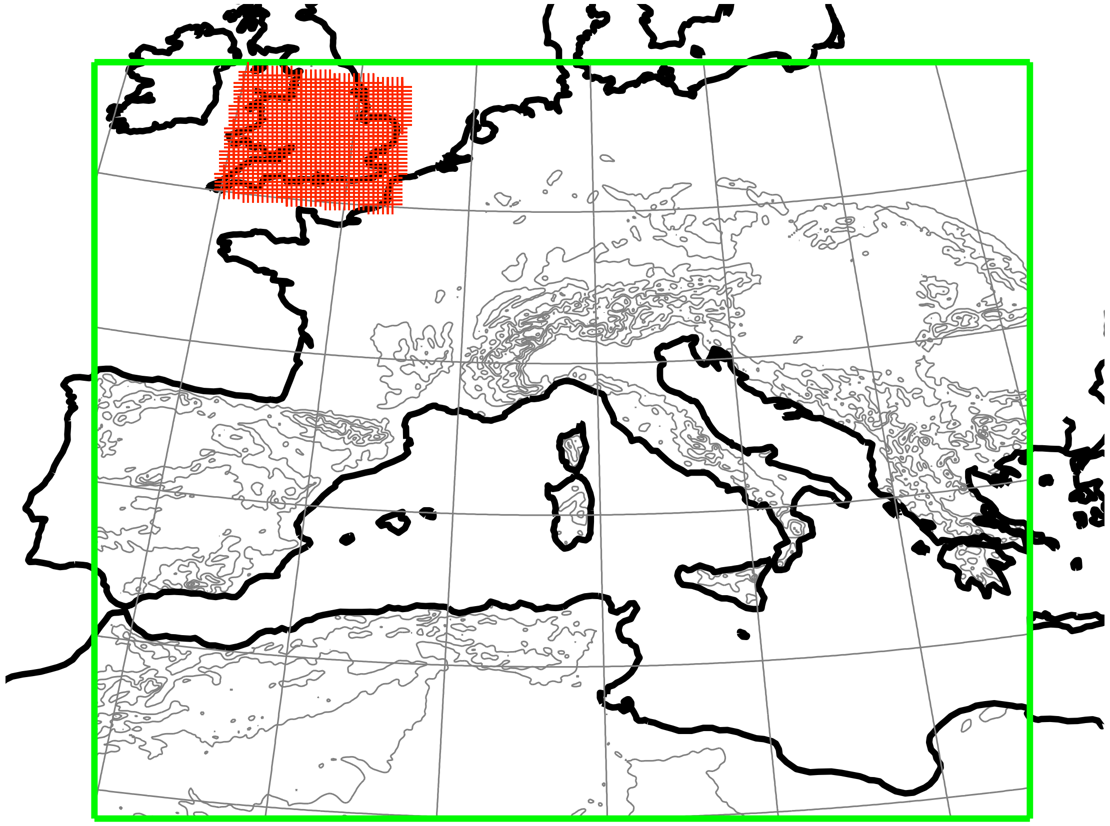

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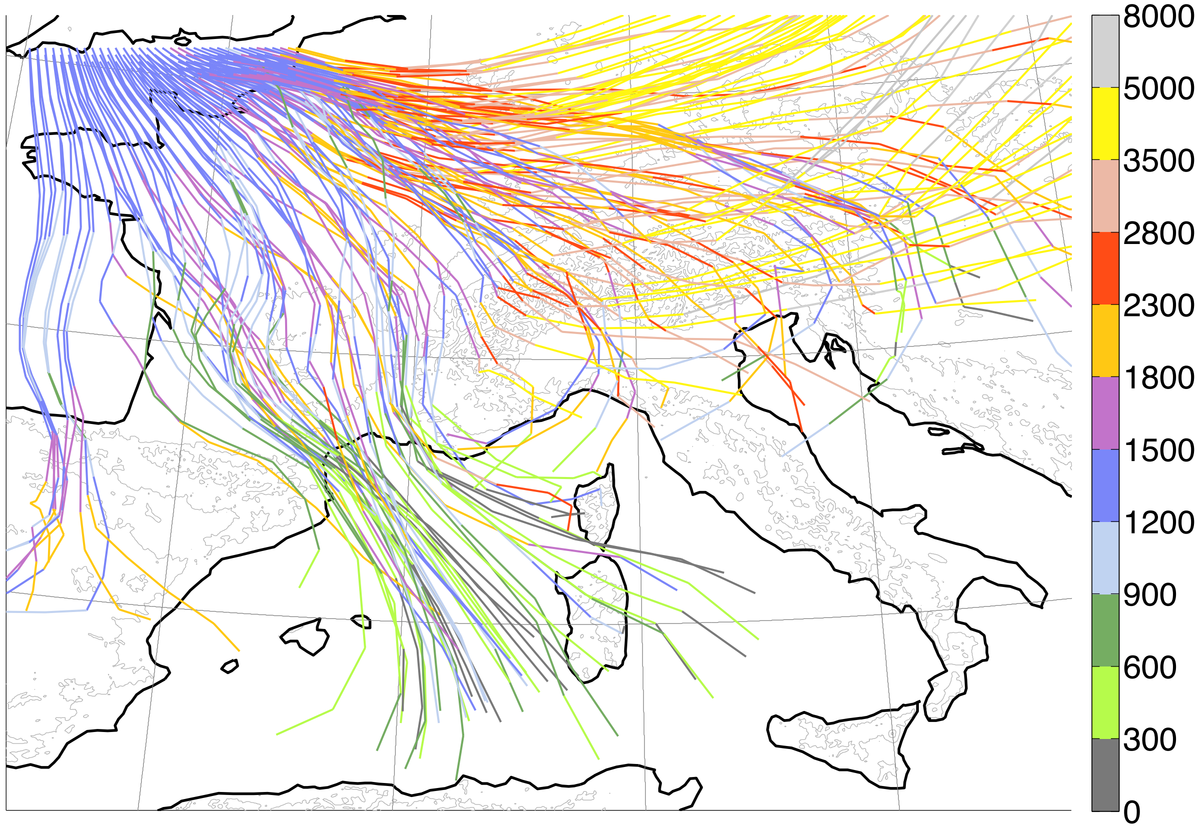
Δt = 3h; offline trajectories (COSMO2.2)



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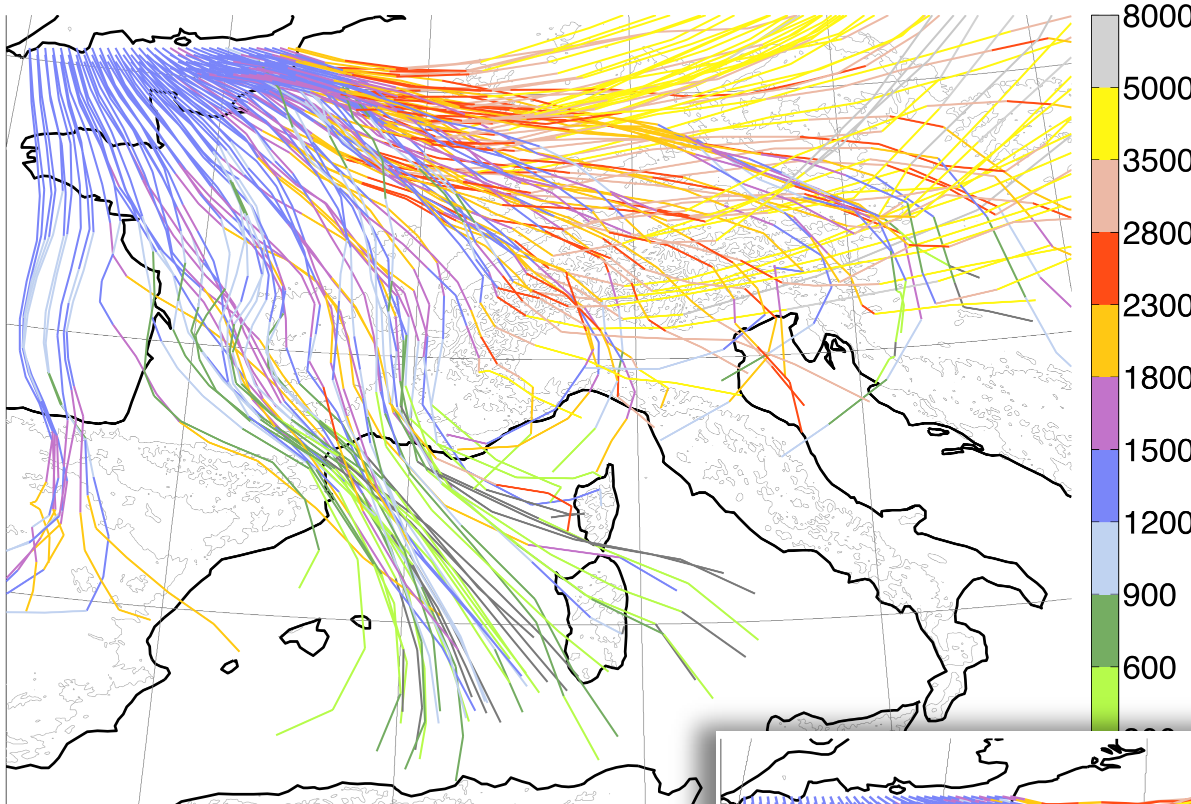
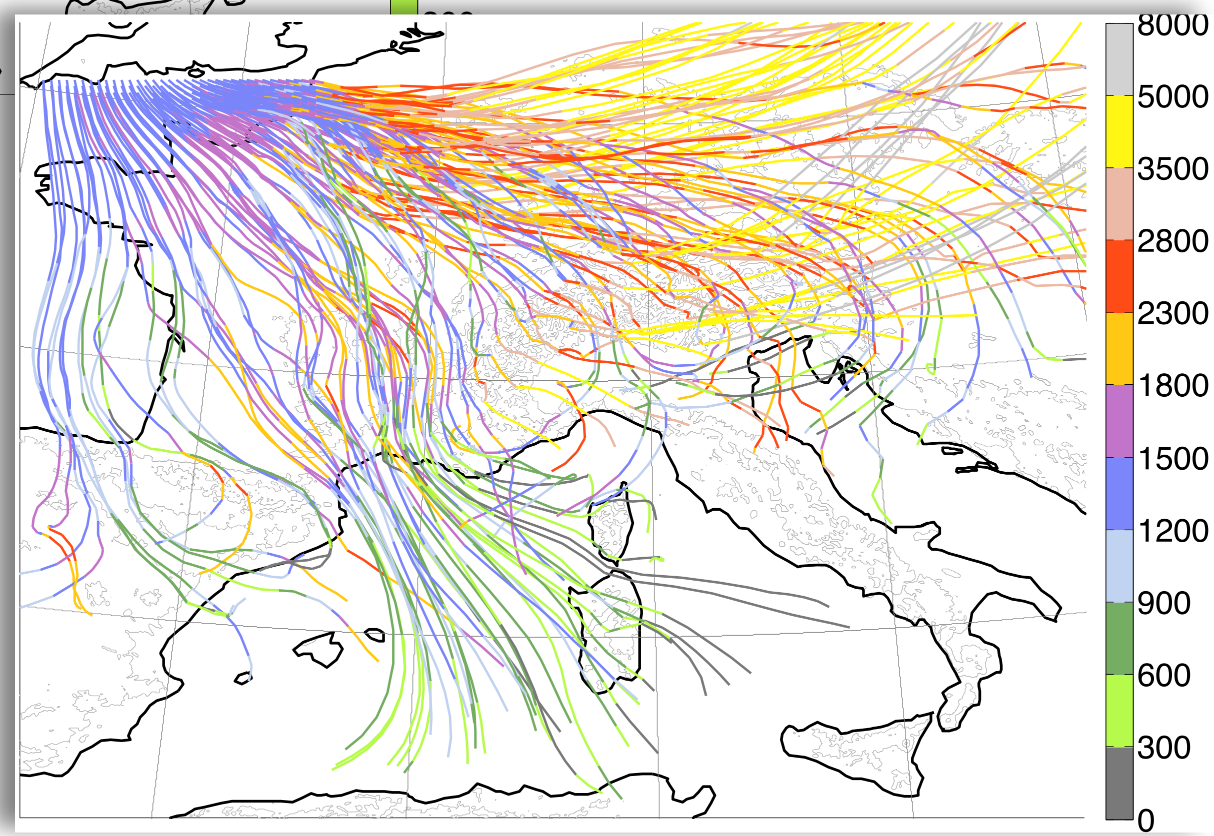


Δt = 1h; offline trajectories (COSMO2.2)



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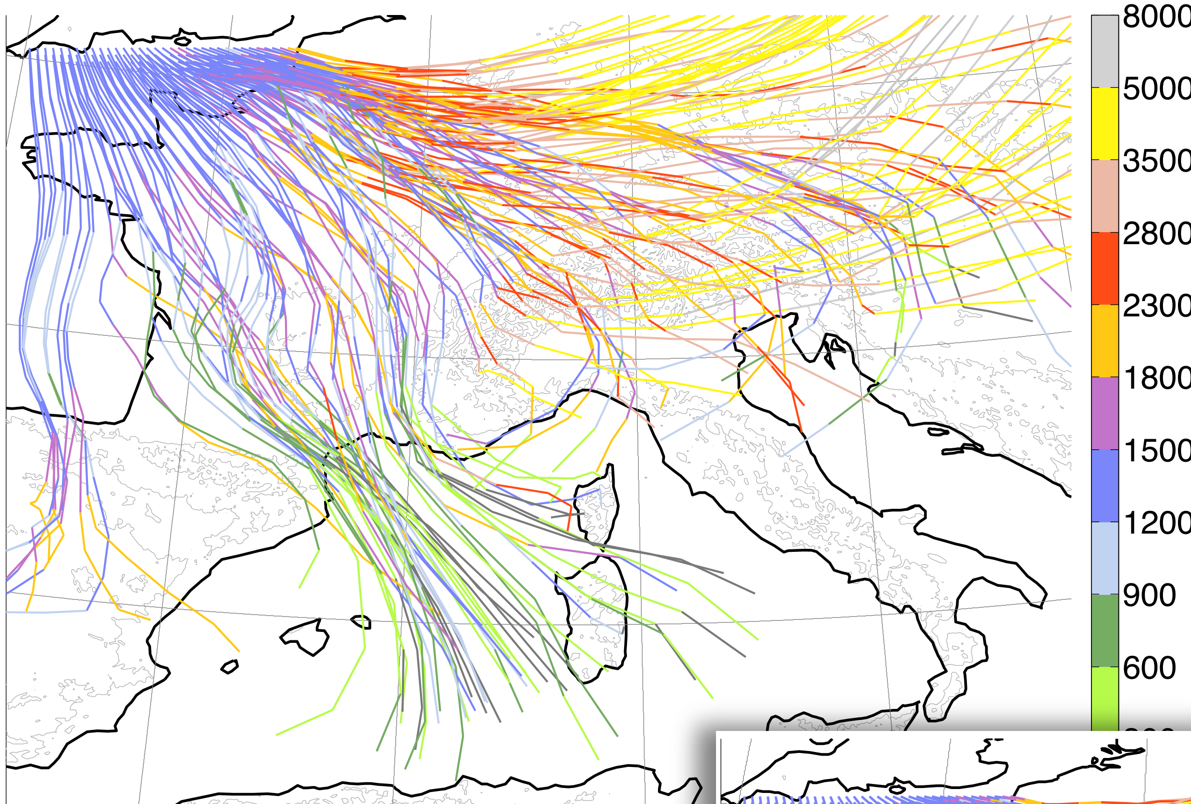
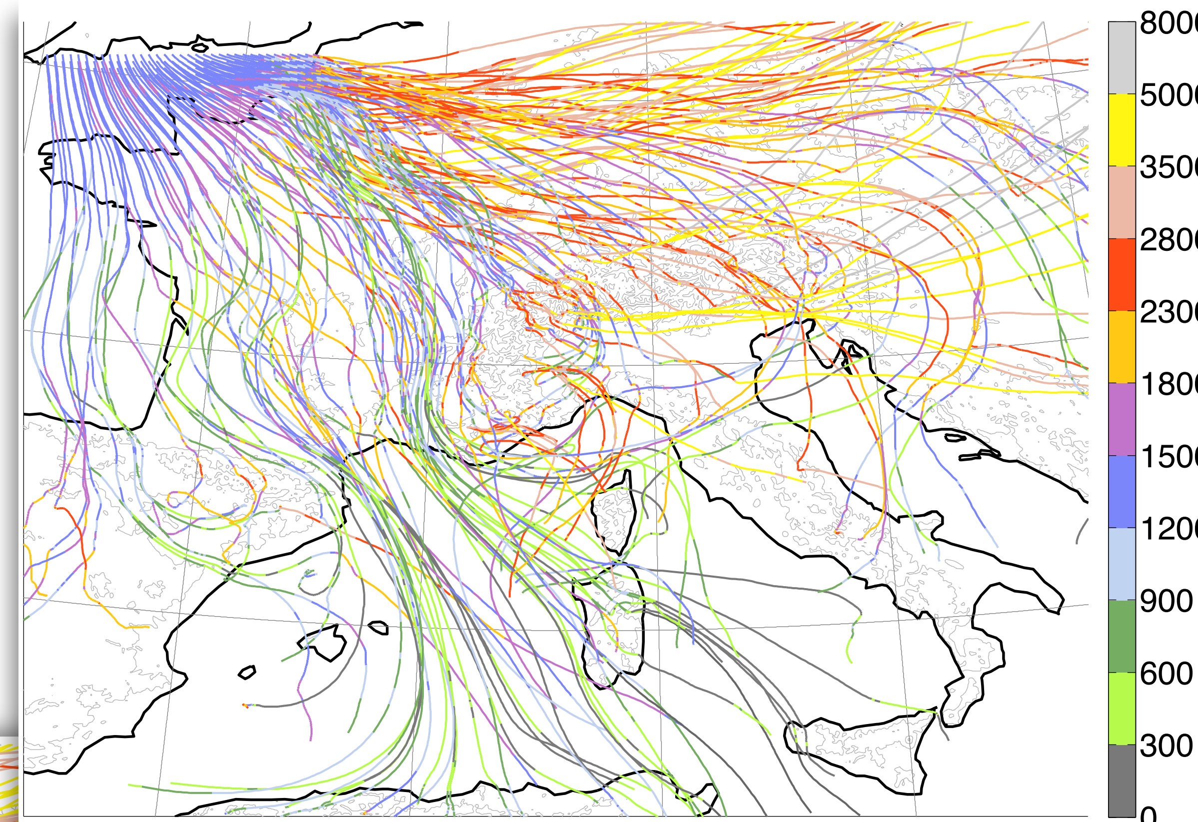


Δt = 20s; online trajectories (COSMO2.2)



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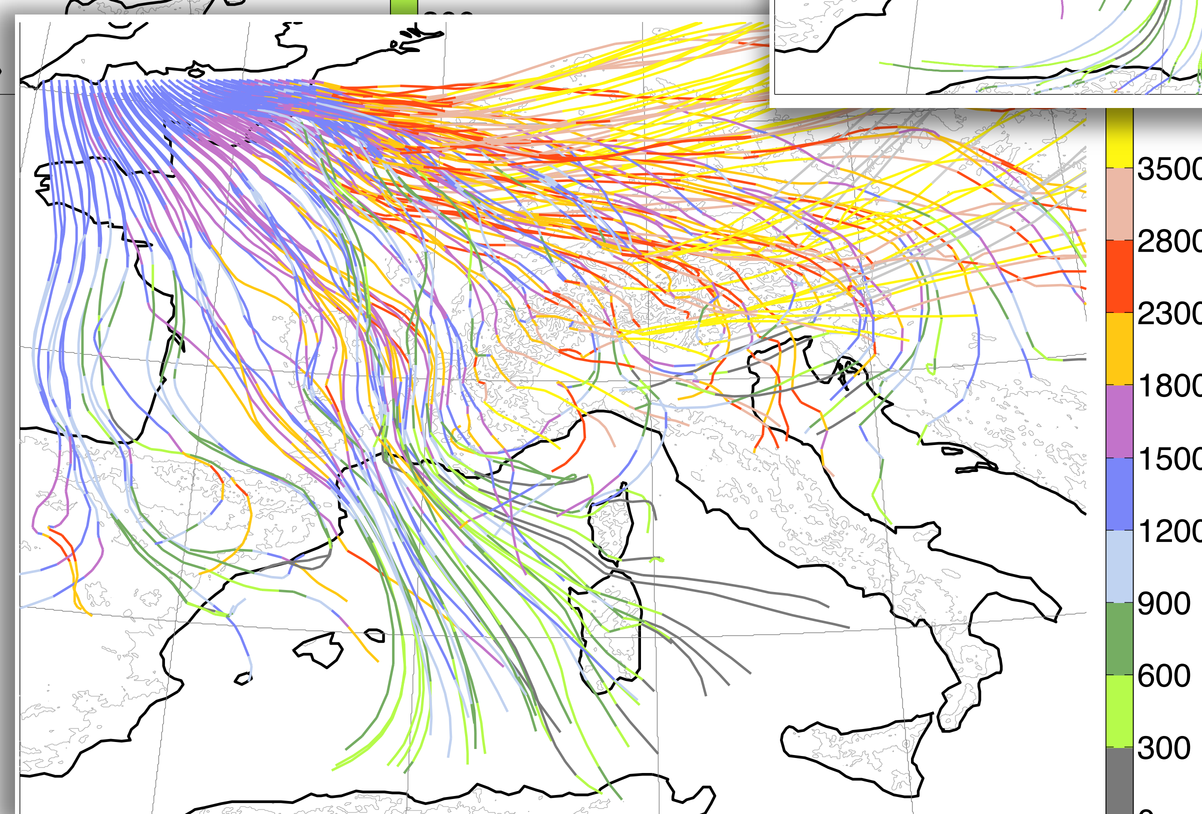
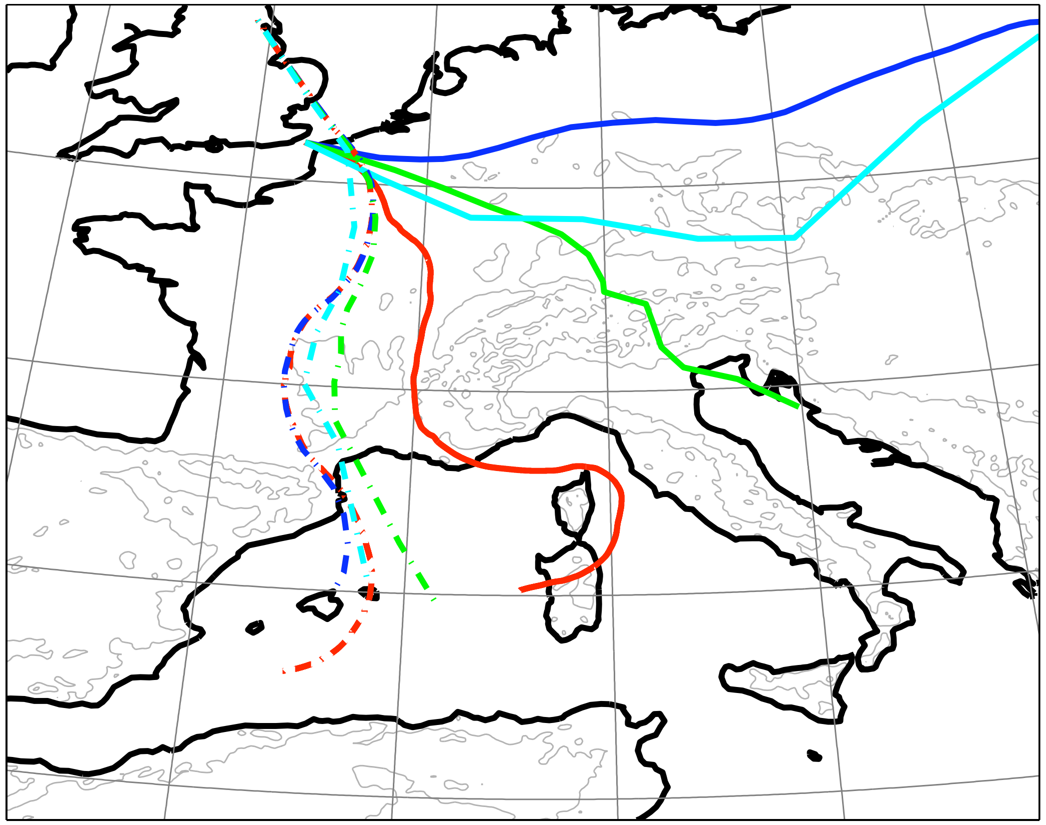
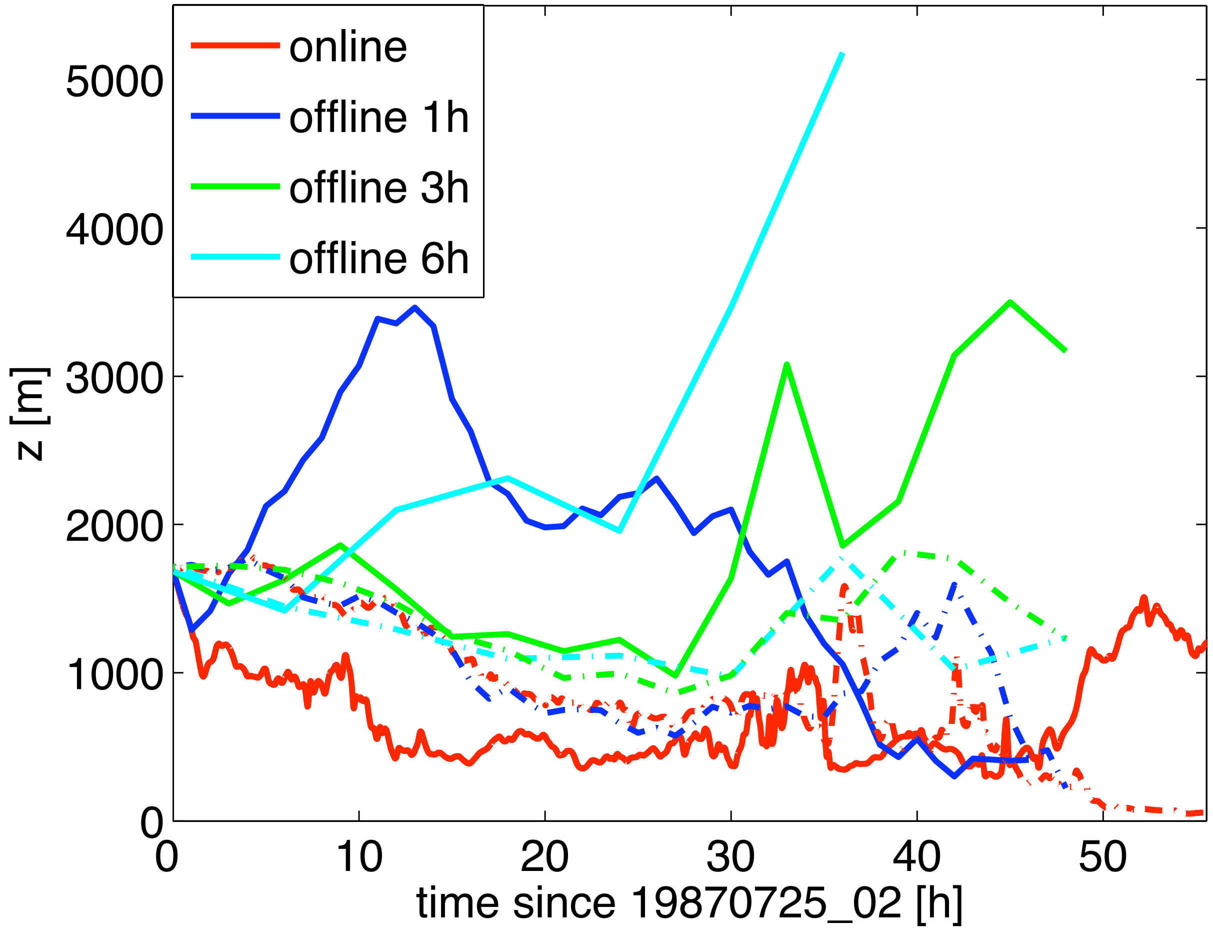


an alpine foehn event: 25 - 27 July 1987





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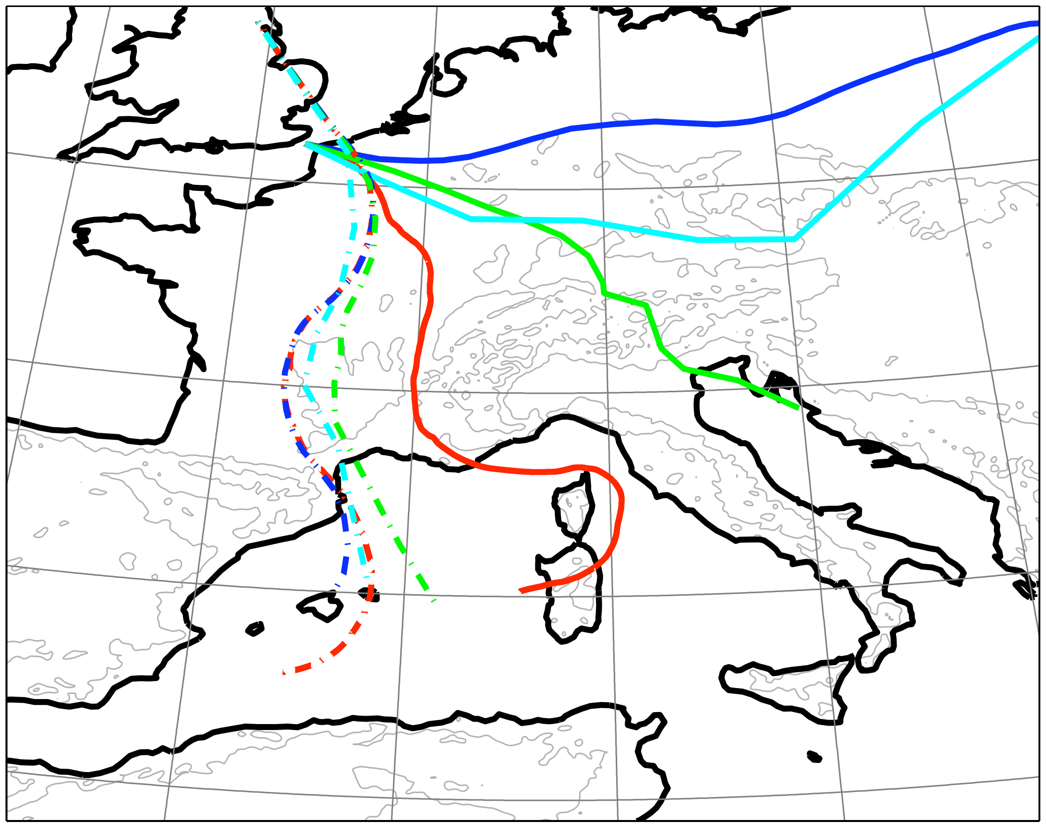

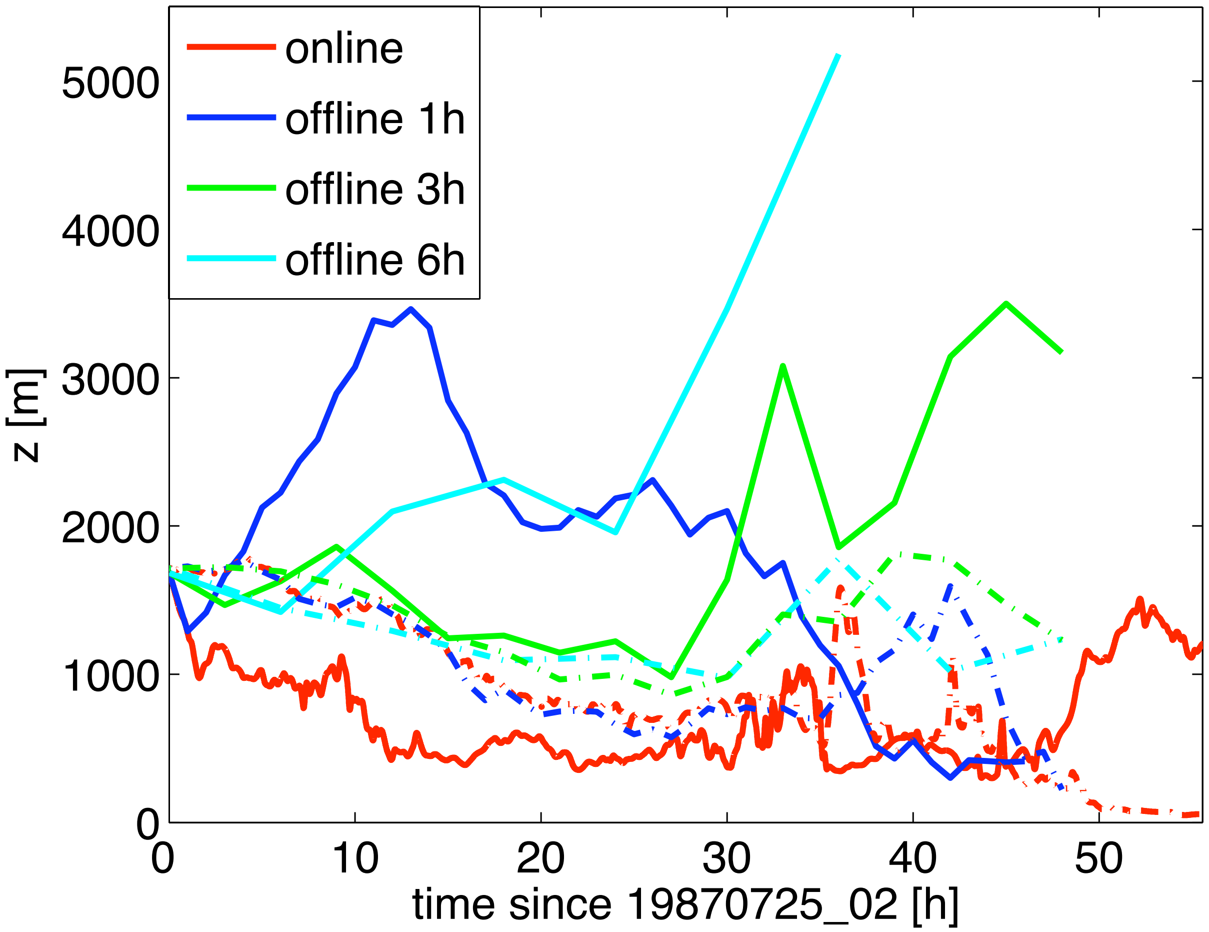

- average horizontal displacement after 48 h : 210 - 500 km
- average vertical displacement after 48 h : 445 - 980 m

I. Challenges

- no backward trajectories possible
- specification of starting region
- terrain intersection problem

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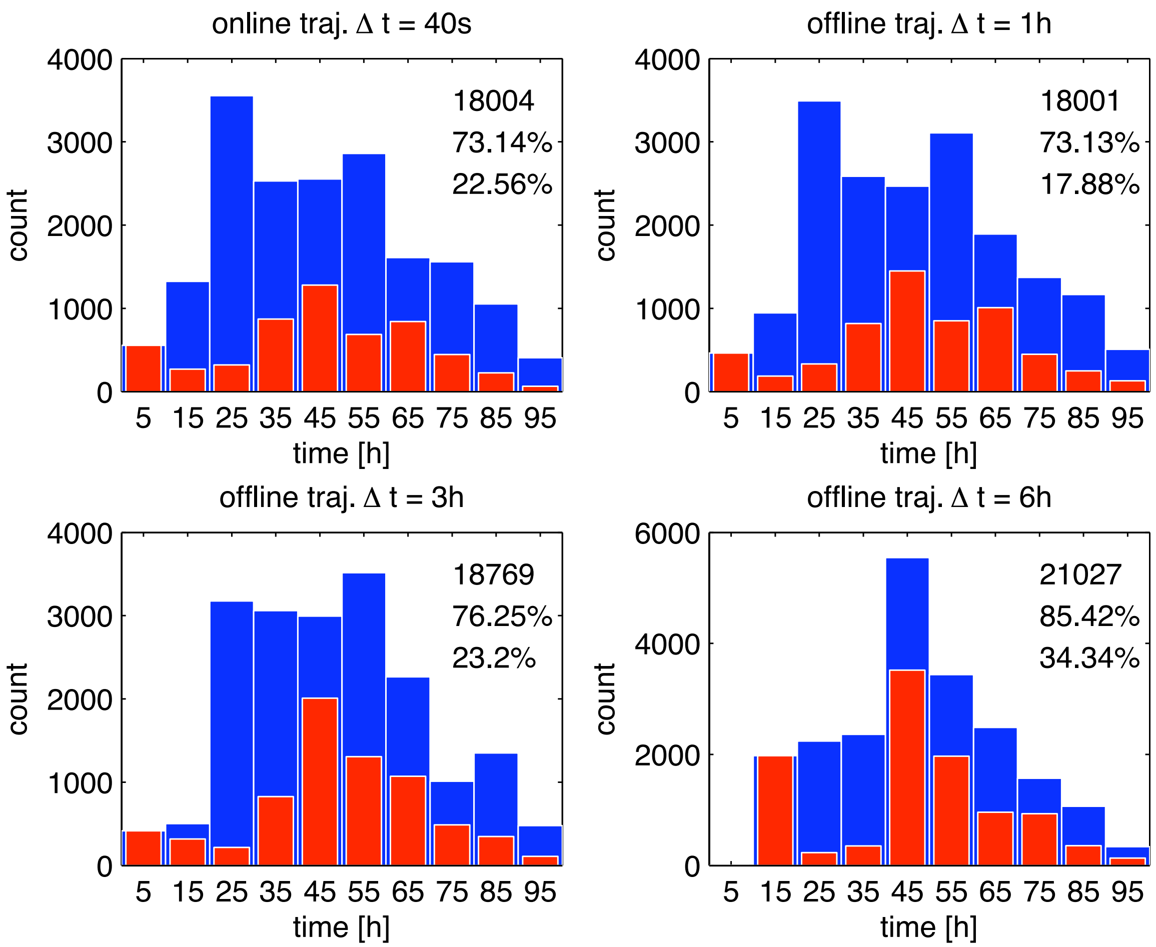

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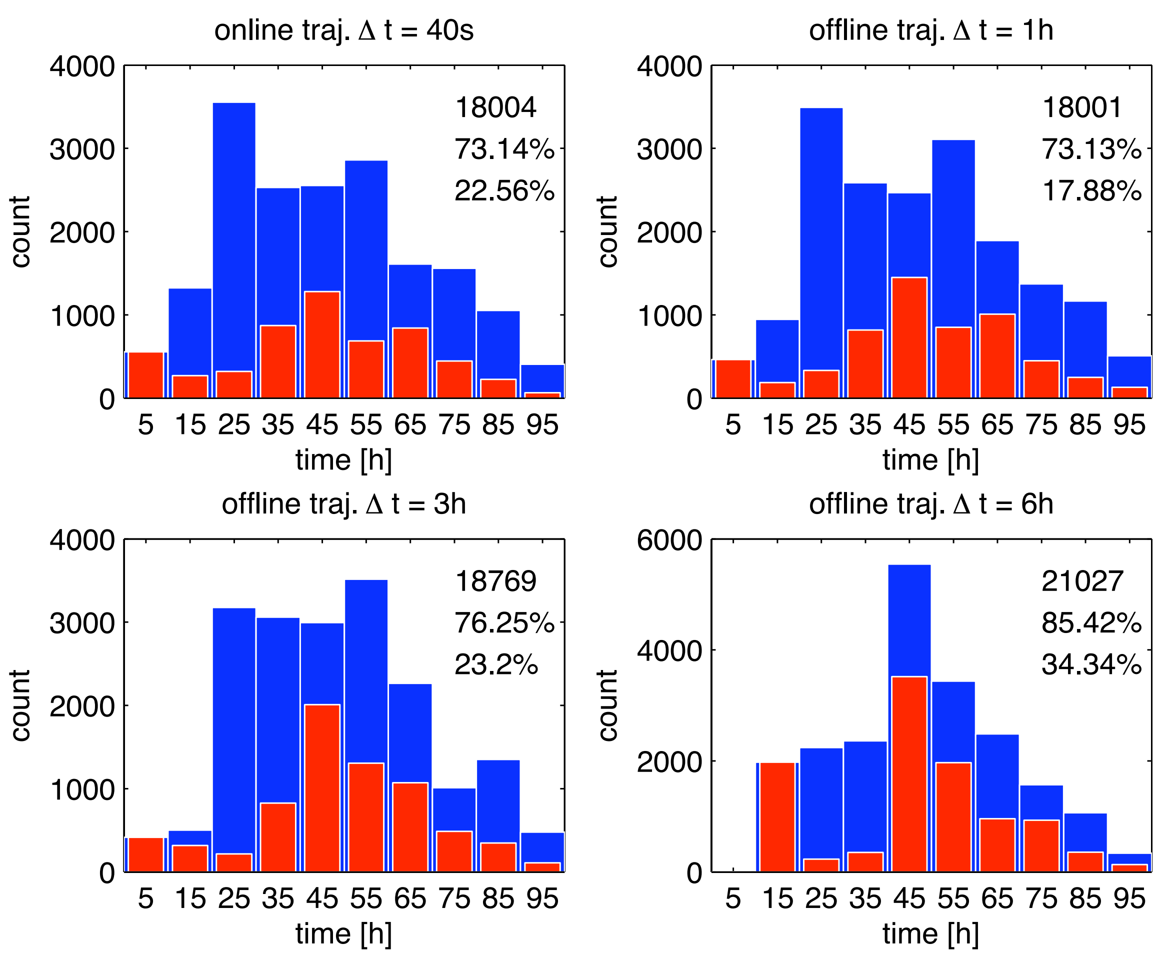

II. Potentials

I. Challenges

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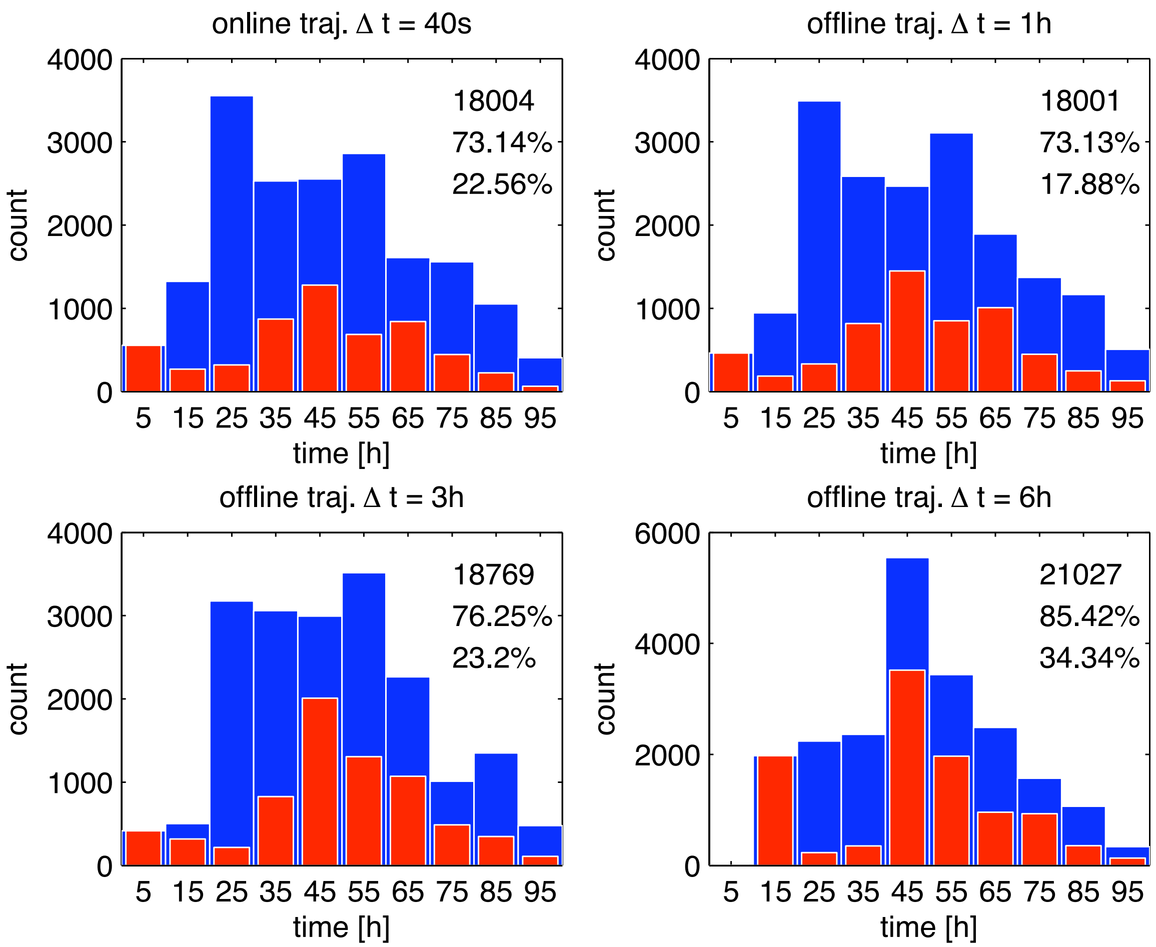
- specification of starting region
- terrain intersection problem



II. Potentials

- small numerical errors
- very high temporal resolution matching high spatial resolution
- run time increase below 30%
- appropriate for small scale phenomena

 Challenges & Potentials

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- specification of starting region
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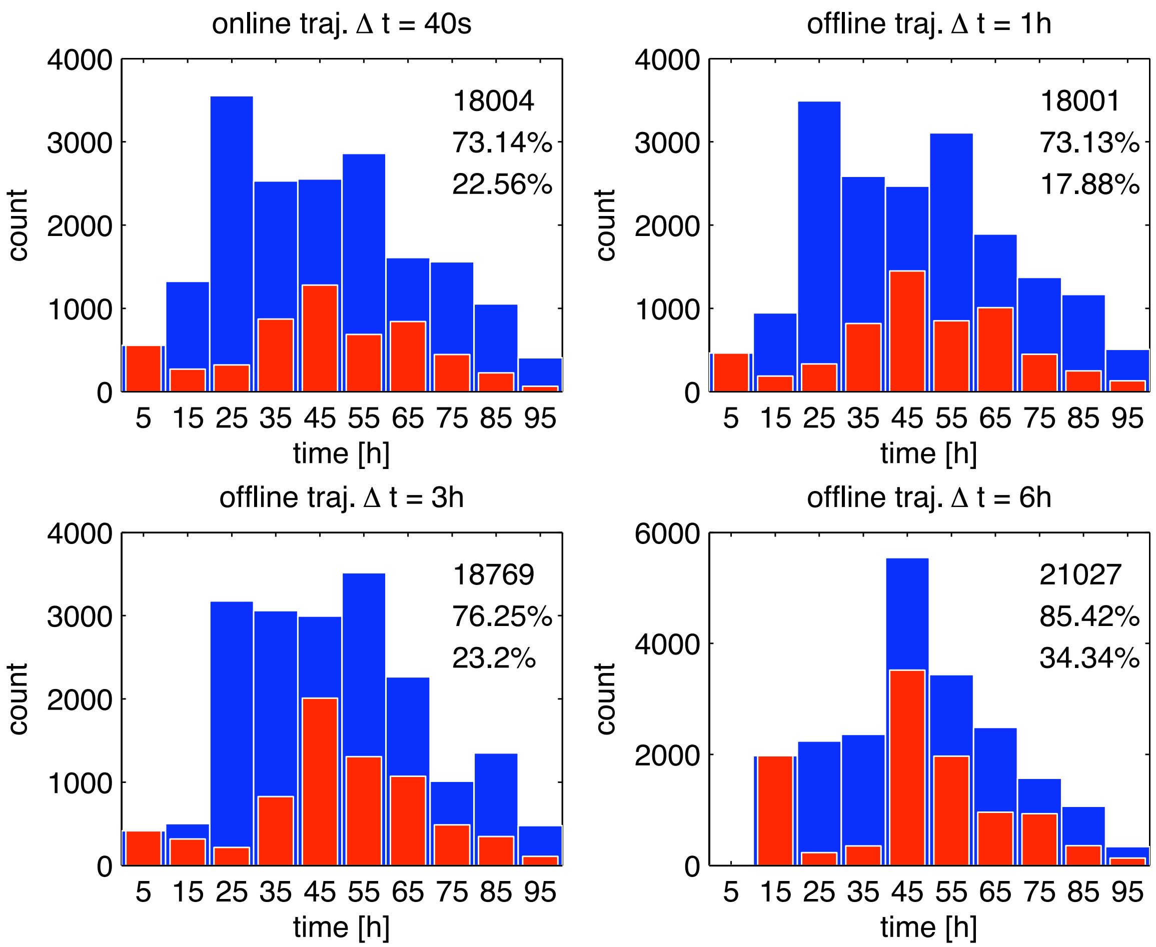

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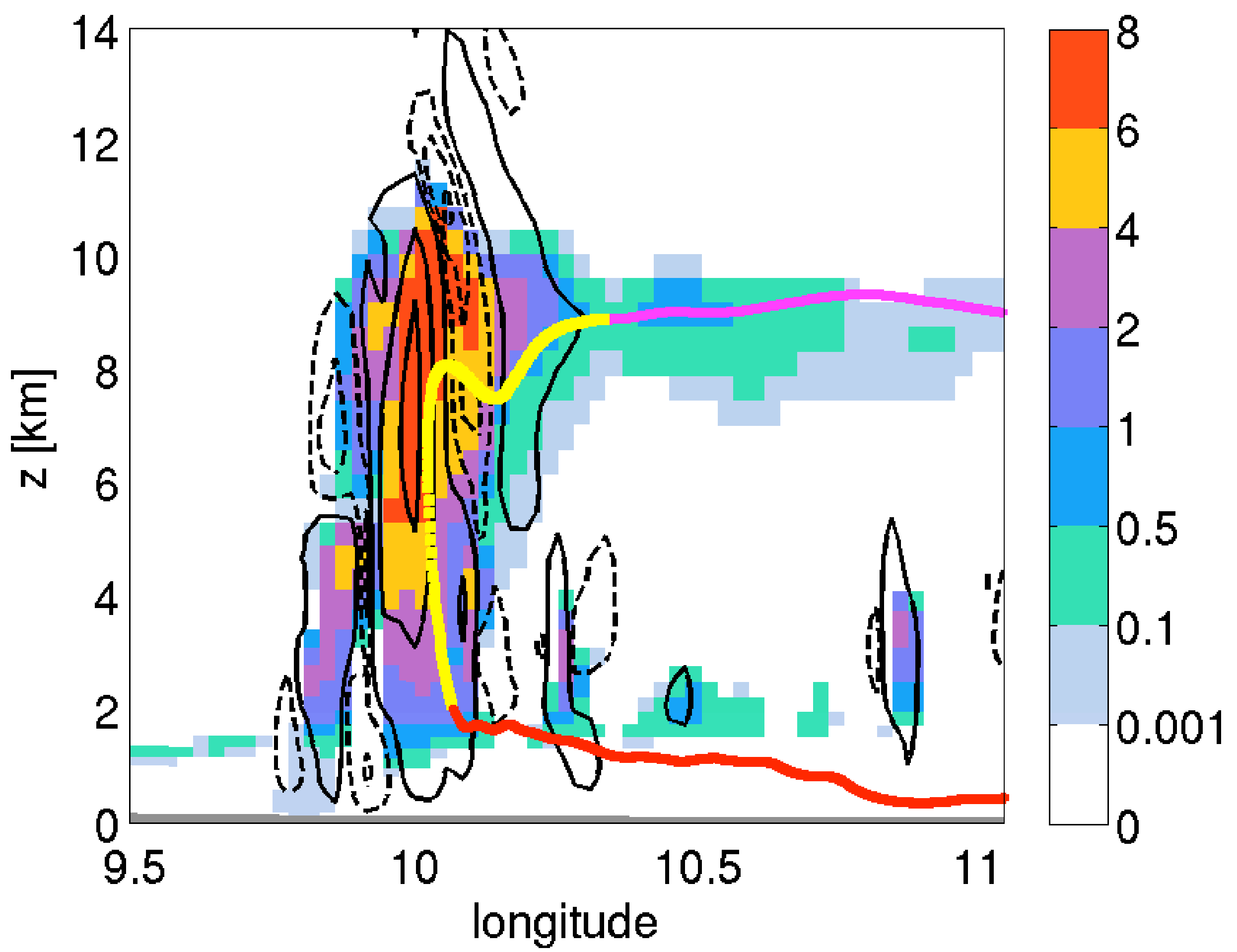
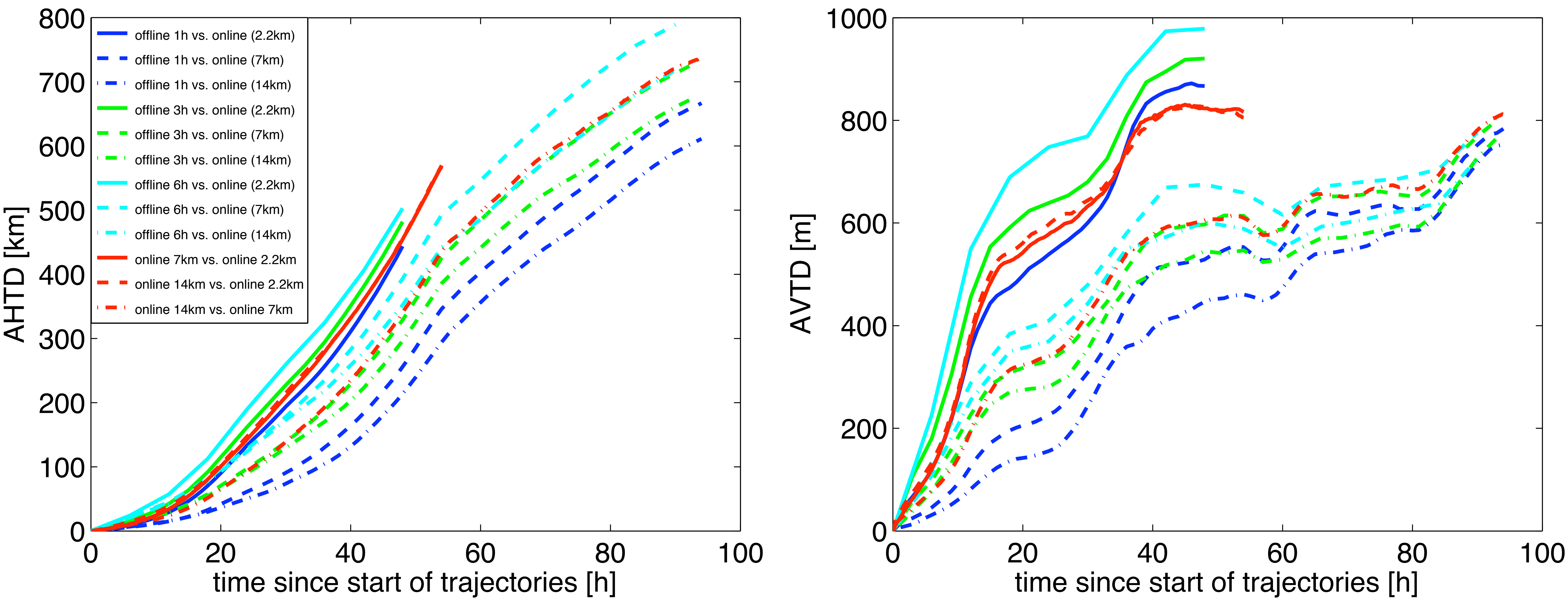


Appendix



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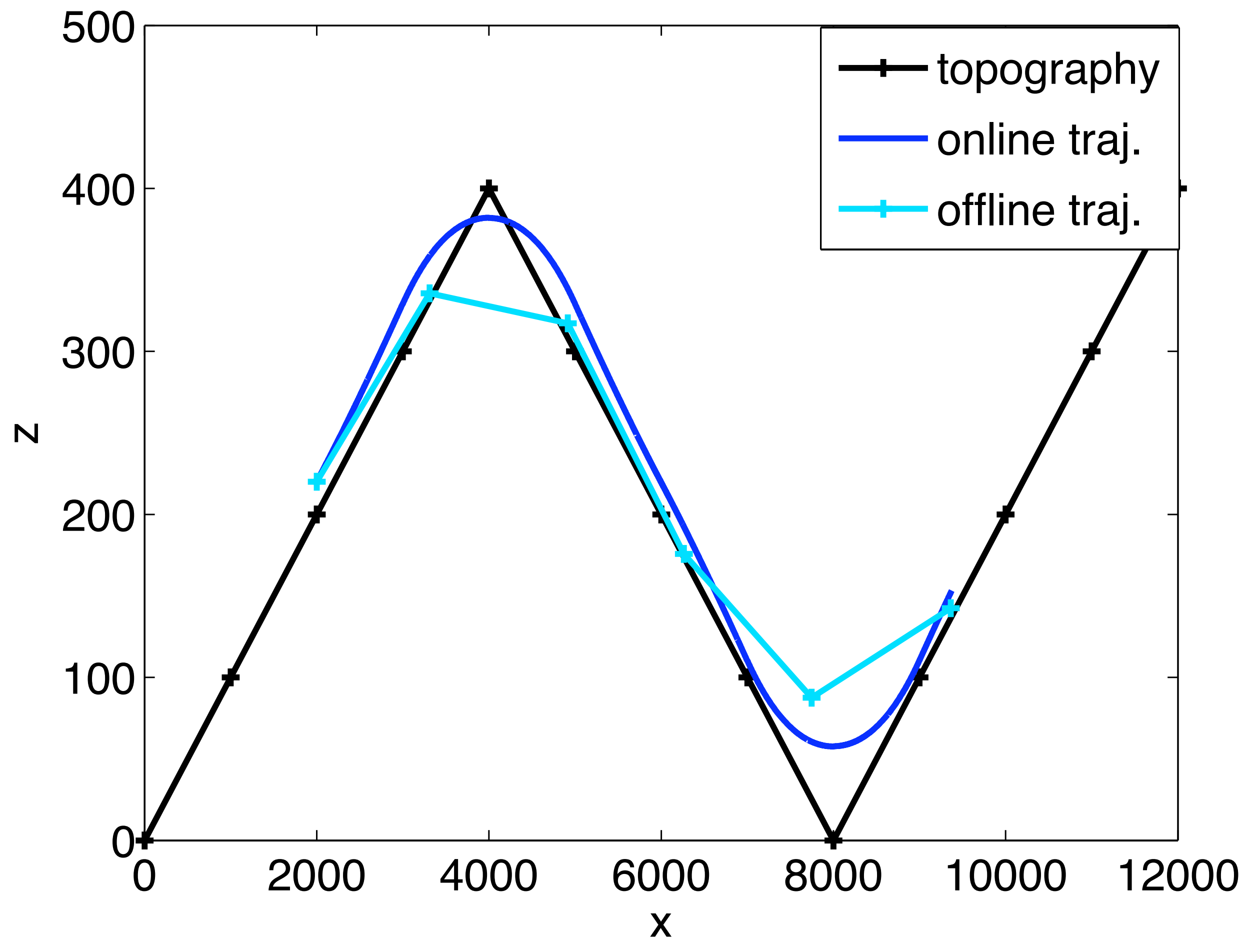
[distance measure $\mathrm{AHTD}(t) = \frac{1}{N}\sum_{n=1}^{N}\left((X_n(t)-x_n(t))^2+(Y_n(t)-y_n(t))^2\right)^{0.5}$]

Performance of COSMO with online trajectory module for the Alpine case study
(16 processors for COSMO14 and COSMO7; 128 for COSMO2.2)

	Δx = 14 km	Δx = 7 km	Δx = 2.2 km
without trajectory module (reference: COSMO14 without trajectory module)	0.00	3.16	13.2
with trajectory module (reference: COSMO14 without trajectory module)	0.264	3.45	13.6
with trajectory module (reference: simulation without trajectory module)	0.264	0.0681	0.0366

Appendix



500
400
300
200
100
0
z
0
2000
4000
6000
8000
10000
12000
x
topography
online traj.
offline traj.