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Mediterranean Forests in Transition (MEDIT): Deliverable No10

Title: Report on large scale simulation results

Due to Project Month 36, Date: 31/3/2015

Summary

This report presents the finding of the work done in Work Package 6, activity 6.2 of the MEDIT Project entitled "Large scale simulations of forest dynamics under baseline and climate change conditions". This is an integration of work made in different Working Packages (WPs) and in particular brings together the developments of the hybrid TFS (in WP3 and WP6) and the functional traits data measured (in WP4) and analysed (in WP5).

The scientific aim of this deliverable is validate the performance of the TFS model under baseline (current) conditions and subsequently apply it under climate change scenarios to explore potential shifts in the dynamics of the focus forest types in MEDIT, in particular the Mediterranean Evergreen Forests (MEB), the Mediterranean Coniferous Forests (MC) and the Mediterranean Deciduous Broadleaved Forests.

Introduction

Understanding forest dynamics is a key component of the Earth's carbon and water balance (Schröter et al. 2005, Coomes et al. 2014). Various models have been used to integrate our knowledge and data of ecosystem processes and their integration with climate (Crammer et al. 2001, Sitch et al. 2008, Sitch et al. 2015). Usually the ecological/biochemical processes of interest include, the way carbon is acquired from the atmosphere and redistributed to vegetation, the way water and nutrients flow between the soil-plant-atmosphere continuum and the way the structure and function of vegetation regulates the above. These models are usually developed with existing data and tested against datasets of field observations for key variables of interest. In order to project the potential effects of climate change to the dynamics of the ecosystems, scenarios of future climate are used to force the "optimally parameterised" and "validated" versions of these vegetation models in the near future.

Two important criticism of such models concern a) the way demographic processes are accurately represented (Purves and Pacala 2008) and b) the extent to which the wealth of plant species and their variation in response to given environmental conditions is taken into account (Lavorel et al. 2007, Scheiter et al. 2013).

The Trait-based Forest Simulator (TFS) is a hybrid model, that can be applied at both small and large geographical scales and has been initially developed by the researcher for Tropical forest (Fyllas et al. 2014). It addresses the issues of the models mentioned above, by a) specifically accounting for tree-to-tree interactions by simulating light competition and access to a commonly shared water pool and b) representing the diversity of plant form and function through by traits continua and not static PFTs. In previous Deliverables we have described developments made to TFS in order develop a dynamic version (instead of the original static/snapshot one) capable of extrapolating simulations for more than a few years, by developing the recruitment and mortality algorithms. Furthermore we have also described the way plant functional traits data measured and analysed in WP4 and WP5 can be used to parameterise TFS for Mediterranean forest.

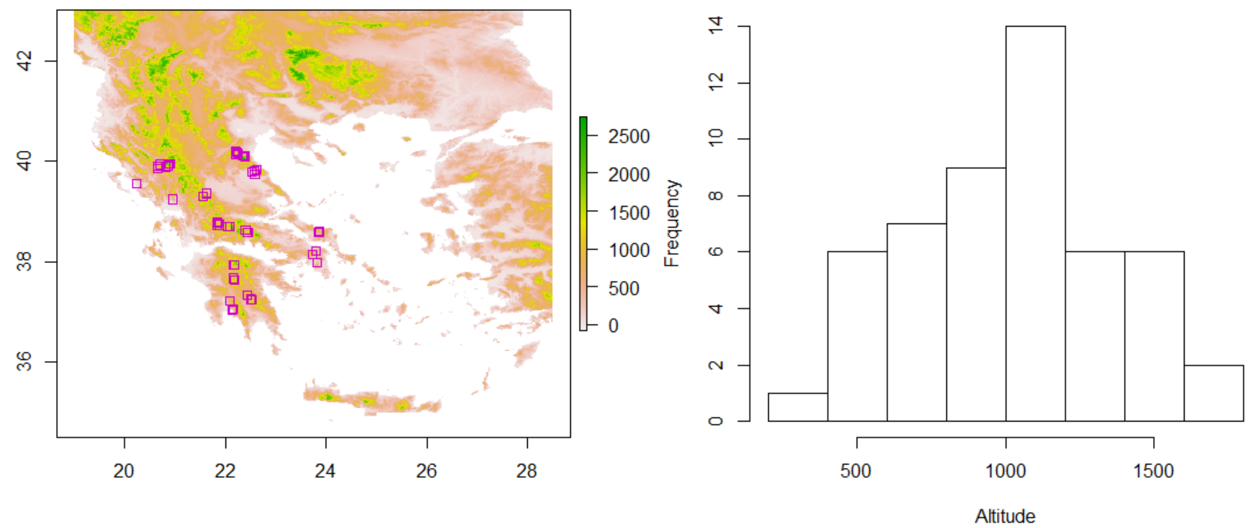
In this report we will describe a further set of simulations made with this models under both current and climate change conditions, and then present an up scaling approach to estimate some key ecosystem level properties at the Mediterranean scale. Adjustments to new model parameters such as leaf chemical and structural values, photosynthetic and respiratory rates as well as tree architecture are continuously been made as new data are coming in from our field campaigns. Parameters for some important tree species are still missing with the last campaign (postponed due to a car accident) will be completed this year.

Below we present and validate the simulations made with TFS for the forest types of interest under both baseline and climate change conditions. We then describe the upscaling approach used to estimate key ecosystem level variables at the Mediterranean scale.

TFS Simulations under Baseline-Current Conditions

Previous TFS simulations presented in Deliverable 5 (D3.2) were made in a subset of 15 MEDIT test sites. With new data coming in during the last period the TFS model was set up to run for 46 of the MEDIT study sites (Fig. 1). These sites represent each one of the forest types that are the focus of the MEDIT project i.e. Mediterranean Lowland Coniferous Forests (MLC) with typical species including: *Pinus halepensis* and *Pinus brutia*, Mediterranean Evergreen Broadleaved Forests (MEB) with typical species including: *Quercus coccifera, Quercus ilex, Pistacia lentiscus, Phillyrea latifolia, Arbutus unedo* and *Arbutus andrachnae,* Mediterranean Mountainous Coniferous Forests (MMC) with typical species including: *Abies cephalonica, Abies borisii-regis, Pinus nigra* and *Pinus sylvestris*, and Mediterranean Deciduous Broadleaved Forest (MDB) with typical species including: *Quercus frainetto, Quercus cerris, Castanea sativa, Ostrya carpinifolia, Carpinus orientalis, Fraxinus ornus* and *Fagus sylvatica*.

Figure 1: MEDIT study sites and the altitudinal range where the TFS model has been applied



The model was initialised using observed site-specific trait distributions as well as size class distribution. Soil mechanical properties (soil depth, and texture) were set based to site-specific field observations/measurements. The climate data used were extracted from the Princeton Climate Database (Shefield et al., 2006) and represent daily climatological patterns over the 20th century. The model was set up to run for 200 years, by randomly selecting a whole annual climatic year from the available data. A spin-up period of 100 years was initially considered, allowing TFS to reach equilibrium in terms of carbon and water fluxes. Then the last 100 simulation years were used to predict patterns of GPP, NPP and LAI for each study plot.

Figure 2 present the site specific estimates of GPP at each one of the MEDIT study plots, along with the mean GPP estimate for the forest type of interest. In general lowland conifers (MLC) are simulated to have the highest productivity followed by mountainous conifers (MMC), deciduous (MDB) and evergreen broadleaved (MEB) forests. All these estimates are within the range of values reported from other independent sources, as summarized in Table 1.

Table 1: Comparisons of TFS simulated GPP per forest type with the range reported in the literature

GPP($kgCm^{-2}y^{-1}$) per Forest Type	Range reported in literature*	TFS estimate
MLC	1.38...1.59	1.49±0.12
MEB	1.24...1.36	1.19±0.37
MDB	1.12...1.37	1.27±0.23
MMC	1.20...1.64	1.41±0.24

* Range values exported from Jung et al. (2007), Chirisi et al. 2007 and Luyssaert et al. (2007)

Figure 2: Simulated GPP for each MEDIT test site (left panel) and mean values per Forest type.

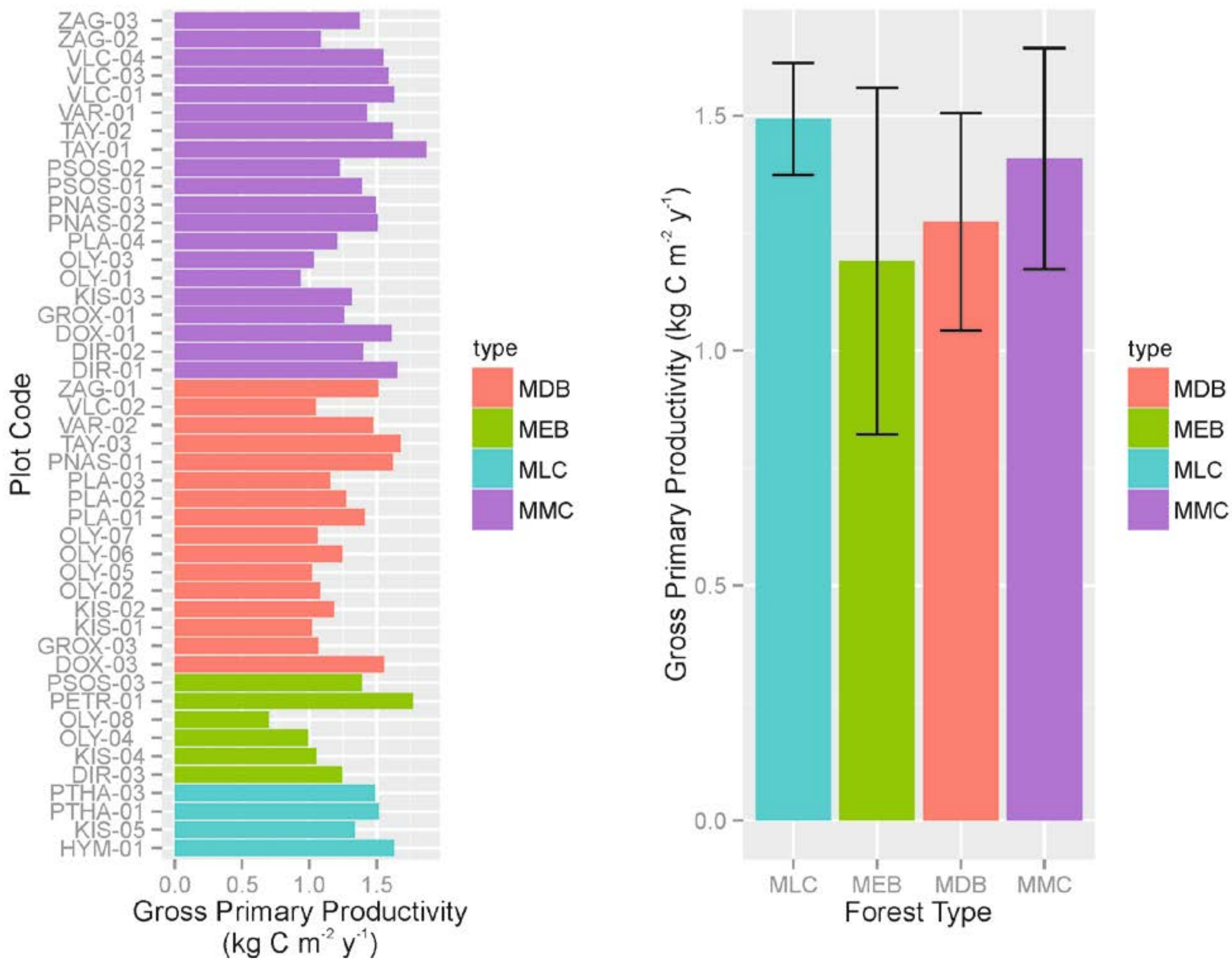


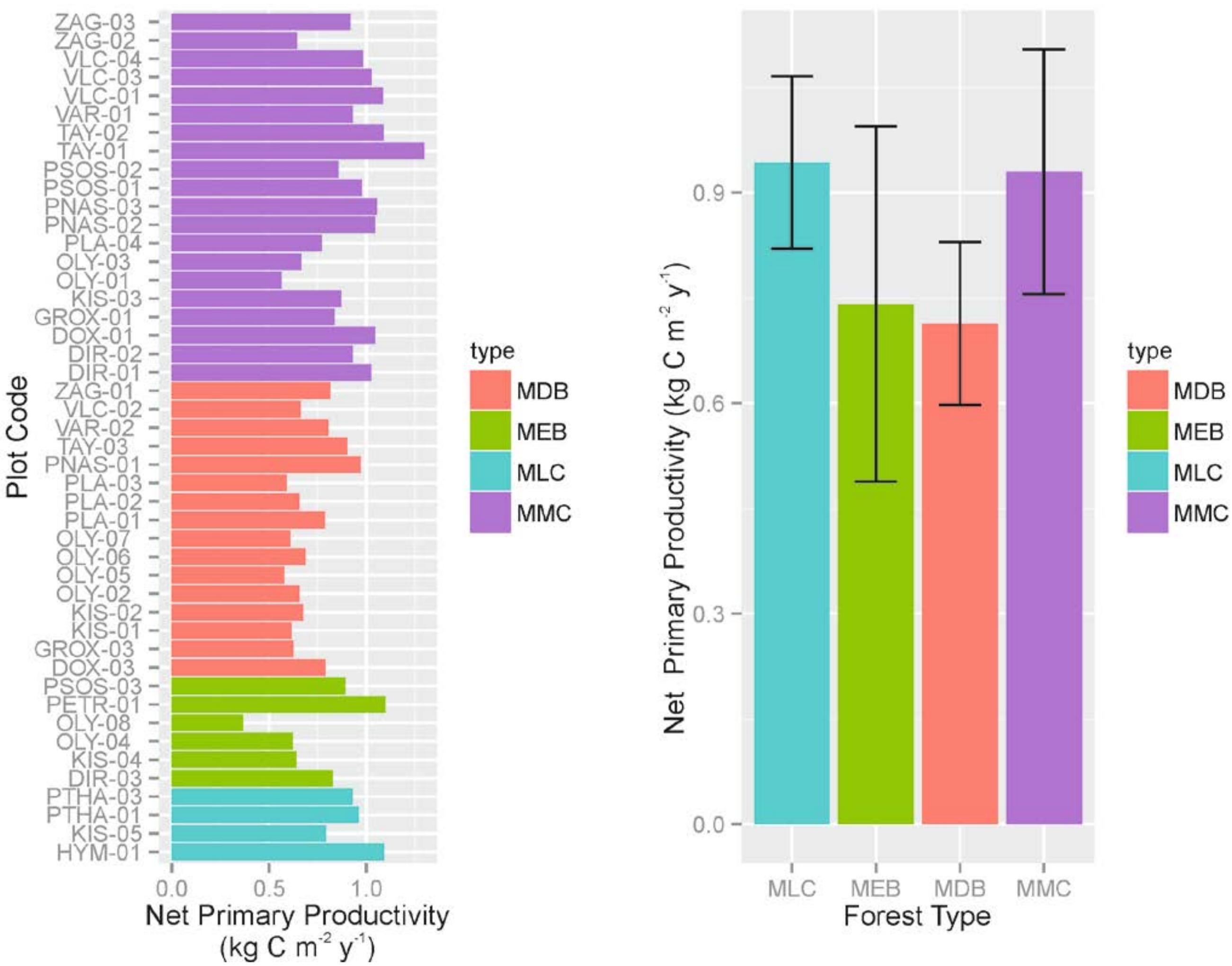
Figure 3 presents the respective results for net primary productivity (NPP). Highest NPP is simulated for conifers and the lowest on for evergreen broadleaved forest. In this case TFS simulations seem to be at the upper range of reported values for broadleaved forest and slightly overestimating coniferous ones. This is probably due to a common stomatal conductance (gmax) used in these simulations.

Table 2: Comparisons of TFS simulated NPP per forest type with the range reported in the literature

NPP($kgCm^{-2}y^{-1}$) per Forest Type	Range reported in literature*	TFS estimate
MLC	0.67...0.75	0.94±0.17
MEB	0.58...0.80	0.74±0.25
MDB	0.57...0.74	0.71±0.12
MMC	0.69...0.78	0.93±0.17

* Range values exported from Chirisi et al. 2007 and Luyssaert et al. (2007)

Figure 3: Simulated NPP for each MEDIT test site (left panel) and mean values per Forest type.



Large scale predictions

In order to upscale TFS predictions we used a statistical procedure where the average TFS outputs for the variables of interest from each one of the 46 study sites long-term runs where used as the dependent variable in stepwise backward elimination models. The stand-level variables of interest included:

- Gross Primary Productivity, expressing the C assimilated through photosynthesis over a year
- Net Primary Productivity, expressing the available C after autotrophic respiration
- Leaf Area Index, representing the community level foliage area per ground area
- Zstar, the mean community canopy height
- Community mean Leaf mass per Area (LMA), used to identify vegetation synthesis
- Community average Wood Density (WD), used to identify vegetation synthesis

The predictor variables were extracted from the latest version of the WORLDCLIM database (Hijmans et al. 2005) at a very high resolution of 1 km^2. A set of key bioclimatic variable, related to fundamental plant processes were selected. These included:

- Mean annual Temperature (Tmax) related to the available thermal energy a plant has over the year
- Min annual Temperature (Tmin) frequently used to define the upward range of expansion of typical Mediterranean taxa
- Temperature range (Trange) over the year, expressing the variation of climatic variability and related stresses plant are facing
- Total annual precipitation (Prec) a good indicator of water availability throughout the year
- Precipitation of the driest month (Prec_d), representing water availability during the drought period
- Precipitation seasonality (Pres_s), expressing the seasonal distribution of water

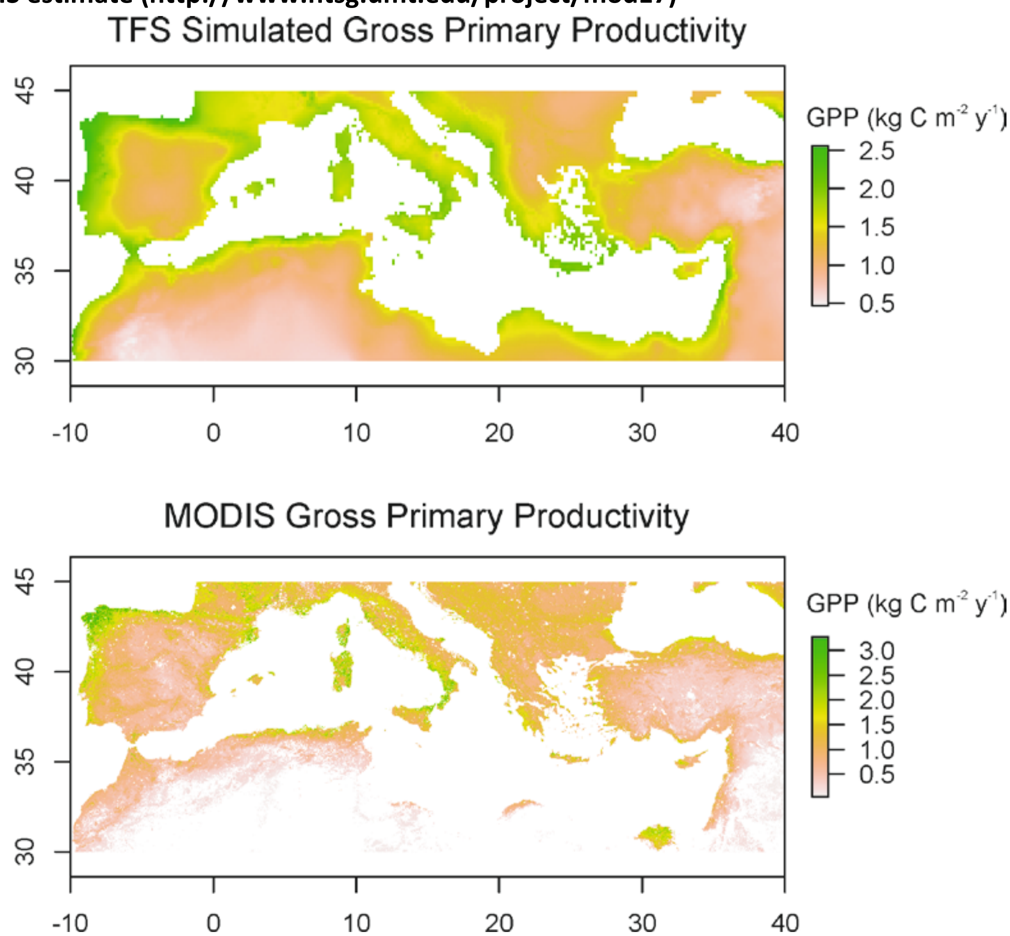
The backward elimination models were applied to each one of TFS predictions of interest. The following table summarises some of these results (Table 3). Most of these outputs are compatible with basic physiological properties, for example an expected increase of GPP with temperature and precipitation, a relatively negative effect of temperature to NPP (through increased respiration rates), an increase of LAI with precipitation, an increase of canopy height with precipitation (over drought periods), and an increase community level wood density at warmer places (drought tolerance trait).

Table 3: Summary of the backward elimination models, for some key ecosystem level variables. In all cases the linear models gave a statistically significant fit

TFS estimate	Intercept	Tmean	Tmin	Trange	Prec	Prec_d	Prec_s	R^2
GPP	2.493	0.0245		-0.0612	0.0005			0.592
NPP	2.397	-0.1225	0.1184					0.601
LAI	5.046	-0.1836	0.1852		0.0009			0.336
Zstar	5.568					0.0758	0.0416	0.181
LMA	413.53	-22.409	21.367					0.177
WD	0.318	0.028				0.0032		0.349

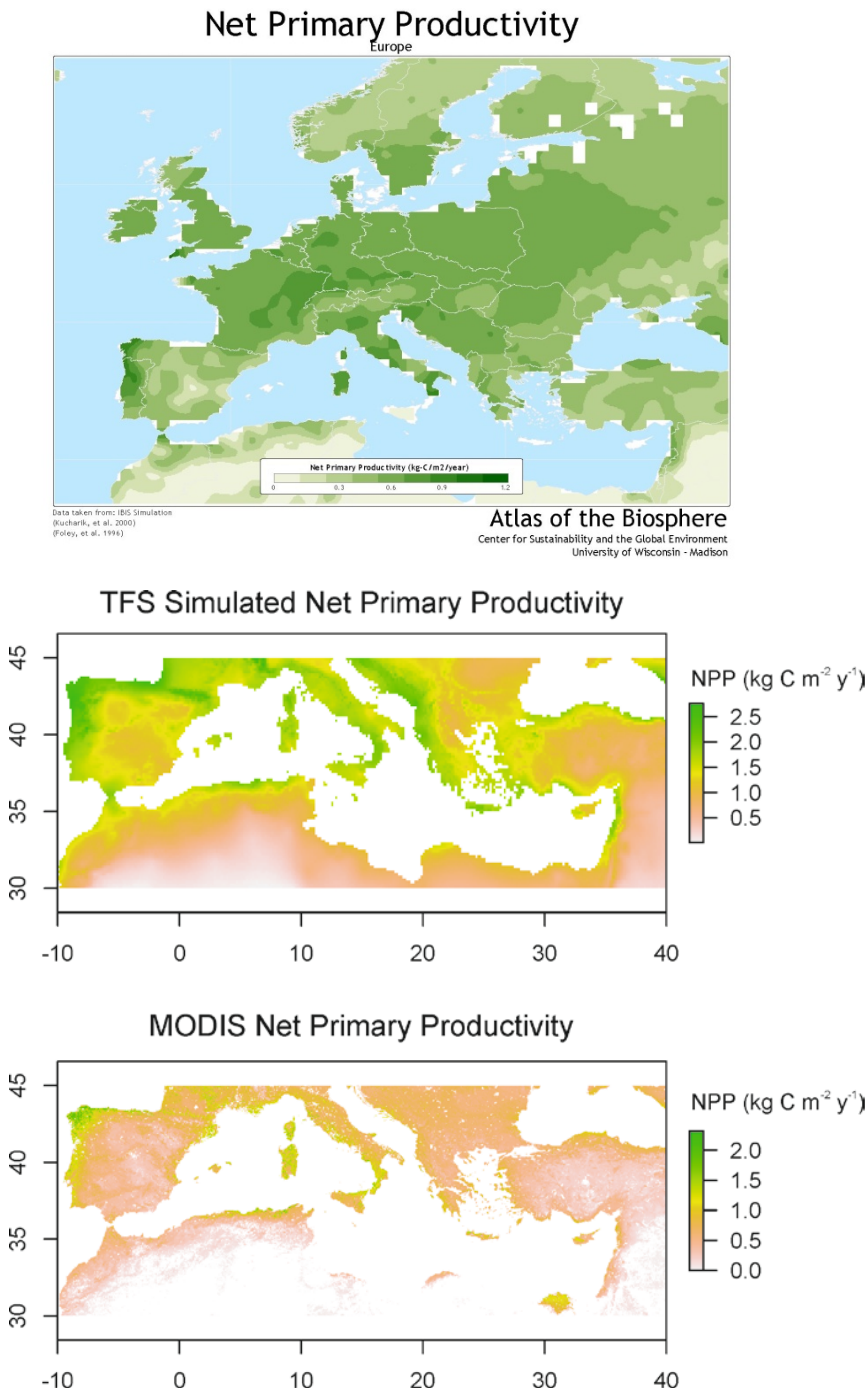
Using the prediction of the linear model we extrapolated TFS results to the Mediterranean scale. The following figures presents the upscaled patterns of some key ecosystem level properties, along with estimates from independent sources. Overall, a relatively adequate performance of the TFS method was achieved. Geographic patterns such us the highest GPP at the western part of the Iberian peninsula, Corsica, the area above Cicely, the western part of Greece, and some areas at the Northern part of Africa were captured. The TFS simulations showed a lower range of GPP with upper values around 2.6 kgC m^{-2} y^{-1}.

Figure 4: TFS simulated GPP for forest around the Mediterranean basin (upper panel) and comparison with the MODIS estimate (http://www.ntsg.umt.edu/project/mod17)



TFS simulations of NPP in contrast to the MODIS estimates are illustrated in Figure 5. In this case, as also seen in the forest type specific simulation TFS seems to overestimate NPP. The geographic pattern is adequately captured, as in GPP.

Figure 5: TFS simulated NPP for forest around the Mediterranean basin (upper panel) and comparison with the Atlas of the Biosphere and MODIS NPP estimate (http://www.ntsg.umt.edu/project/mod17)



TFS Simulations under Climate Change Conditions

In order to develop climate forcing scenarios for global change conditions, we used the latest regional temperature and precipitation projection from Gualdi et al. (2013). In this study a set of climate models have been produced to simulate small scale climatic features of the basin, by taking into account the role of the Mediterranean Sea. Within this multimodel ensemble approach a range of "expected changes" in temperature and precipitation have been suggested for the year 2050 (Fig. 5 of Gualdi et al. 2013), following the IPCC A1B green house gas emissions scenario. Using these projections we defined a set of potential drying trends, that where then used to force our TFS vegetation model. These scenarios are summarised in table 4.

Table 4: Climate Scenarios used to run the TFS model, based on the range of "expected" changes reported in Gualdi et al. 2013.

Scenario	Temperature Change $\Delta T(^oC)$	Precipitation Change $\Delta P(\%)$
BL	0	0
S1_09	1	10
S2_09	2	10
S2_08	2	20
S3_08	3	20
S3_07	3	30
S4_07	4	30

These anomalies were incorporated as linear shifts on the site specific baseline climate of the 20th century (Sheffield et al. 2007). The model was again spinned-up to reach equilibrium for 100 years and then the anomalies of each scenario were applied. Initialization was made with site-specific trait and size class distributions. Indicative outputs for scenarios BL, S2_09 and S4_07 are summarised in Fig. 6. Interestingly the simulations suggest that following an increase of 2^oC and small decrease of 10% in precipitation (S2_0.9) both GPP and NPP do not decrease. However a substantial decrease in both measured of productivity is simulated following the more extreme S4_07 scenario.

Shifts in the distributions of functional traits were also observed under different climate forcing scenarios (Fig. 7). As TFS does not determine vegetation in terms of species but rather in terms of traits, two key traits defining vegetation type were selected. These are LMA and WD where in both cases, increases in the mean community value suggest a shift towards more drought tolerant - conservative life strategies. Fig 7 then suggest that coniferous stands (both MLC and MMC) are less vulnerable compared to MEB communities. Importantly MDB communities presented the highest divergence between different forcing scenarios, shifting to more drought tolerant trait distributions.

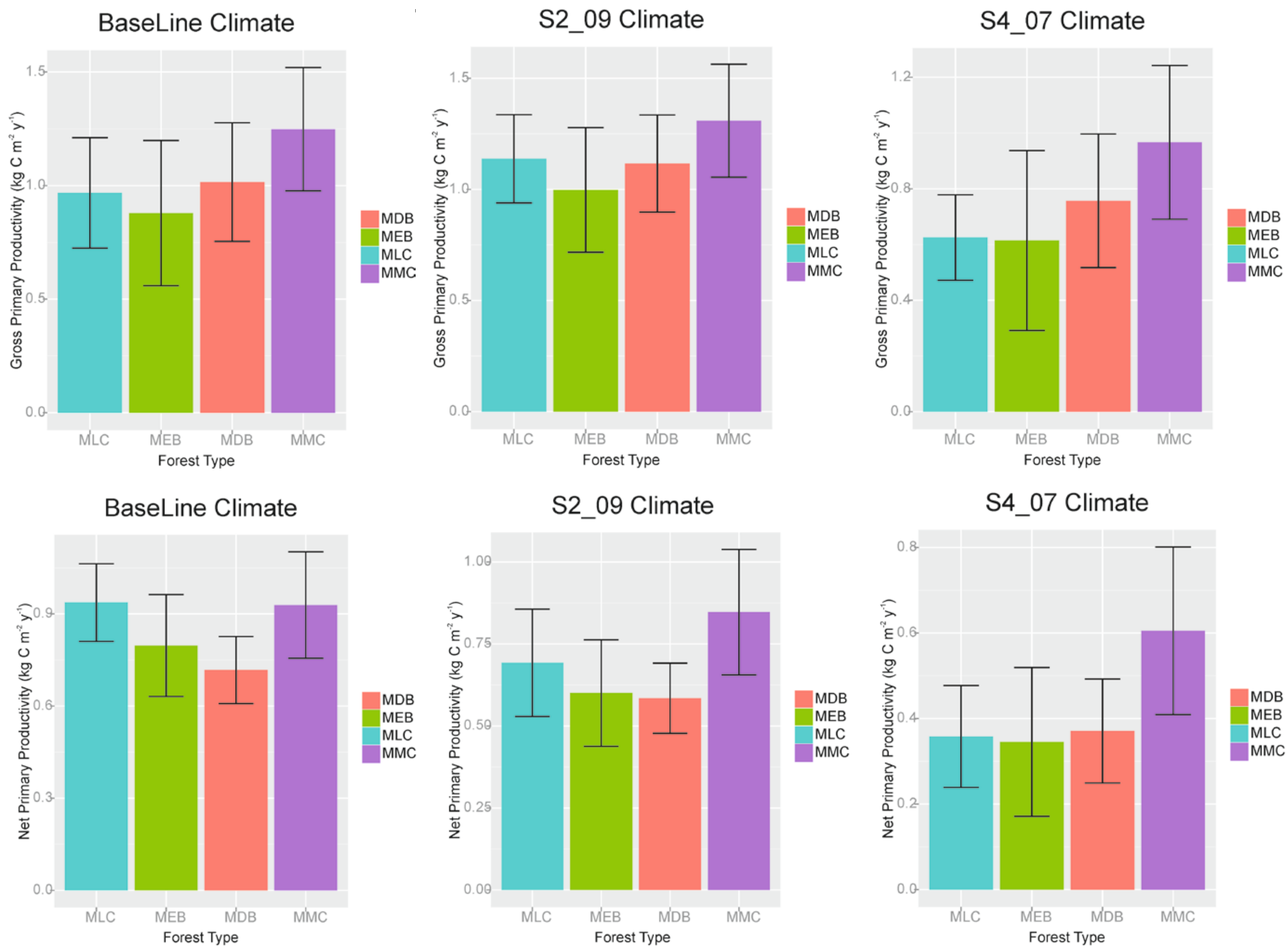
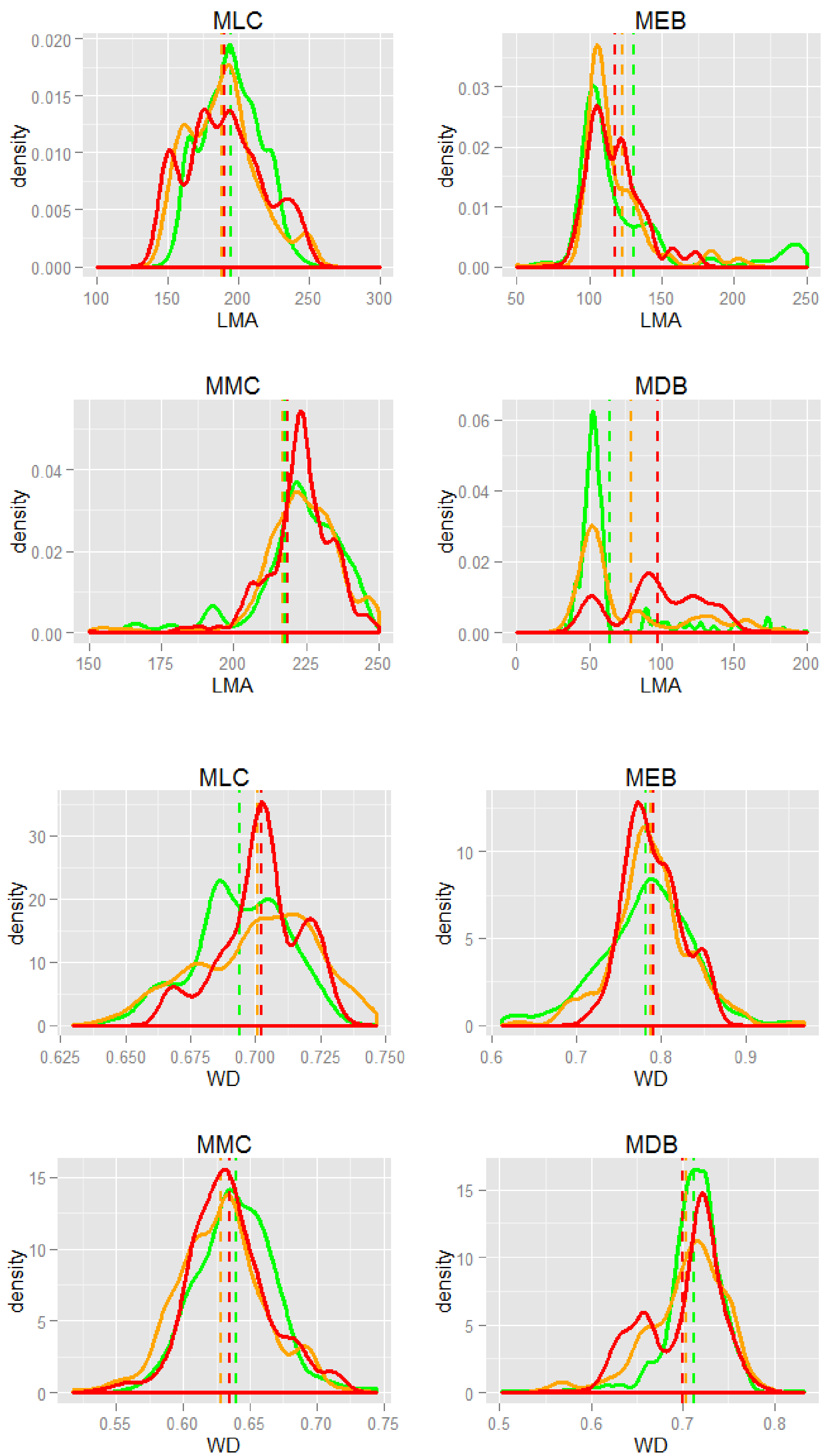

BaseLine Climate
S2_09 Climate
S4_07 Climate
Gross Primary Productivity (kg C m⁻² y⁻¹)
Net Primary Productivity (kg C m⁻² y⁻¹)
Forest Type
MLC
MEB
MDB
MMC
0.0
0.5
1.0
1.5
0.4
0.8
1.2
0.3
0.6
0.9
0.00
0.25
0.50
0.75
1.00
0.2

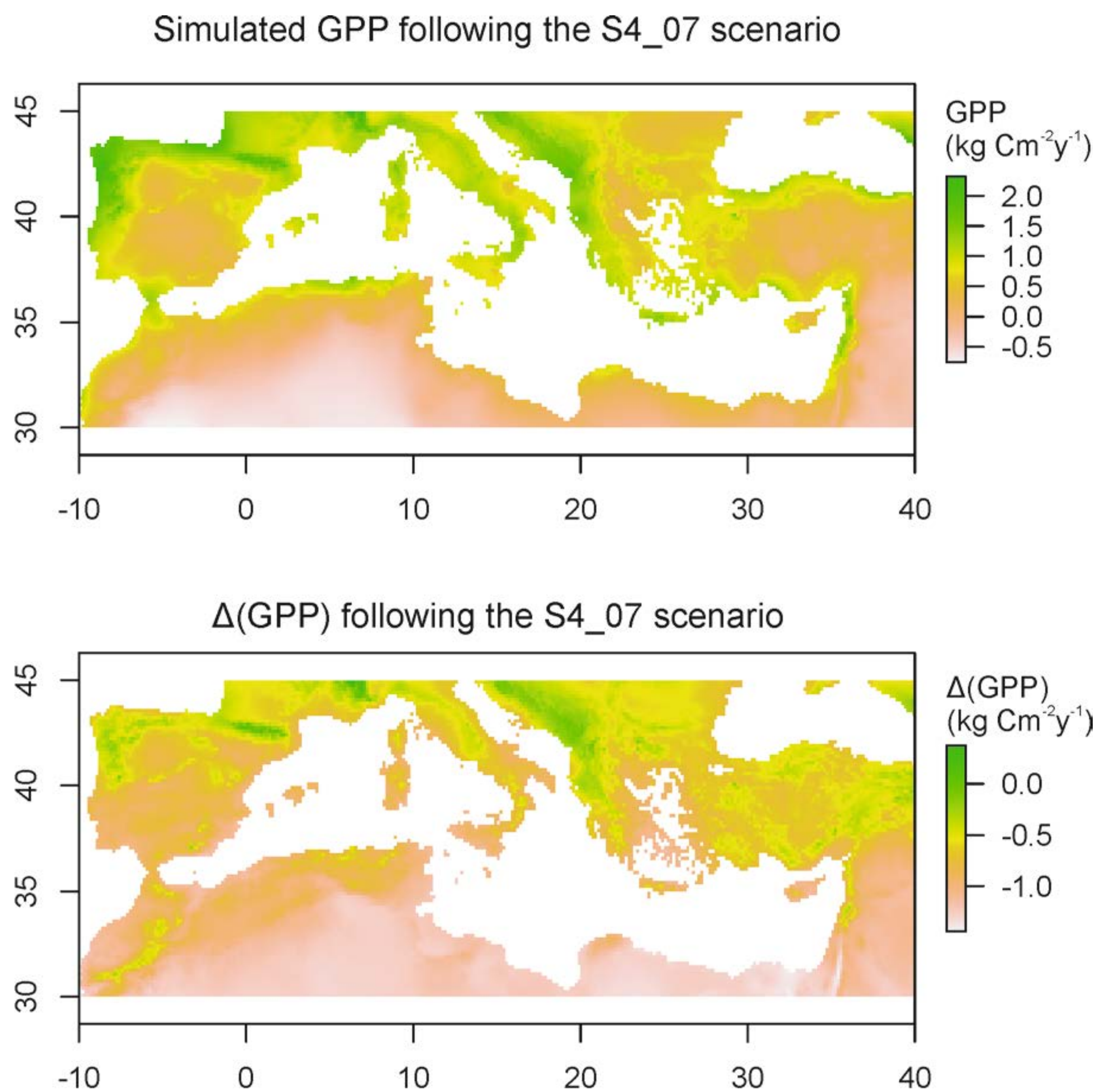
Figure 7: Shifts in trait distributions under different forcing scenarios.Green=BaseLine,Orange=S2_09, Red=S4_07



Large scale predictions

Following a similar approach to simulations under baseline conditions, large scale projections of changes to GPP and NPP across the Mediterranean basin are presented below. We only present simulations under the extreme S4_07 scenario. In the upper panel of Figure 8 the projected GPP across the basin for the year 2050 is presented. In the lower panel, the anomaly, i.e the difference between the S4_07 and the reference (BL) and estimates are presented. Negative values indicate higher vulnerability, for example the eastern parts of Spain and Greece.

Figure 8. Simulated differences in GPP across the Mediterranean Basin under an extreme S4_07 scenario



Conclusions

The applied TFS model adequately captured the geographic patterns of key ecosystem level variables such as GPP and NPP across the Mediterranean basin. Under a mild climate change scenario, some of the forest types studied in MEDIT (in general mountainous) could present a stable or even a small increase in GPP and NPP. However under an extreme climate scenario, significant changes in both stand level productivity and species synthesis is expected, particularly at deciduous forests.

Acknowledgments

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