Ice Cloud Formation Pathways and their Isotopic Signals in High-Resolution COSMO_{iso} simulations of the African Monsoon

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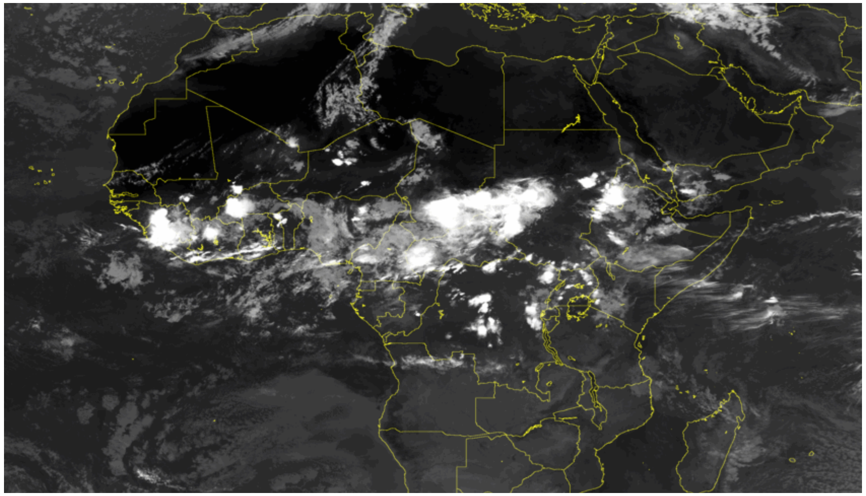
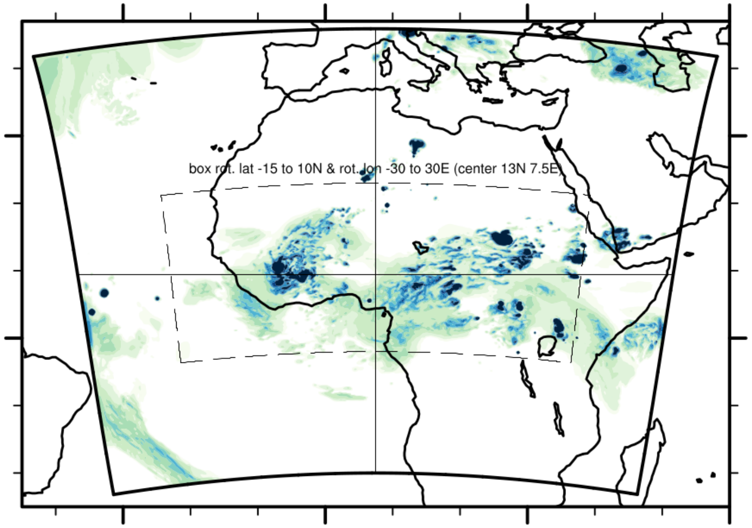


Infrared satellite image of 16 June 2016, 1800 UTC (from archive of www.sat24.com)



COSMO_{iso} cloud ice & snow content (200 hPa), 16 June 2016, 1800 UTC

Swiss National Science Foundation

ETH Zürich

Motivation and Aim of the Study

Tropical ice clouds key element of the Earth's climate system
- influence global radiation budget
- interaction with the circulation
- poorly represented in climate models

(*Mini Cloud Atlas*)

Improve our understanding of formation, structure and variability of tropical ice clouds using high-resolution convection-permitting model simulations

Aims of the study
1) distinguish ice cloud formation pathways (in situ versus via liquid phase)
2) assess isotopic signatures in these pathways
3) elucidate moisture origin and transport pathways for ice cloud formation

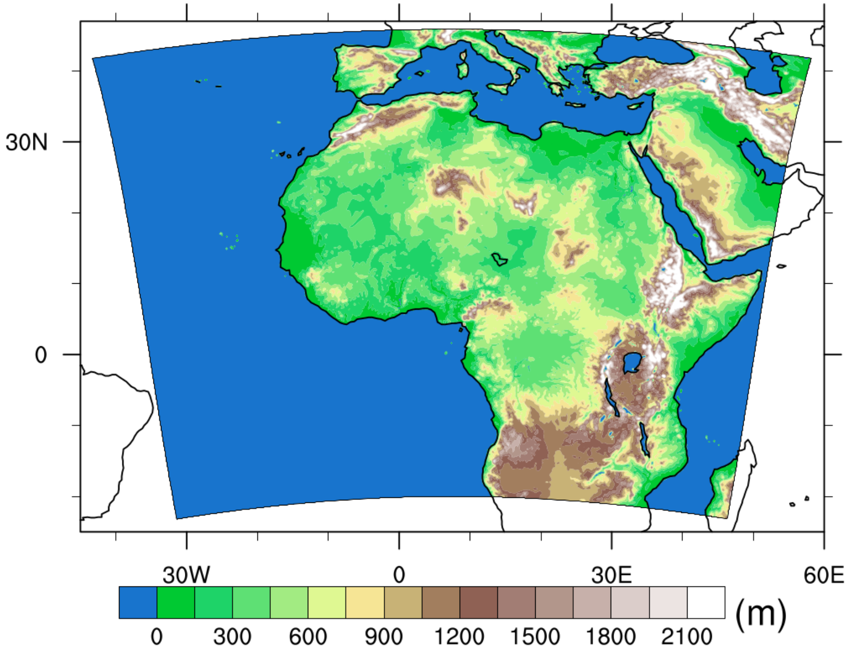
Model Simulations, Tools and Data

ETH Zürich

Model simulations

- COSMO (v. 4.18) isotope-enabled version $H_2{}^{18}O$ and HDO; $COSMO_{iso}$ (*Pfahl et al.*, 2012)
- interactive soil moisture scheme (*Christner et al.*, 2018)
- initial & boundary conditions from $ECHAM_{wiso}$ (Martin Werner, AWI)
- June & July 2016; DACCIWA field campaign (*Knippertz et al.*, 2017)
- rotated grid (36°W-51°E, 20°S-46°N)
- hourly output

COSMO domain & topography



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$Cosmo_{iso}$ model simulations

	resolution	grid points	Δt	convection
1	14 km, 40 mlev	696 x 528	60 s	parameterized
2	**14 km, 40 mlev**	**696 x 528**	**60 s**	**explicit**
3	7 km, 60 mlev	1392 x 1056	40 s	explicit

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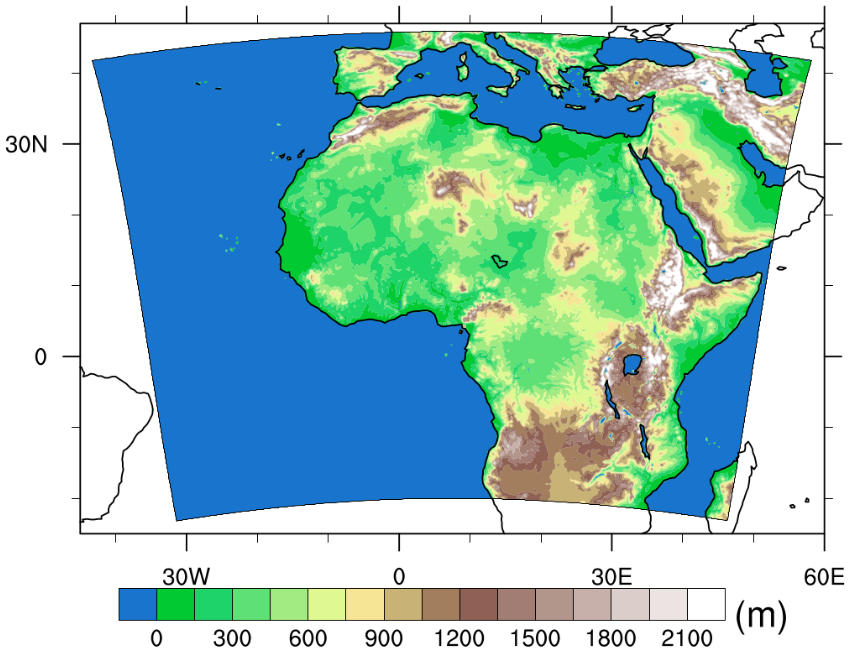

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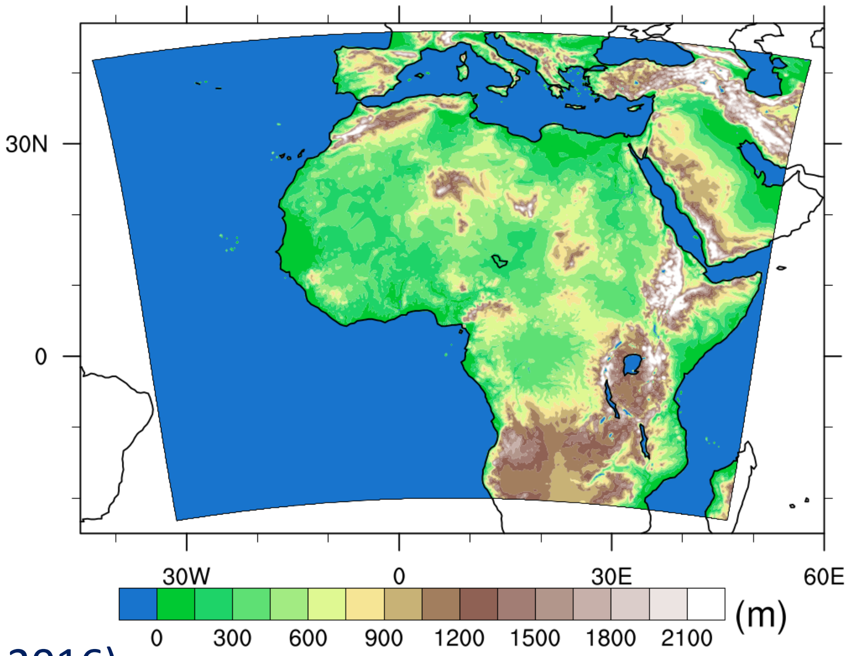

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Tools

- trajectories (*Sprenger and Wernli*, 2015)
- classification ice cloud formation (*Wernli et al.*, 2016)

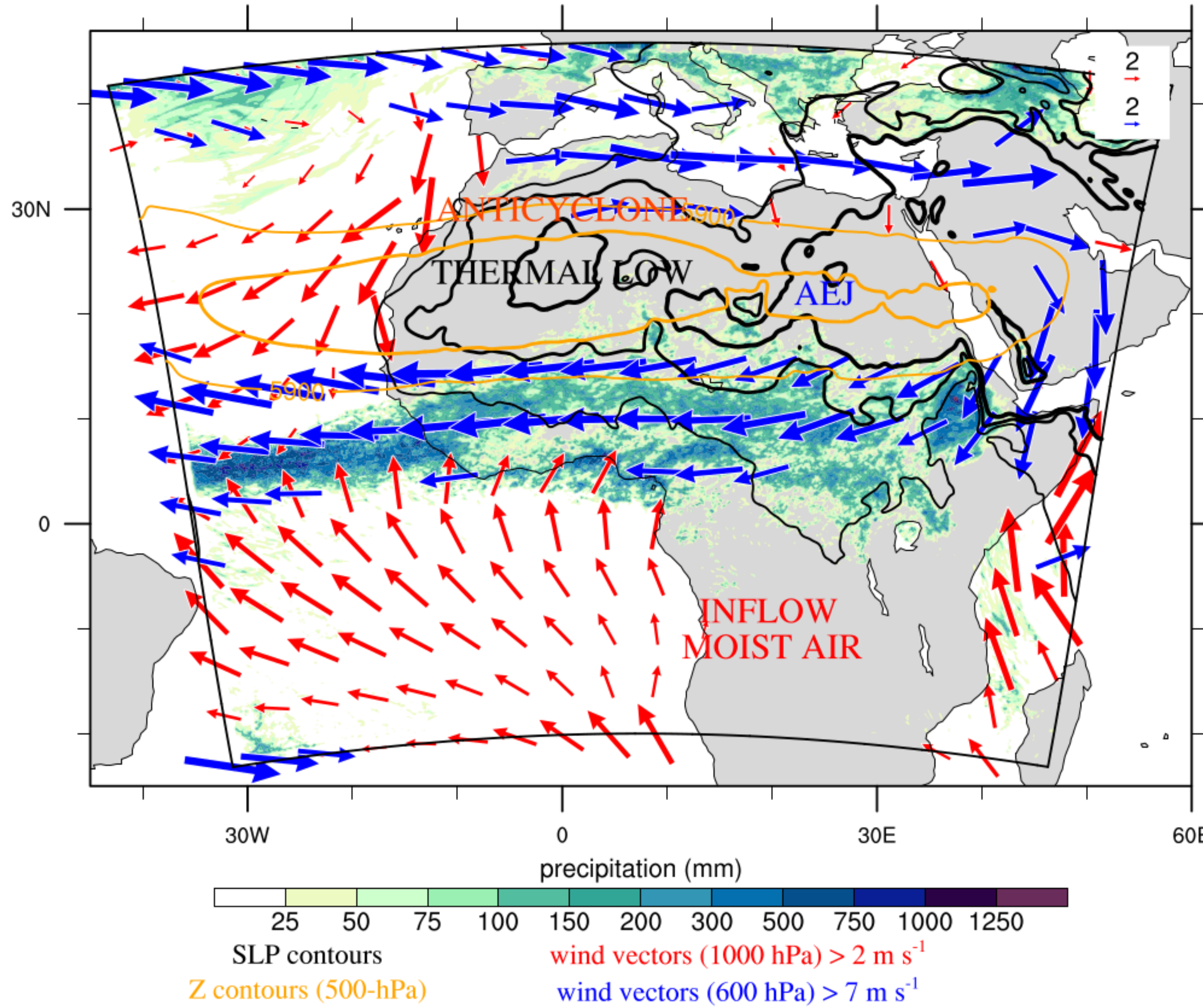
Data

- GNIP (*Rozanski et al.*, 1993)

Large-Scale Circulation

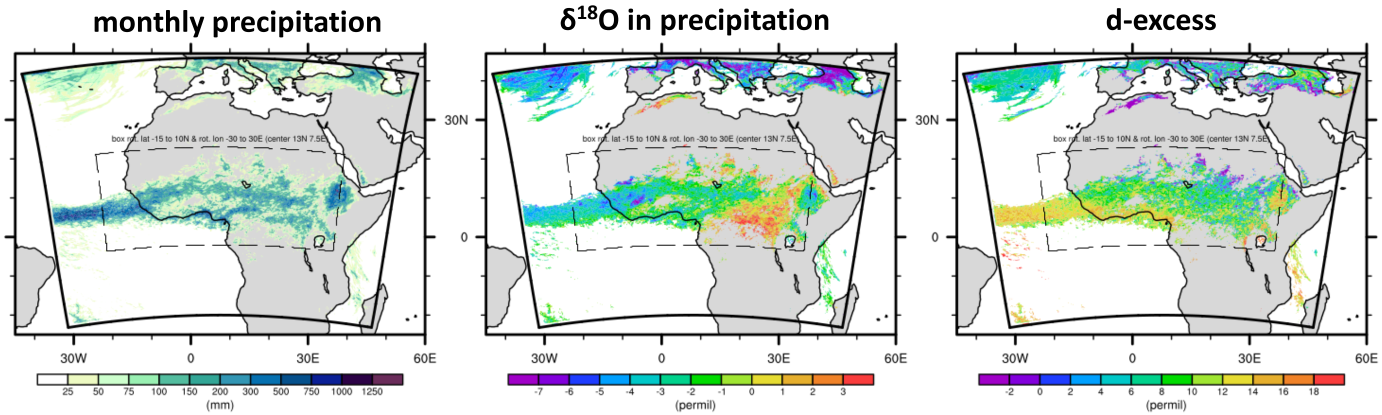
West African monsoon system
- tropical rain belt
- **Saharan heat low**
- **anticyclone & subsidence**
- **inflow moist air**
- **African easterly jet (AEJ)**

precipitation & circulation (June 2016)



Precipitation in $COSMO_{iso}$ & GNIP (June 2016)

$COSMO_{iso}$



- gradient δ-values from West Africa to central Africa (different moisture sources & evapotranspiration)

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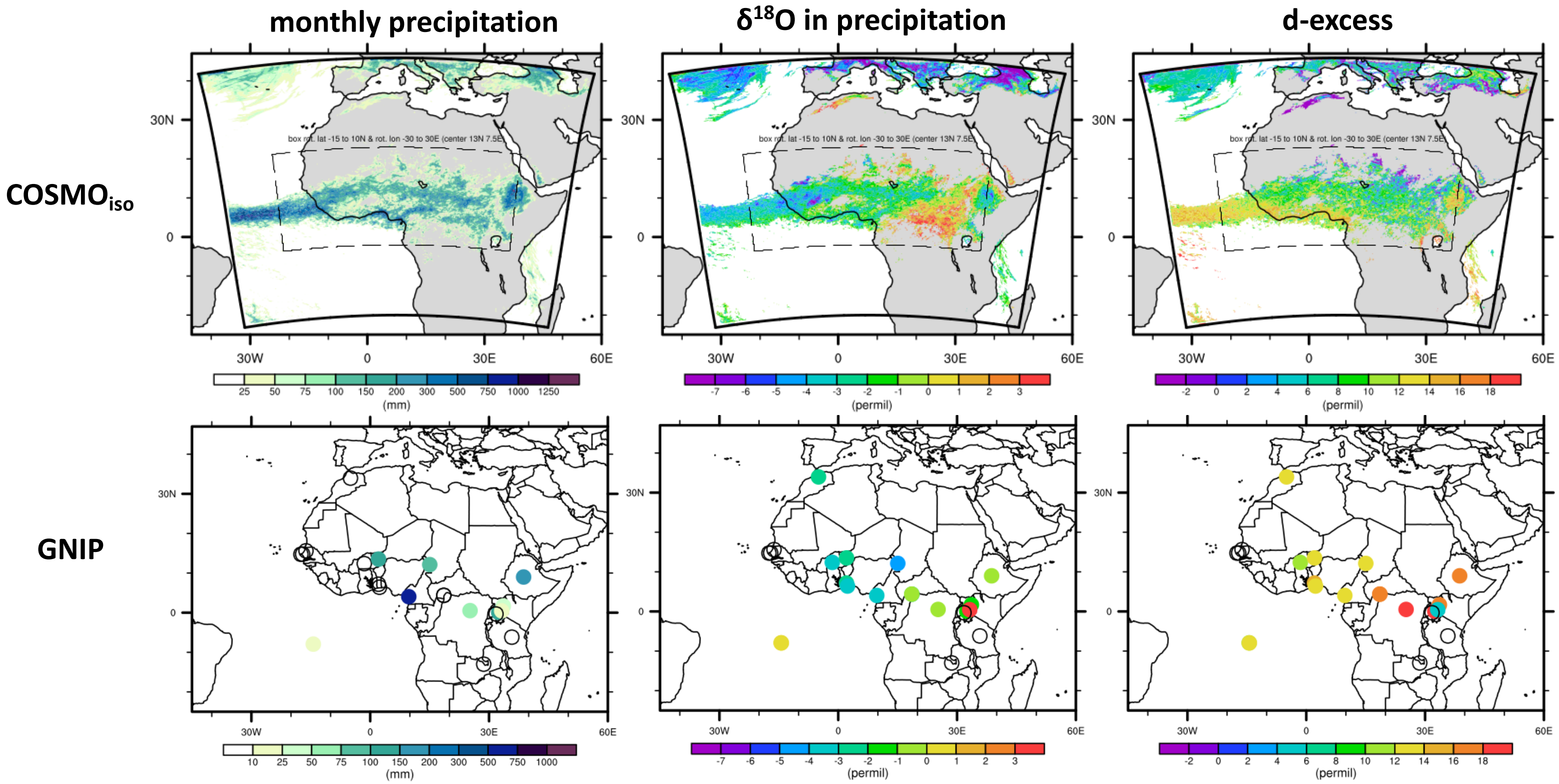

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- overall, COSMO$_{iso}$ represents precipitation & isotopic composition reasonably well

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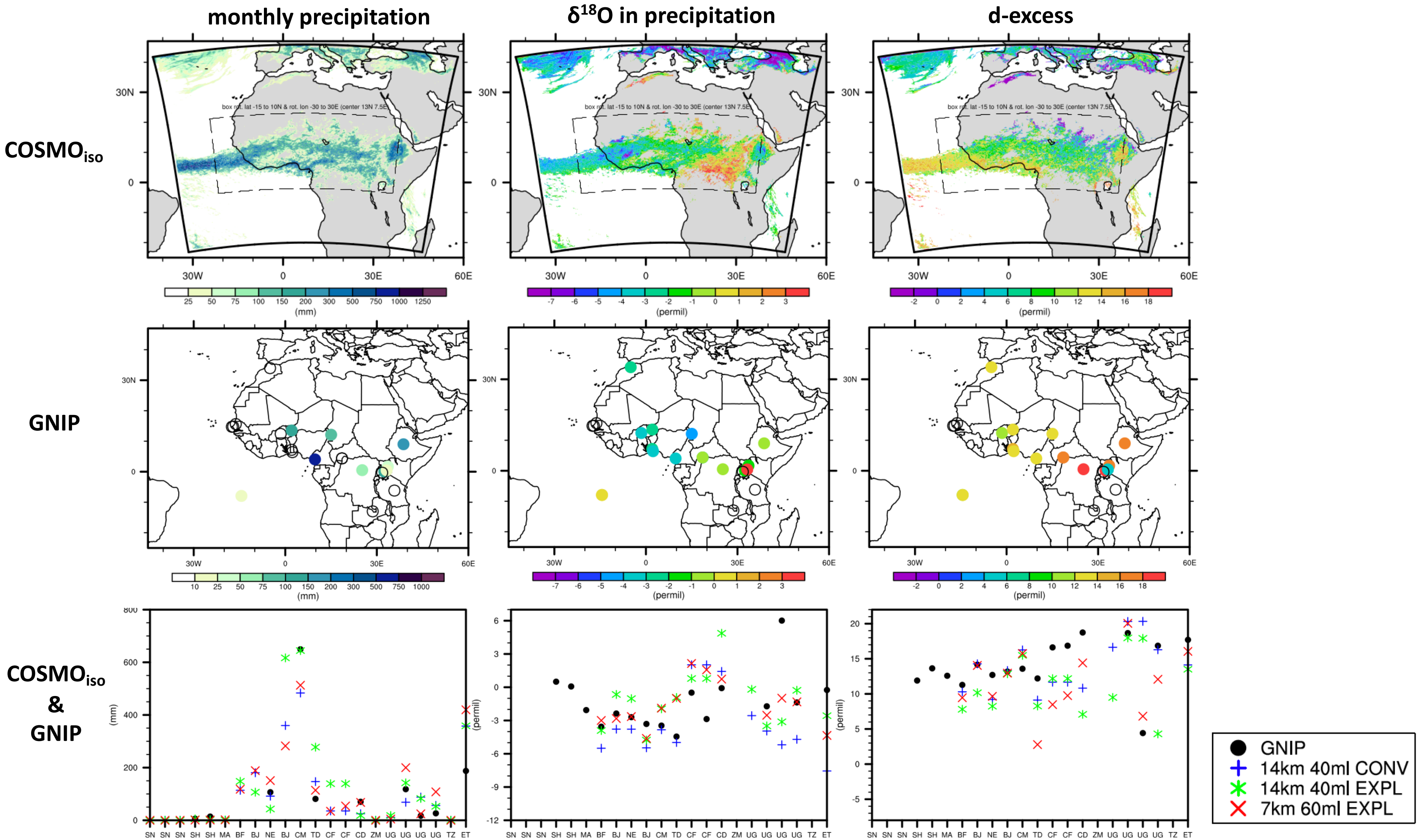

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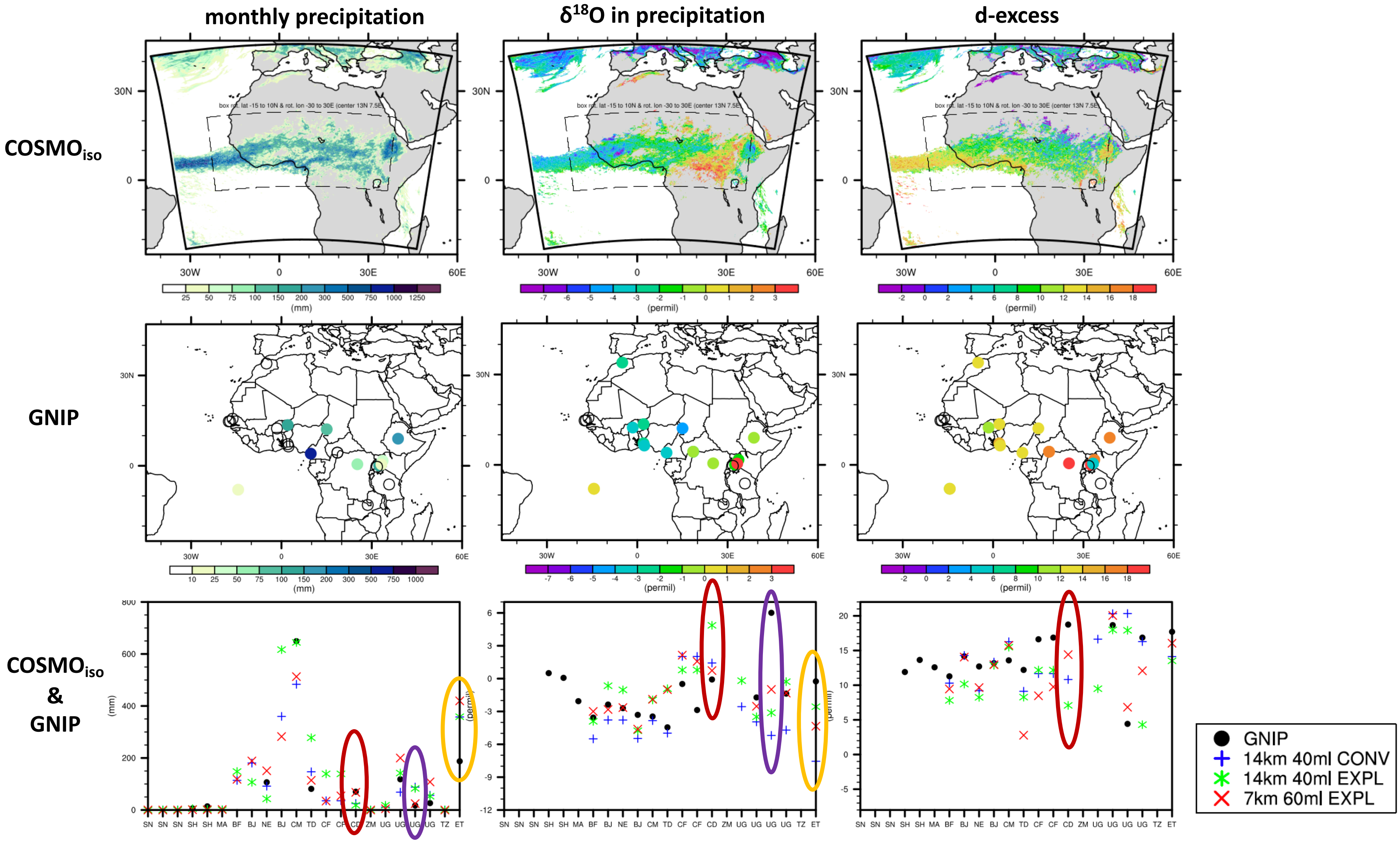
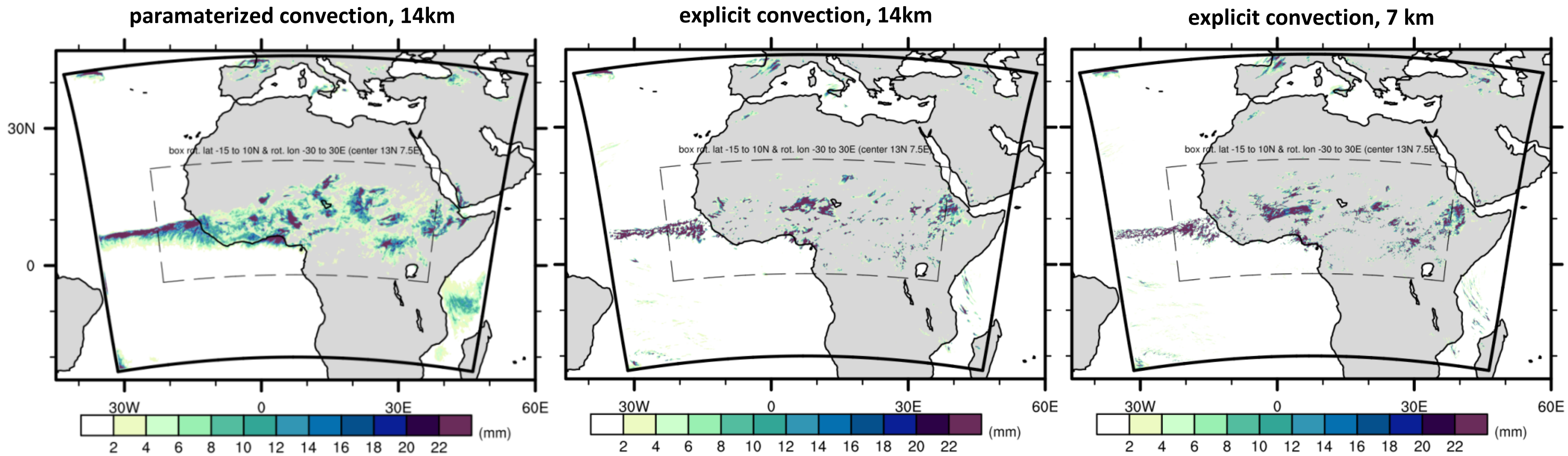


- gradient δ-values from West Africa to central Africa (different moisture sources & evapotranspiration)
- overall, COSMO$_{iso}$ represents precipitation & isotopic composition reasonably well
- too low δ-values (**ET**, **UG**), too high δ-values & too low d-excess (**CD**)

Representation Convection & Diurnal Cycle Precipitation

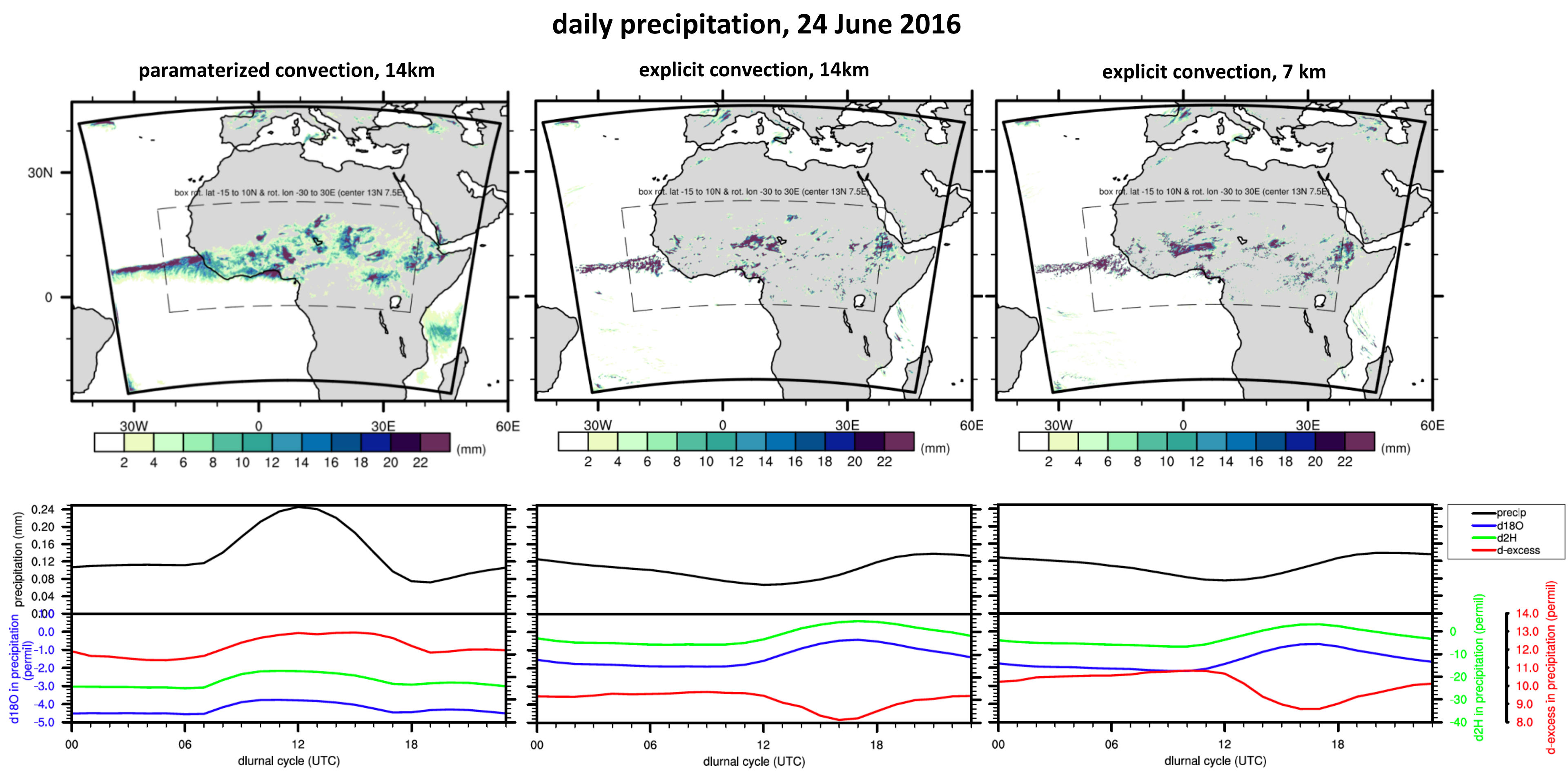
daily precipitation, 24 June 2016



Influence of representation convection on precipitation

- substantial differences in precipitation patterns

Representation Convection & Diurnal Cycle Precipitation



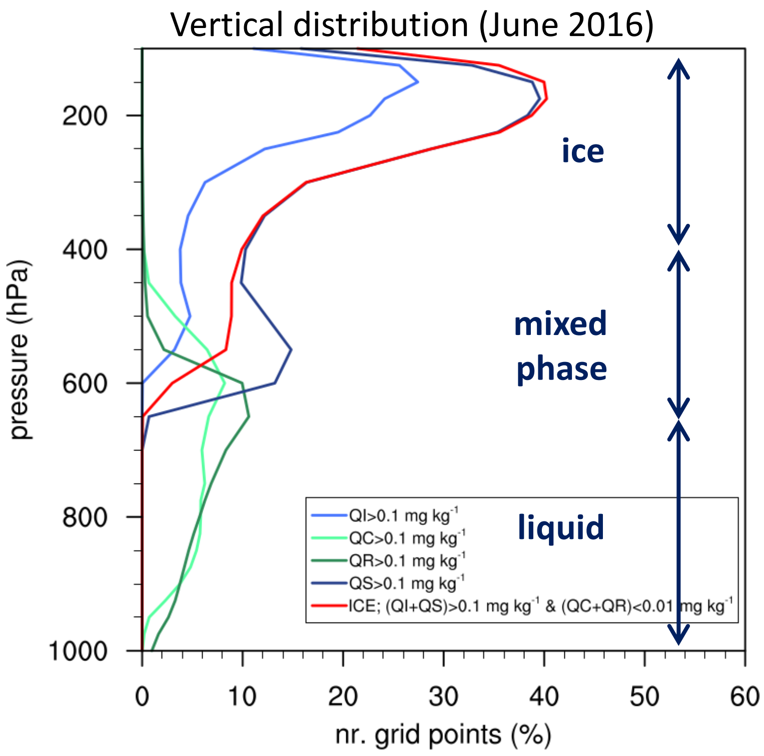
Influence of representation convection on precipitation

- substantial differences in precipitation patterns
- convection-permitting simulations solve noon-peak issue (cf. *Marsham et al.*, 2013; *Birch et al.*, 2015)
- large isotopic differences between parameterized and explicit convection simulations

Definition Pure Ice Clouds & Formation Pathways

Cloud and hydrometeors in $COSMO_{iso}$ (v.4.18)

- ice (QI), snow (QS), liquid cloud (QC), rain (QR)
- no graupel



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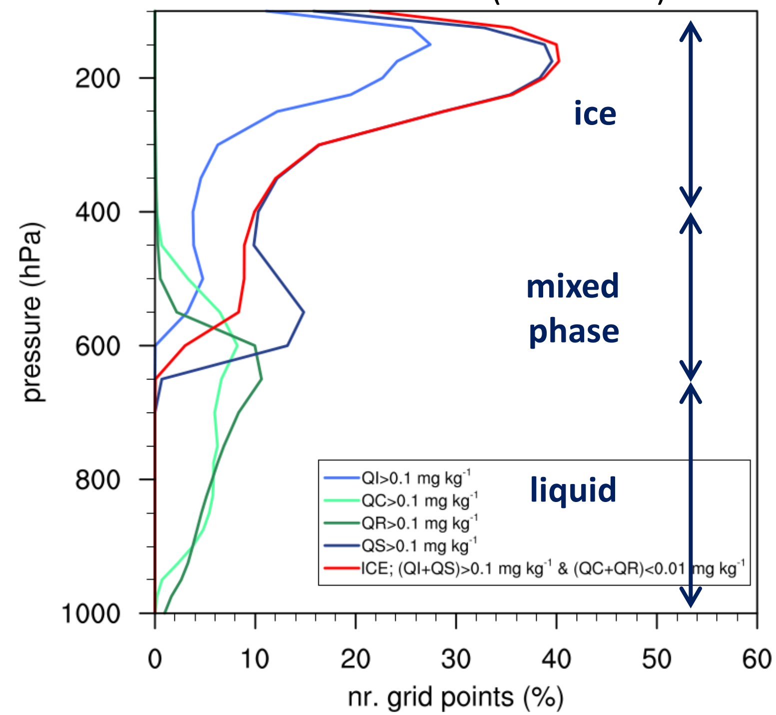
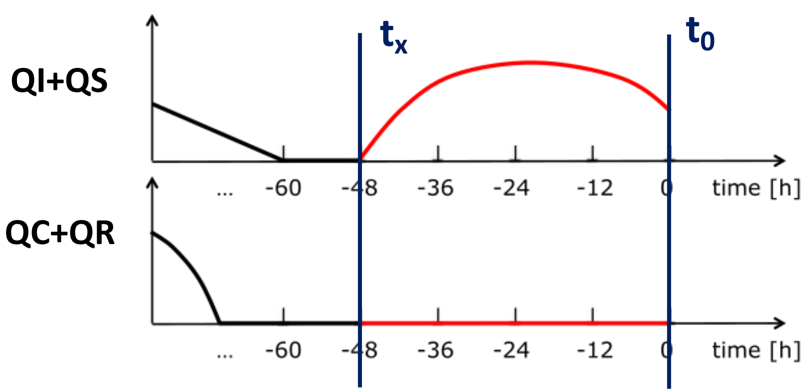
Classification ice cloud formation (*Wernli et al.*, 2016)
1. 'pure' ice cloud
   QI+QS>0.1 mg kg^{-1} & QC+QR<0.01 mg kg^{-1}
2. compute backward trajectories t_0 to t_x
3. distinguish in situ and via liquid phase formation

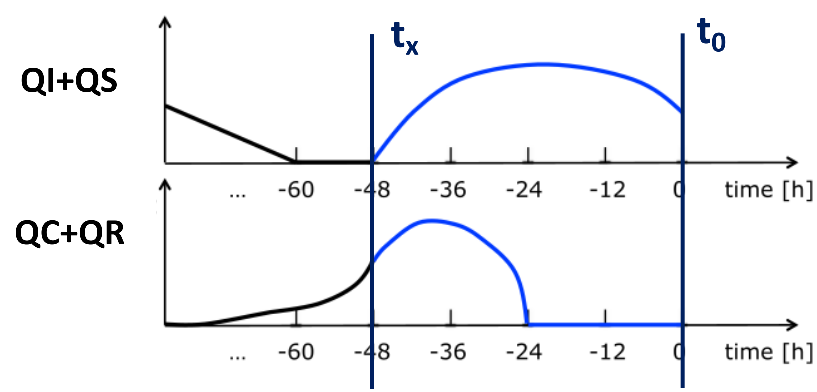
Vertical distribution (June 2016)



in situ formation



via liquid phase

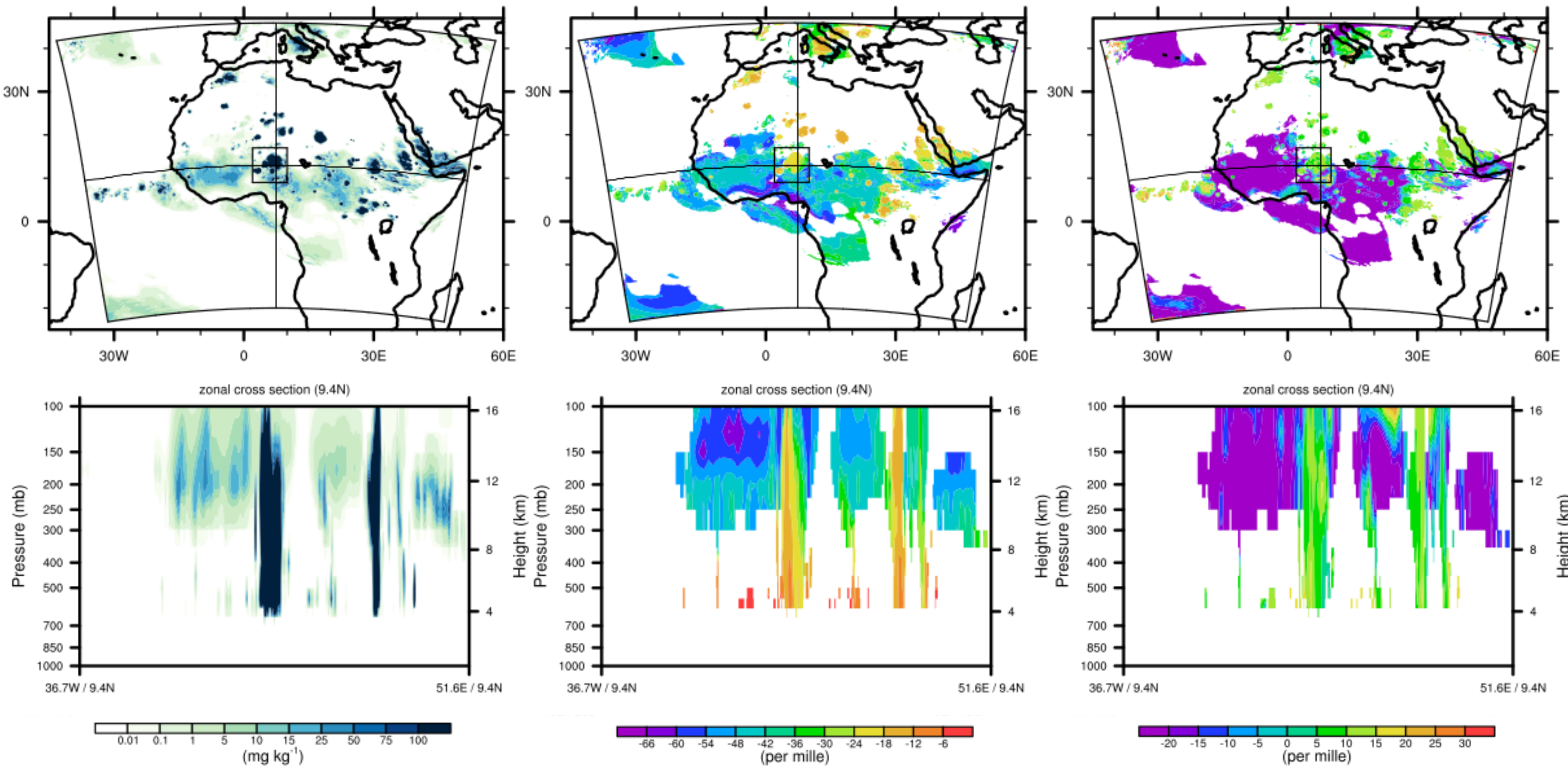


(*Wernli et al.*, 2016)

Cloud Ice and Snow & Isotopic Composition

24 June 2016, 1800 UTC (200 hPa)

sum cloud ice & snow **$\delta^{18}O$ in cloud ice & snow** **d-excess cloud ice & snow**



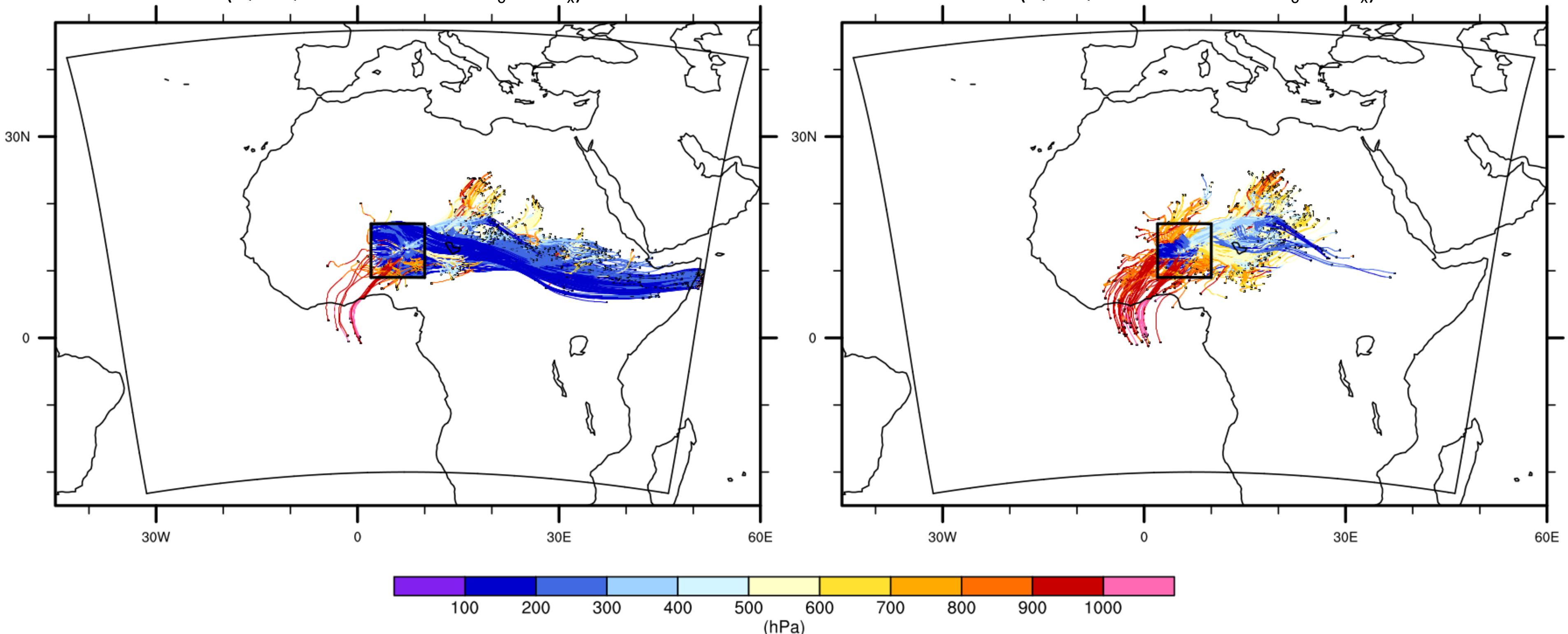
Isotopic composition in cloud ice & snow reflect strong signatures of convective systems

Backward Trajectories Ice Clouds

3-day backward air parcel trajectories from pure ice clouds at 200 hPa starting at 24 June 2016, 1800 UTC

in situ formation
(QC+QR < 0.01 between t_0 and t_x)

formation via liquid phase
(QC+QR > 0.01 between t_0 and t_x)



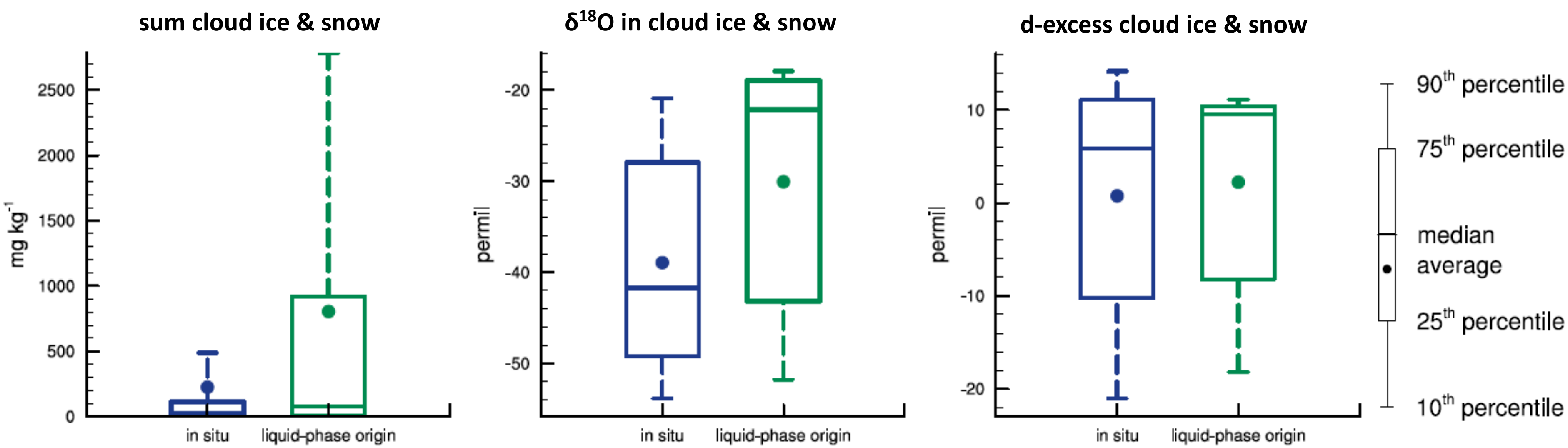
Some numbers

- grid points = 3,995 pure ice clouds = 3,003 in situ = 1,979 (66%) liquid-phase = 1,024 (34%)

In situ and via liquid-phase ice cloud formation pathways can have different moisture origin and transport pathways

Isotopic Signals in Ice Cloud Formation

Statistical dispersion of pure ice clouds and their isotopic composition on 24 June 2016, 1800 UTC (200 hPa)



In situ and via liquid-phase ice cloud formation pathways can have different isotopic signatures

Summary

(Preliminary) Conclusions

COSMO$_{iso}$ simulations

- represent precipitation and its isotopic composition reasonably well
- switching-off the convection scheme impacts the circulation, hydrological cycle and isotopic composition

ice cloud formation

1) in situ and liquid-origin
2) distinct moisture origin and transport pathways
3) different isotopic signatures

Outlook

- 2 case studies of ice cloud formation in different areas
- 'quasi-climatological' analysis (June & July 2016)
- interannual variability monsoon stage and intensity