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Cycling of carbon and water in mountain ecosystems under changing climate and land use
A progress report

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Main objectives

- Collect available flux data for ecosystems typical for the Alps
- Explore available remote sensing data and techniques for producing high quality evapotranspiration (ET) maps over vegetated areas in the complex structure of the Alpine region
- Improve Two Source Energy Balance (TSEB) models by combining them with enhanced satellite-derived products to obtain ET information at higher spatio-temporal resolution
- Calibrate and validate a simple biosphere model (SiB4) on the collected flux data
- Calculate future weather scenarios using a Weather Generator (WG)
- Simulate future land-use scenarios for alpine regions
- Combine the obtained knowledge to explore future climate scenarios for the Alps

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Regional land-use scenarios

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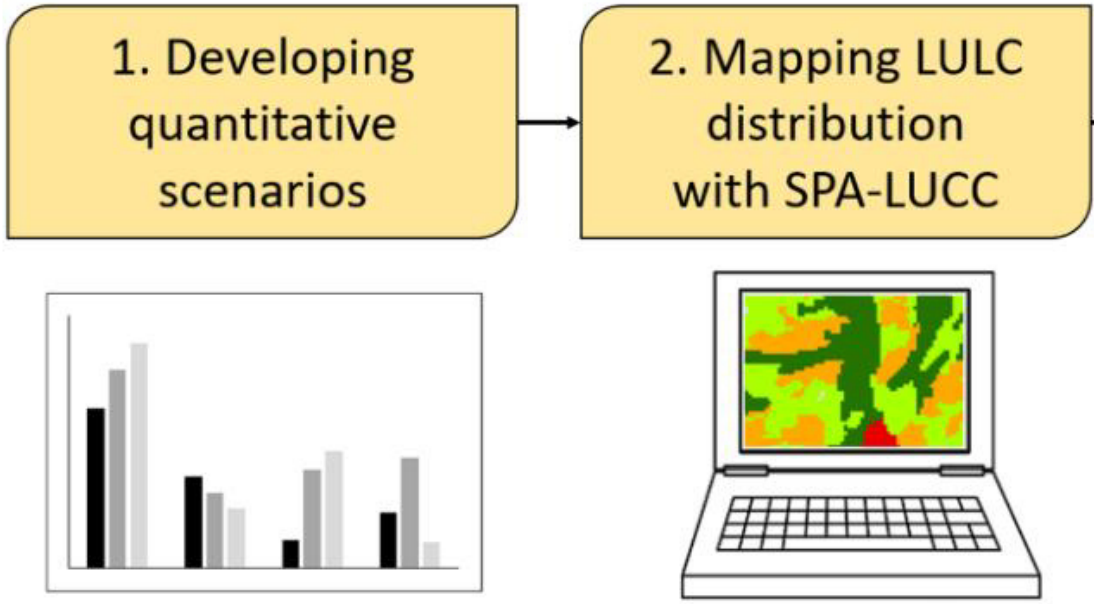
Land-use scenarios: methodical background



Analysis steps applied in this study to assess past and future LULC changes due different socio-economic scenarios.

Land-use scenarios: methodical background

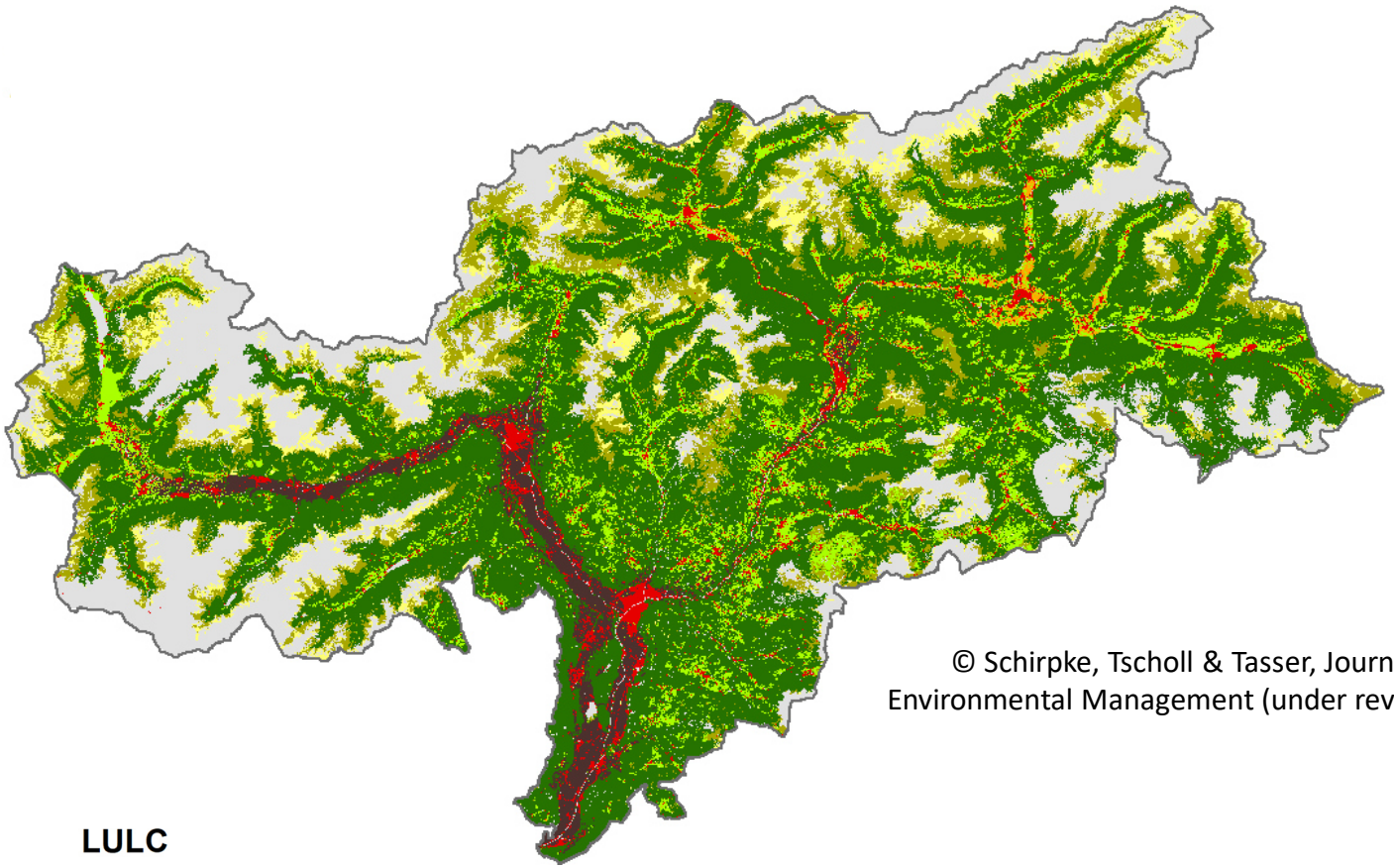
Scenarios based on 1) local workshops (Bayfield et al., 2008; Kohler et al., 2017), 2) literature evaluation (Houet et al., 2017; Malek and Boerboom, 2015; Strasser et al., 2019; Vannier et al., 2019, 2016), and 3) new social trends (FAO et al., 2019; Maggio et al., 2015)

Scenarios:

1. ‘Business as usual’ (BAU)
2. ‘Liberalisation’
3. ‘Rewilding’
4. ‘Food sovereignty’

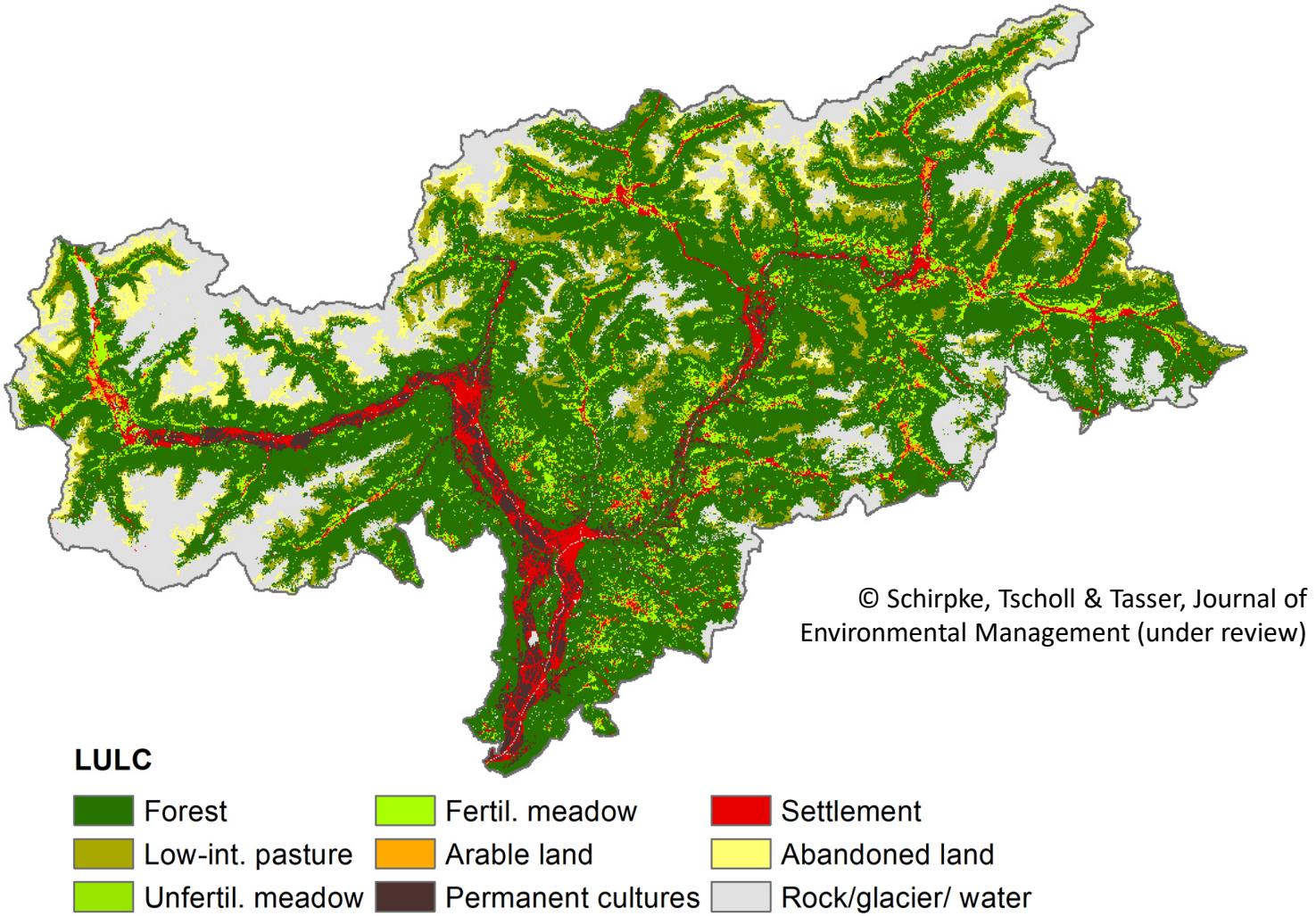
Land-use scenarios: results

Current land use



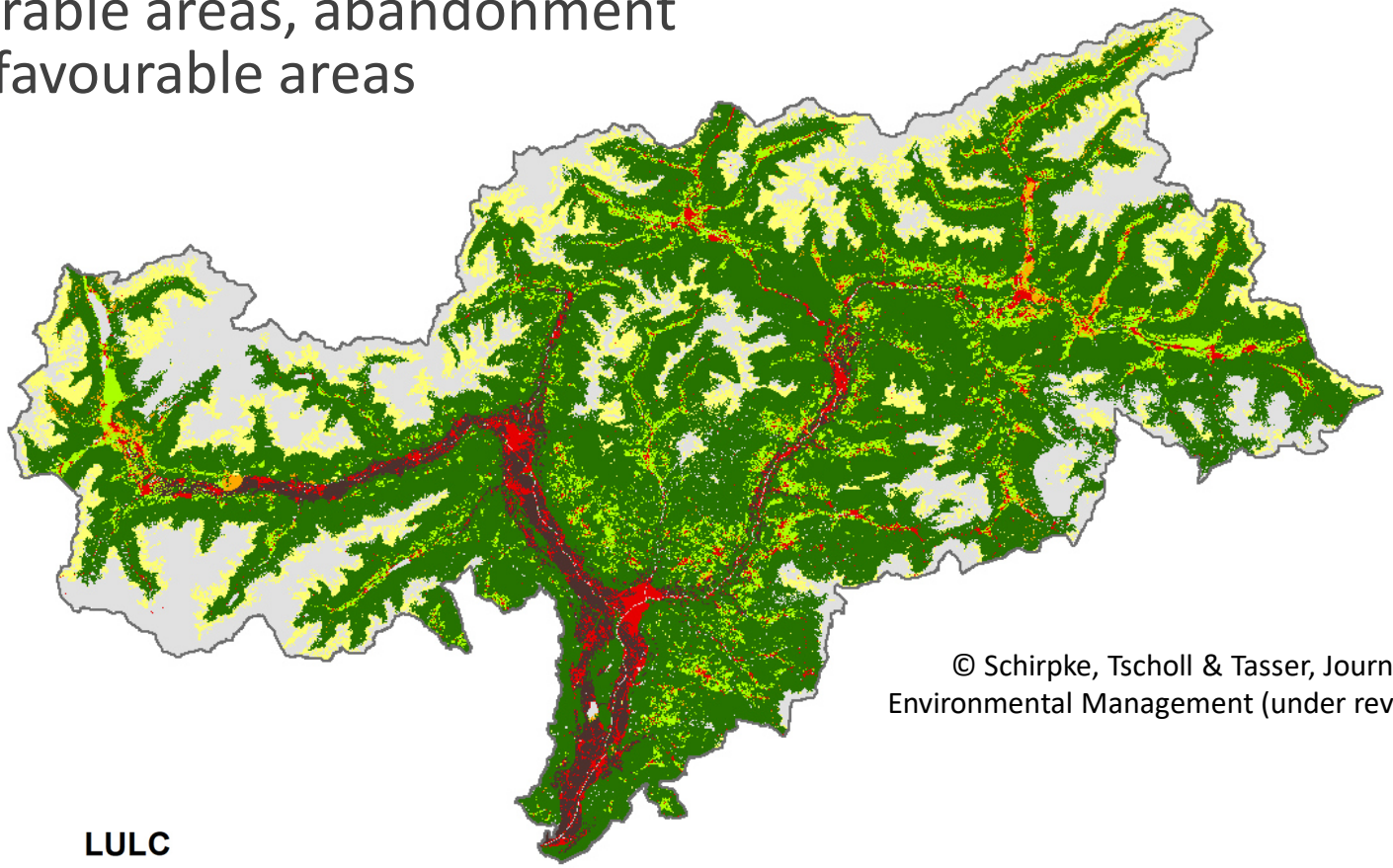
Land-use scenarios: results

'Business as usual' (BAU): Continuation of the land use dynamics of the past 50 years



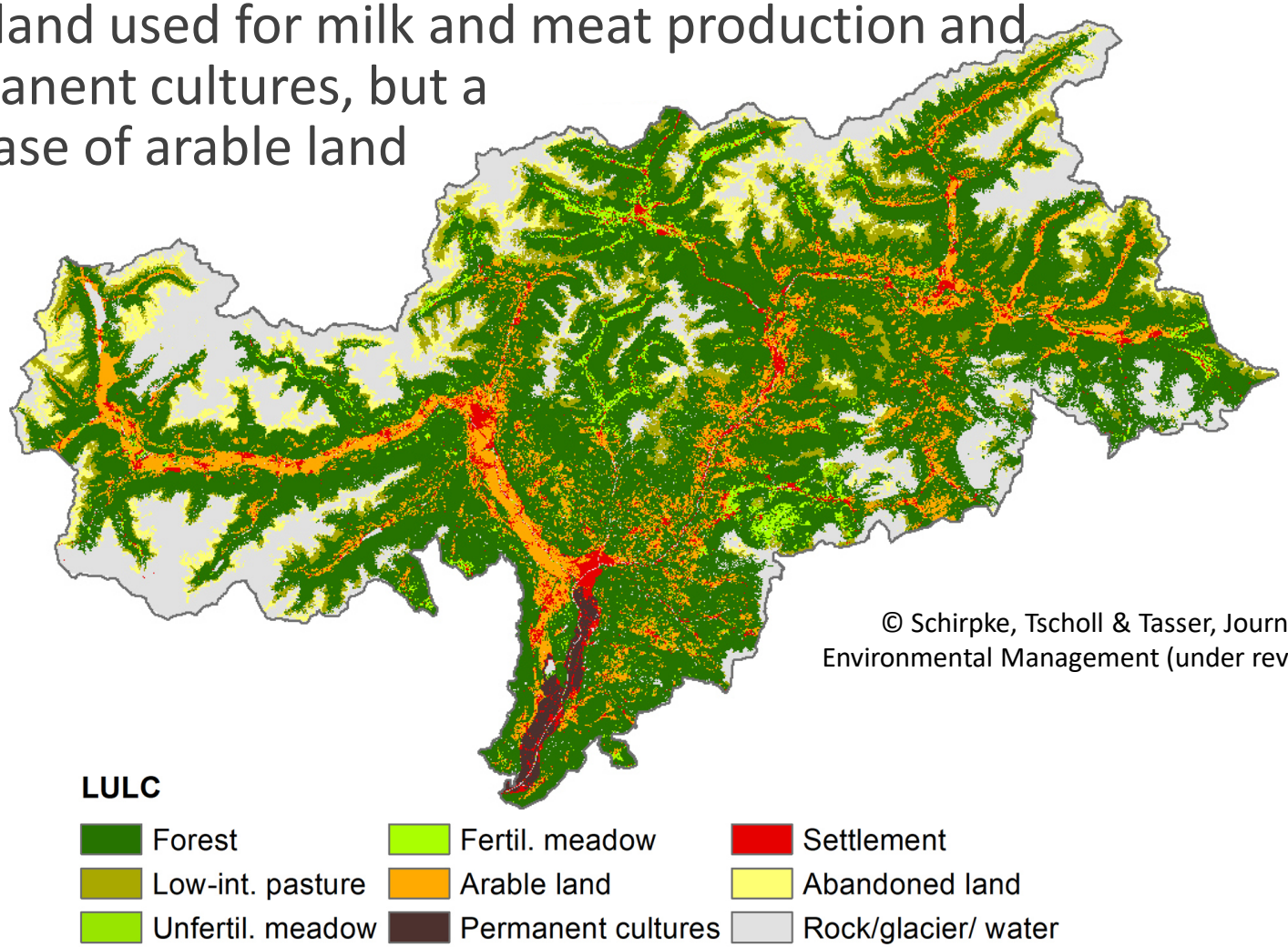
Land-use scenarios: results

'Liberalisation': Economic development driven by private investment leading to an increasing intensification of agriculturally favourable areas, abandonment of unfavourable areas



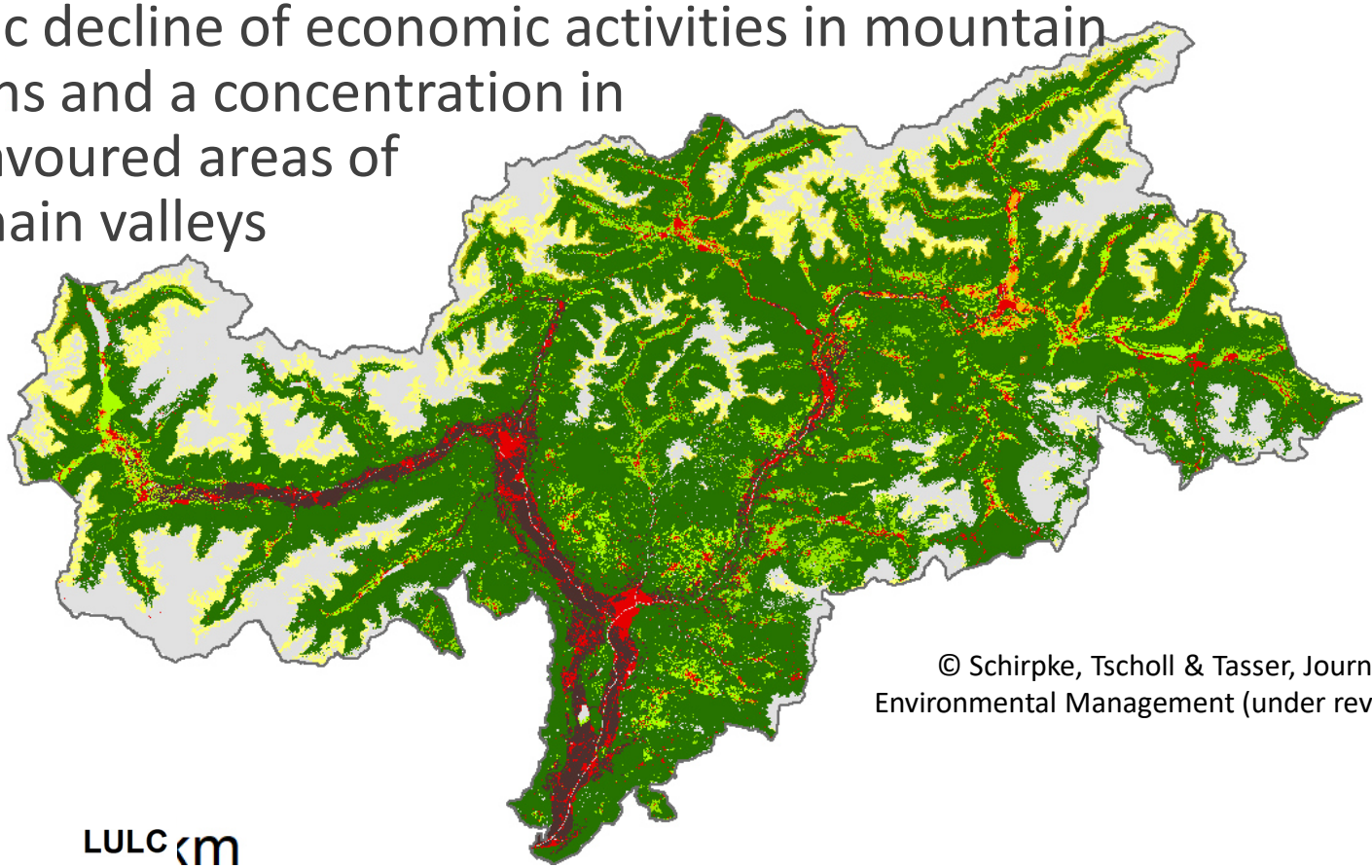
Land-use scenarios: results

'Food sovereignty': Current trend of increasing food sovereignty and security lead to a decrease of the proportion of grassland used for milk and meat production and permanent cultures, but a increase of arable land



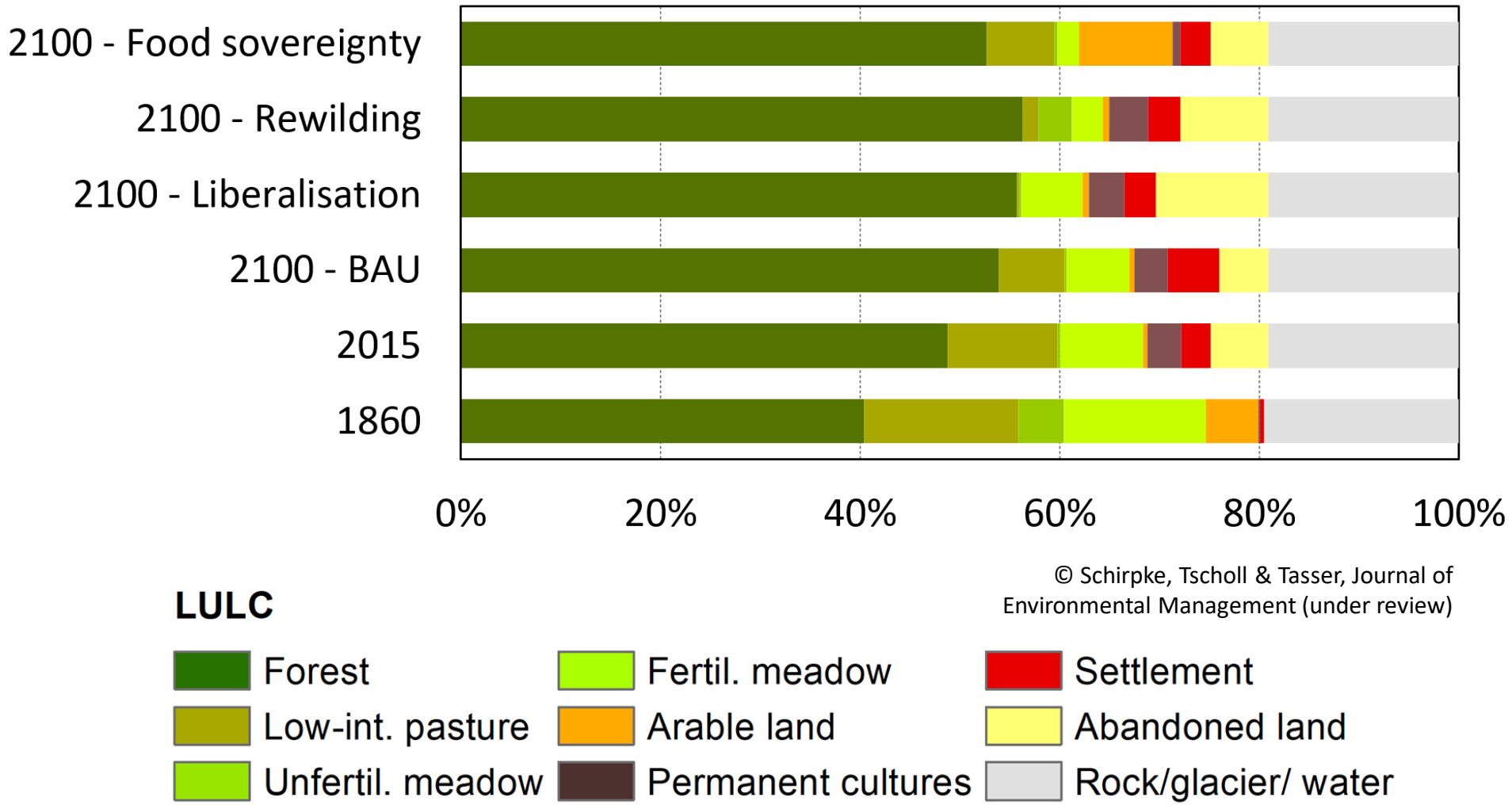
Land-use scenarios: results

'Rewilding': Characterized by a rapid decline in direct area-based payments (only environmental are paid out) leading to a drastic decline of economic activities in mountain regions and a concentration in the favoured areas of the main valleys



Land-use scenarios: results

Distribution of areas (% of total area)



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Remote sensing

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Methods

- Two Source Energy Balance (TSEB) modelling exploits time-differential land surface temperature (LST) from remote sensing imagery and limited number of meteorological data [Castelli et al., 2018]. Thanks to the thermal data fusion scheme of the model, it is possible to retrieve ET at finer spatial resolution in heterogenous areas [Kustas et al., 2011].
- In mountainous regions characterized by complex topography and land-cover heterogeneity, the performance of TSEB is limited by common overcast, large pixel size and low temporal resolution of satellite data. In *CYCLAMEN* project we overcome this limitations by applying gap-filling and downscaling to produce 250-m daily LST maps. Firstly, we disaggregate 1-km MODIS LST by applying DEM and NDVI as predictors with Random Forest (RF) algorithm (Fig. 1). Next, missing pixels are recovered by investigating relationships between LST and meteorological data under clear- and cloudy-sky conditions.

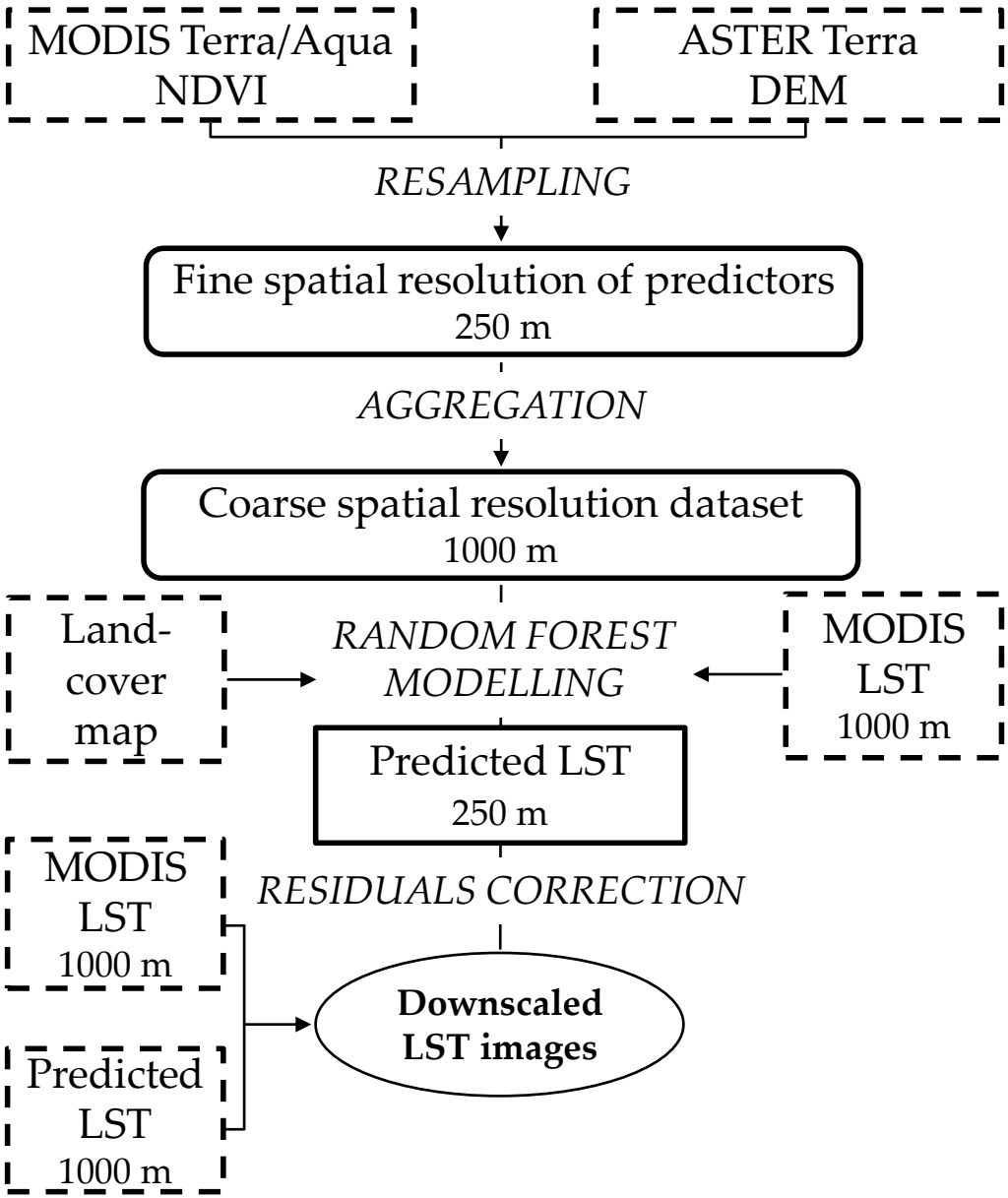

Fig.1. Scheme of the RF downscaling approach [Bartkowiak et al., 2019]

Results

- To assess Random Forest performance, the downscaled maps were validated against time-coincident Landsat LST images acquired in different seasons, i.e. spring, summer and autumn (Fig. 2). Additionally, the reference data were compared with the original MODIS LST images (Fig. 3).

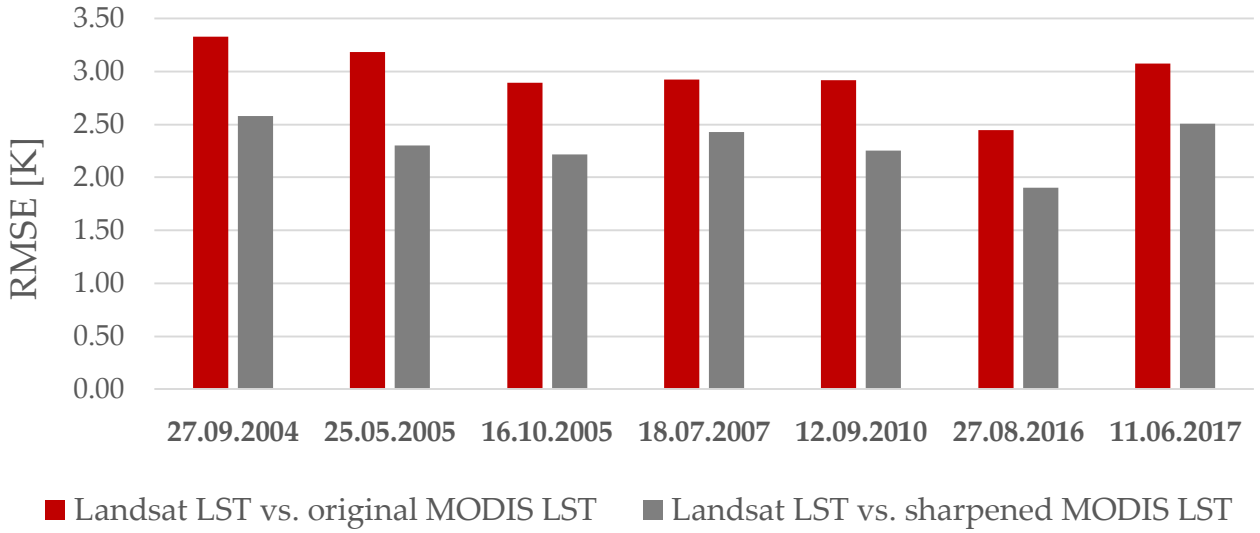

Fig. 2. Root Mean Square Error (RMSE) between reference Landsat LST images and original and downscaled MODIS LST maps.

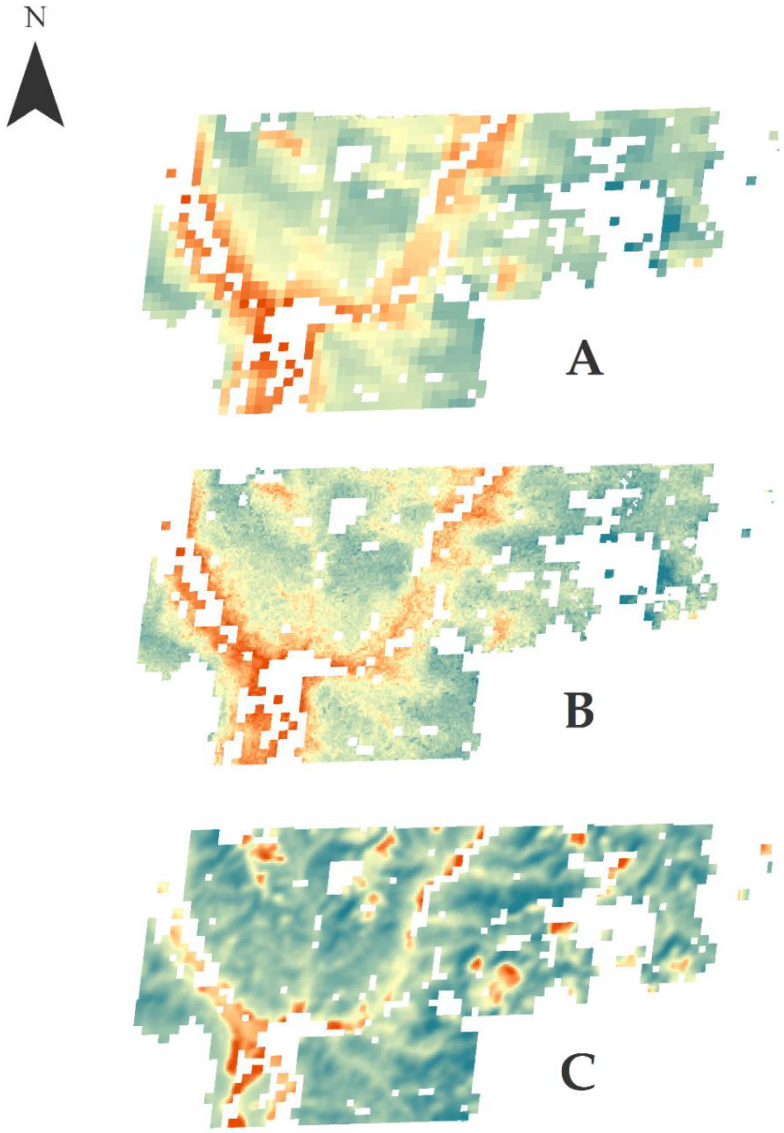

Fig. 3. Visual comparison between MODIS and Landsat LST: **A.** original MODIS LST (1000 m), **B.** downscaled MODIS LST (250 m), **C.** degraded Landsat reference image (250 m) on 25 May 2005 [Bartkowiak et al., 2019].

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Weather Generator

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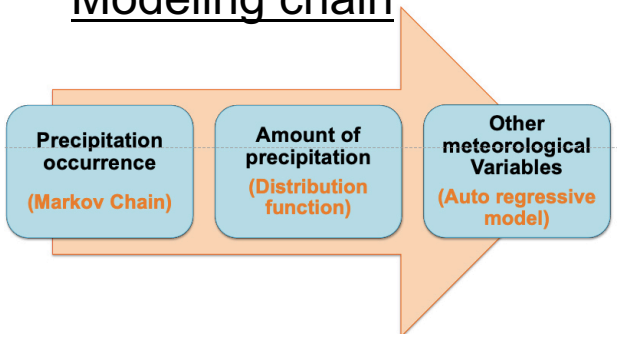
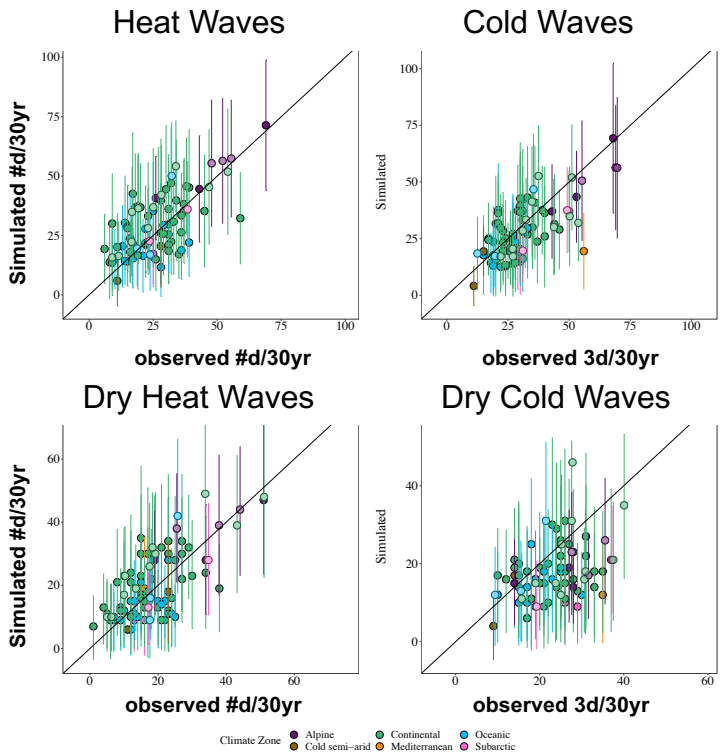
Weather Generator for Atmospheric input Data

Modeling chain



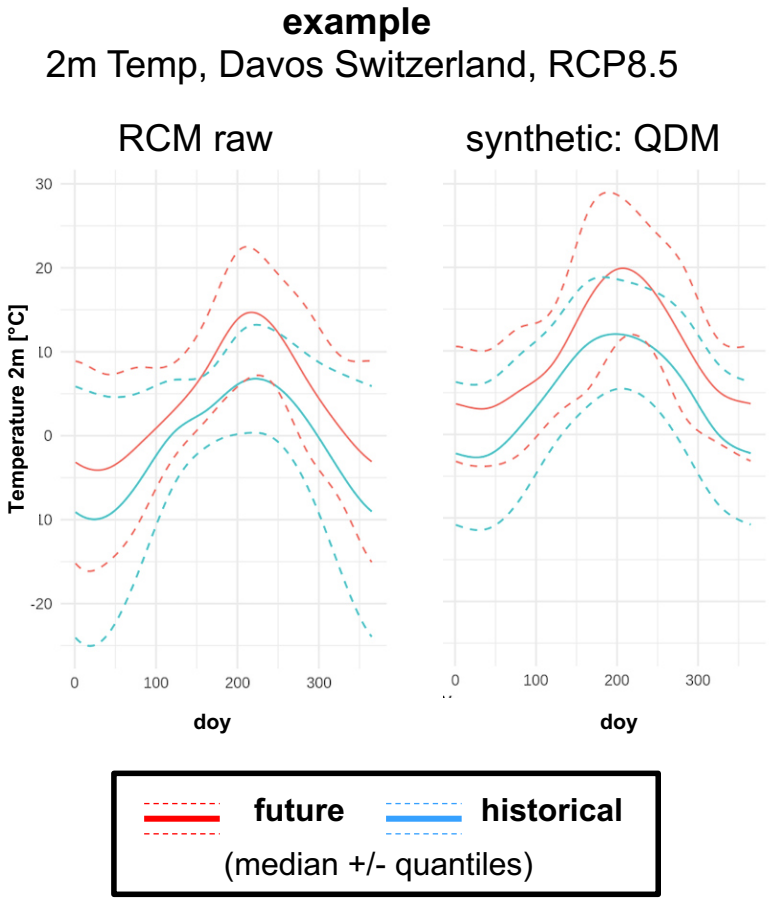
- Statistical downscaling method
  → ‚generate' statistically consistent weather data
  → train for current climate
- Validate Weather Generator
  → mean conditions (not shown)
  → 'extreme events' & multivariate extremes
- Climate data from 3 different horiz. scales
  → Europe / Austria / 'Ötztal' [valley in Austria]
- Example result
  → extremes 'astonishingly well' reproduced
  → results not dependent on climate zone
  → multivariate extremes: reasonable reproduction
- Dabhi et al (2020)
  → full paper in review Meteorol Z



Climate Scenarios

- Use regional climate model scenario
  → EURO-CORDEX, different RCPs, different model combinations (realized: 1)
  → use: change in statistical characteristics
  (not: change in physical variables)
  → quantile delta mapping (QDM)

- example result
  → 2 m Temp., Davos Switzerland
  → RCP8.5
- large impact of QDM
  → corrects for bias
  → also distribution
- realistic input for vegetation model



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Data collection, biosphere model calibration and validation

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Methods

- Meteorological tower data was used as input for a simple biosphere model (SiB4)
- Remote sensing data (MERRA-2, NASA) was used for the spin-up of SiB4 simulations
- The results were compared to eddy covariance (EC) measurements at the respective sites

Land-Atmosphere Fluxes

> Carbon: Net Ecosystem Exchange (NEE)
> Carbonyl Sulfide (OCS)
> Energy: Latent and Sensible Heat
> Water: Evapotranspiration

Productivity

> Solar-Induced Chlorophyll Fluorescence (SIF)
> Gross Primary Productivity (GPP)
> Net Primary Productivity (NPP)
> Respiration
- Autotrophic
- Heterotrophic

Output

Weather

> Humidity, Pressure, Temperature, Wind
> Precipitation: Convective/Large-Scale
> Radiation: Shortwave/Longwave

Biomass

> Aboveground Pools
- Leaf, Stem/Wood, Product
> Belowground Pools
- Fine and Coarse Roots
> Net Primary Productivity

SiB4 Input and Output

Land Cover

> Plant Functional Type (PFT)

Input

Land Cover

> Albedo
> LAI
> Surface Carbon
- Litter, CWD

Restart

Soil Properties

> Sand and Clay Fractions
> Soil reflectance

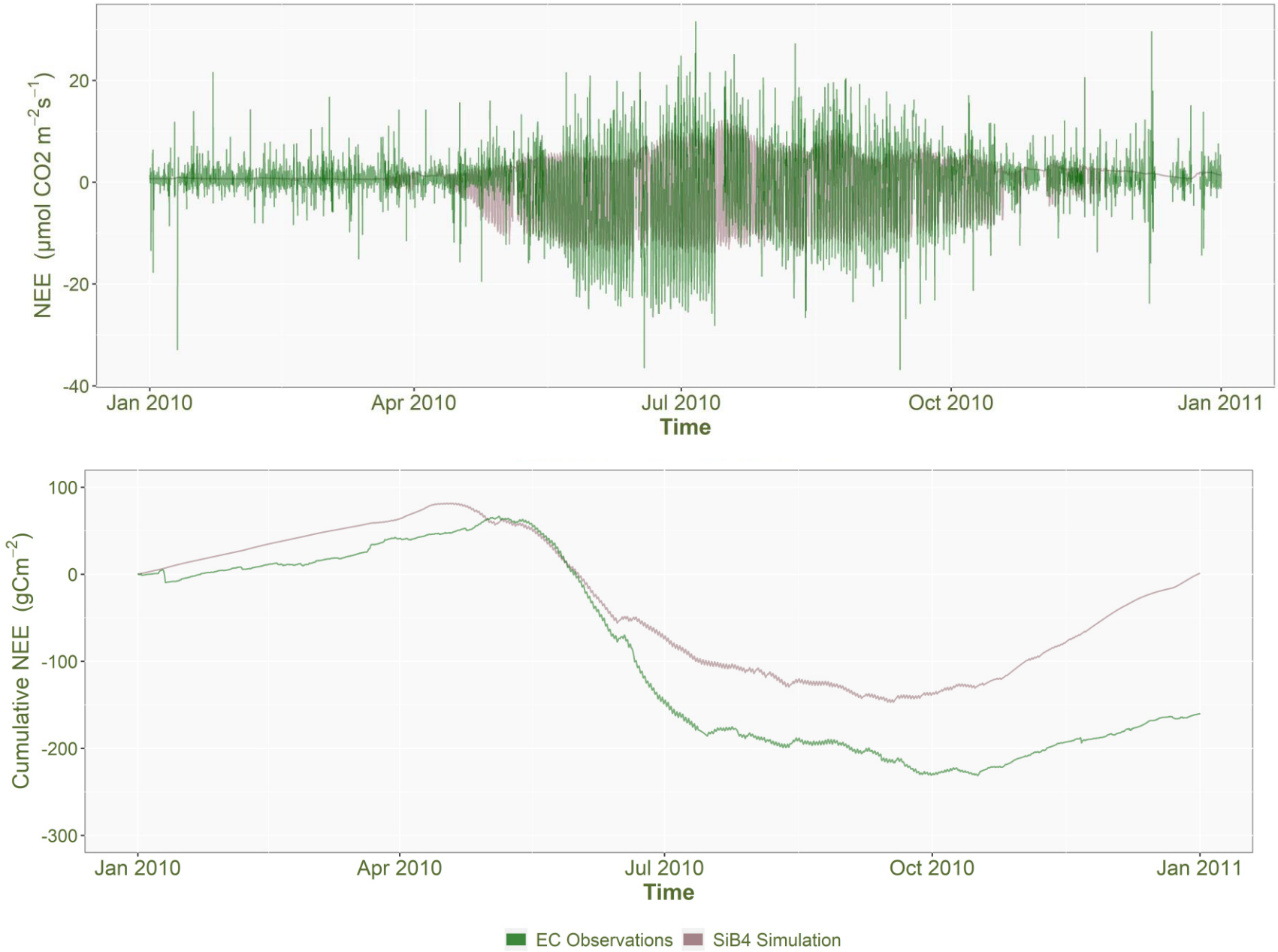
> Soil Water Profile
> Carbon Pools
> Climatology
- Water Availability
- Grazing Loss

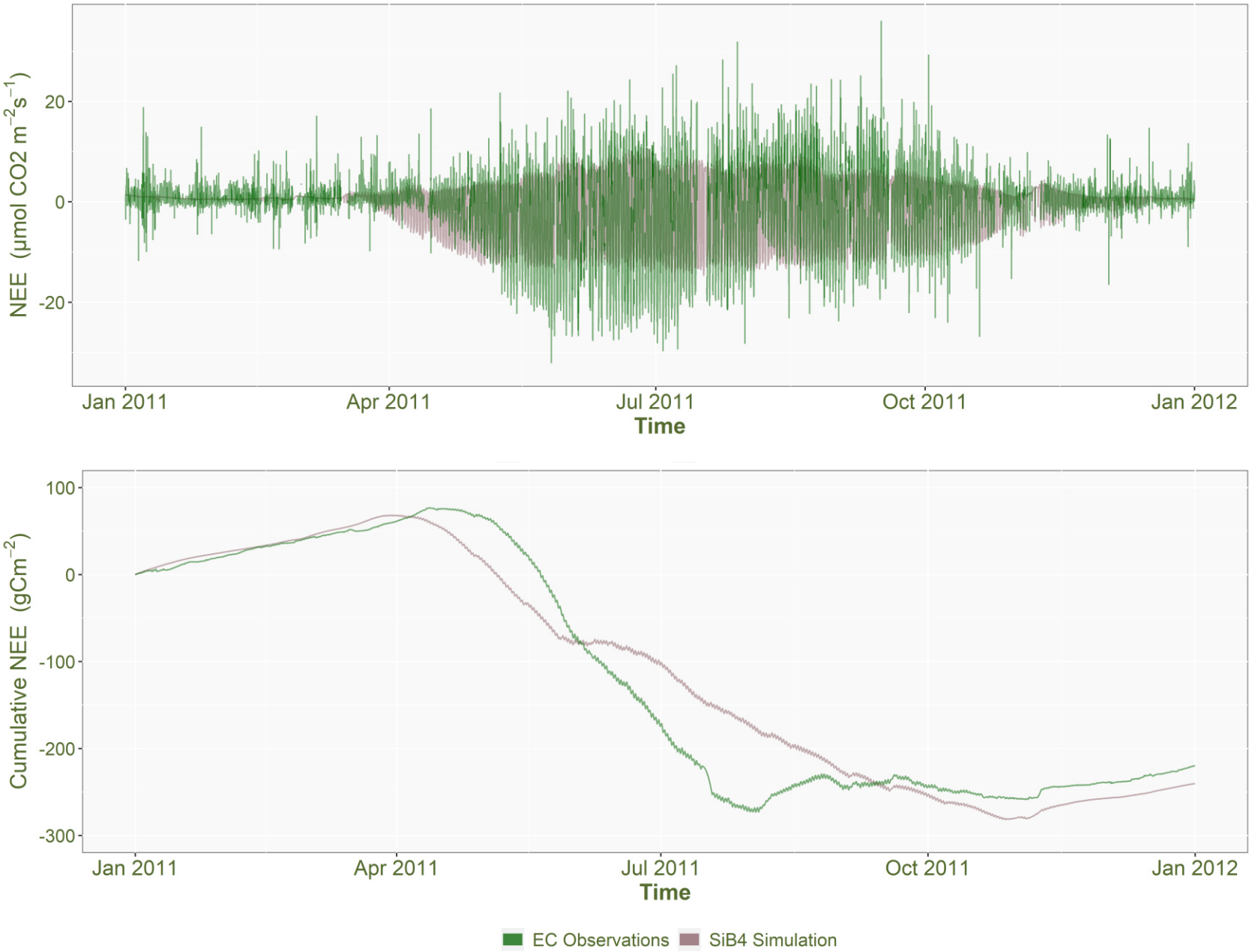
Soil Characteristics

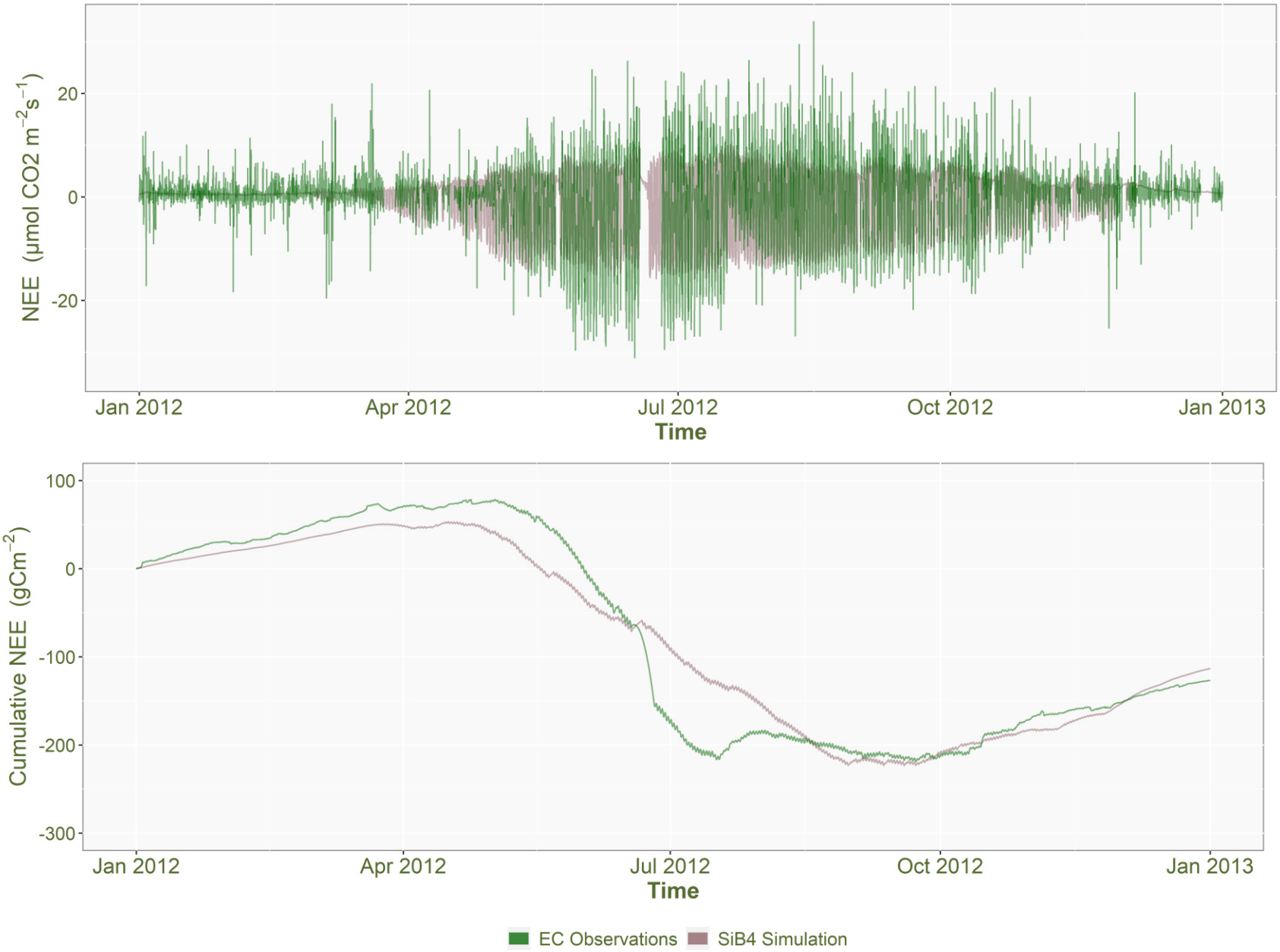
> Soil Moisture/Water Content
> Soil Carbon
- Soil Litter, Slow and Passive

Model performance - grassland

Site Name: Monte Bondone
FLUXNET-ID: IT-Mbo
Country: Italy
Latitude: 46.01472222 N
Longitude: 11.04583333 E
Biome: Grassland
Elevation (msl): 1189
Year: 2010, 2011, 2012
Variable: NEE


NEE (µmol CO2 m^{-2}s^{-1})
20
0
-20
-40
Jan 2010
Apr 2010
Jul 2010
Oct 2010
Jan 2011
Time
Cumulative NEE (gCm^{-2})
100
0
-100
-200
-300
Jan 2010
Apr 2010
Jul 2010
Oct 2010
Jan 2011
Time
EC Observations
SiB4 Simulation


NEE (µmol CO2 m^{-2}s^{-1})
20
0
-20
Jan 2011
Apr 2011
Jul 2011
Oct 2011
Jan 2012
Time
Cumulative NEE (gCm^{-2})
100
0
-100
-200
-300
Jan 2011
Apr 2011
Jul 2011
Oct 2011
Jan 2012
Time
EC Observations
SiB4 Simulation


NEE (µmol CO2 m^{-2}s^{-1})
20
0
-20
Jan 2012
Apr 2012
Jul 2012
Oct 2012
Jan 2013
Time
Cumulative NEE (gCm^{-2})
100
0
-100
-200
-300
Jan 2012
Apr 2012
Jul 2012
Oct 2012
Jan 2013
Time
EC Observations
SiB4 Simulation

Outlook

- Calibration and validation of the SiB4 model for forest ecosystems
- Generating future weather for all EC sites using the Weather Generator
- Using the Weather Generator output and land use scenarios as input for biosphere modelling
- Due to common cloud contamination effect over the Alps, meteorological-based gap-filling to low resolution thermal remote sensing images will be additionally implemented
- Application of the enhanced remotely sensed datasets for TSEB models in order to compare them with SVAT simulations of ET [Wohlfahrt, 2004]

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