Limitations of WRF land surface models for simulating land use and land cover change in Sub-Saharan Africa and development of an improved model (CLM-AF v. 1.0)

Timothy Glotfelty[1], Diana Ramírez-Mejía[2], Jared Bowden[3], Adrian Ghilardi[2], and J. Jason West[1]

1Department of Environmental Sciences and Engineering, University of North Carolina at Chapel Hill, Chapel Hill, NC 27599, USA

2Centre for Research in Environmental Geography, Universidad Nacional Autónoma de México, Morelia, 58190, Mexico

3Department of Applied Ecology, North Carolina State University, Raleigh, NC 27695, USA

Supplementary Material

Addressing Inconsistencies in CLM-AF PFTs

In the savanna category, corn is the fourth most abundant PFT indicating some misclassification with croplands. To eliminate this issue of misclassification, the corn contribution to the savanna category is ignored and the fifth most abundant PFT (broad leaf deciduous tropical trees) is used instead. In the broad leaf evergreen forest category, the third and fourth most abundant PFTs are deciduous tropical and temperate trees. To fix this misclassification, the contributions of each type of deciduous tree are added to their evergreen counterparts (i.e., tropical and temperate) to obtain an appropriate weighted total of tropical to temperate trees. After this, all tropical and temperate trees were assumed to be evergreen to match the MODIS category. In the mosaic cropland category, the fourth most abundant PFT is evenly divided between evergreen and deciduous tropical trees. This is addressed by summing the total deciduous and tropical tree amounts and assuming that all trees within this category were represented by evergreen tropical trees, since most mosaic cropland is in proximity to broadleaf evergreen forests.

Additional Adjustments to LAI Broad Leaf Evergreen Tree Profiles

Some additional adjustments were required for the monthly LAI profiles to ensure the best possible match to the satellite derived climatology. The broad leaf evergreen forest MODIS-IGBP category does not differentiate between tropical and temperate evergreen trees leading to an inconsistency with CLM. As mentioned in the previous section, the broad leaf evergreen forest category is split between tropical and temperate evergreen trees, however, the "one size fits all" approach to PFTs in WRF-CLM does not allow this ratio to change throughout the model domain. This is not reflective of actual PFT distributions as regions like the Congo contain only tropical evergreen trees, while regions like South Africa contain only temperate evergreen trees. To correct for the inconsistency, the broad leaf evergreen temperate trees were given the identical monthly LAI profile as tropical trees in the WW, WWN, and CW regions and the broad leaf evergreen tropical trees were given the identical monthly LAI profiles as the temperate trees in the SSD and SM regions.

Subdivision of Bio-Climate Regions

The central wet (CW) and northeast semi-dry (NESD) bioclimate regions are split into three sub-bioclimate regions. CW is split into central wet north (CWN) and central wet south (CWS) regions, north and south of the equator respectively. The southern portion of Angola that contains the savanna MODIS-IGBP category is further split from the CWS region (CWSA) to better represent the differences in LAI between tropical and subtropical grasses. The NESD region is also split into NESD north (NESDN) and NESD south (NESDS) regions containing the area within the NESD region north and south of 4ºN, respectively. To avoid an arbitrary discontinuity in LAI from occurring at 4ºN, the portion of the NESDN region that contains open shrubland around 4ºN is further split off into a separate region (NESDSH) with its own LAI

profiles. The central moist (CM) region is also split into two sub-bioclimate regions, central mo

Additional Details Regarding Moisture Variable Evaluation

In most regions cloud fraction (CF) NMB and NME compared to MODIS are under 50% across most LSMs (Fig. 8). The areas experiencing the greatest overpredictions and worst performance are those across the northern part of the simulation domain (i.e., ND, ED, NESD, EW, and WSD). This poor performance could result from multiple causes including domain boundary effects, errors in the cloud fraction parameterization, and poor coupling of cloud fraction parameterization to the cumulus parameterization. Similar CF performance occurs also occurs against CRU (Fig. S7) estimates.

The overprediction of precipitation (PRE) the EW region is likely the result of poorly resolved complex terrain in the Ethiopian Highlands at 36km grid spacing, as this poor performance is common to all WRF LSM simulations. Strong underpredictions in the LVW region are also consistent across LSMs. This is likely due inaccurate initialization of Lake Victoria's surface temperatures, which has been shown to substantially reduce simulated precipitation in the region (Argent et al., 2015). In contrast, the magnitude of the underpredictions in PRE within the East Africa regions varies more between LSMs. These regions experience the strongest underpredictions with the Noah LSM, likely as a result of insufficient atmospheric instability from the underpredicted surface temperatures. Some East Africa regions (e.g., SESD and EM) also experience considerable underpredictions in CLM-D, likely as a result of the inaccurate LAI seasonal profile underestimating the LAI during these regions' rainy season (JFD). This indicates that accurate seasonal LAI profiles are an important component to obtaining accurate rainfall predictions in these East African regions. The precipitation performance against TRMM observations discussed above (Fig. 8) are also

generally comparable to GPCP and CRU estimates (Fig. S5), but TRMM error statistics are generally larger due to its greater horizontal resolution and spatial variability.ist north (CMN) and central moist south (CMS) north and south of 1ºN, respectively.

Table S1: Percentage of Plant Functional Types Assigned to MODIS Land Use Categories in the Default CLM

MODIS Land Use Category	1	2	3	4	5	6	7	8	9	10	12	14	16	18	19	20
Bare soil	25	5	50	25	26	20	20	20	-	20	15	15	90	50	60	80
Needle Leaf Evergreen Temperate Tree	75	-	-	-	37	-	-	-	-	-	-	-	-	-	-	-
Needle Leaf Evergreen Boreal Tree	-	-	-	-	-	-	-	-	-	-	-	-	-	13	-	-
Needle Leaf Deciduous Boreal Tree	-	-	50	-	-	-	-	-	-	-	-	-	-	13	-	-
Broad Leaf Evergreen Tropical Tree	-	95	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Broad Leaf Evergreen Temperate Tree	-	-	-	-	-	-	-	-	30	-	-	-	-	-	-	-
Broad Leaf Deciduous Tropical Tree	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Broad Leaf Deciduous Temperate Tree	-	-	-	75	37	-	-	-	-	-	-	-	-	-	-	-
Broad Leaf Deciduous Boreal Tree	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Broad Leaf Evergreen Shrub	-	-	-	-	-	80	50	80	-	-	-	-	-	-	-	-
Broad Leaf Deciduous Temperate Shrub	-	-	-	-	-	-	-	-	-	-	-	-	-	24	-	-
Broad Leaf Deciduous Boreal Shrub	-	-	-	-	-	-	-	-	-	-	-	-	10	-	20	10
C3 Artic Grass	-	-	-	-	-	-	-	-	-	-	-	-	-	-	20	20
C3 Non-Artic Grass	-	-	-	-	-	-	-	-	-	20	-	-	-	-	-	-
C4 Grass	-	-	-	-	-	-	30	-	70	60	-	35	-	-	-	-
Corn	-	-	-	-	-	-	-	-	-	-	85	50	-	-	-	-
Wheat	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

MODIS Land Use Categories: 1 – Evergreen Needle Leaf Forest, 2 – Evergreen Broad Leaf Forest; 3 – Deciduous Needle Leaf Forest; 4 – Deciduous Broad Leaf Forest; 5 – Mixed Forest; 6 – Closed Shrublands; 7 – Open Shrublands; 8 – Woody Savanna; 9 – Savannas; 10 – Grasslands; 12 – Croplands; 14 –Cropland/Natural Mosaic; 16 – Barren/ Sparsely Vegetated; 18 – Wooded Tundra; 19 – Mixed Tundra; 20 – Barren Tundra

Table S2: Default CLM Monthly Leaf Area Index Profiles

Month	1	2	3	4	5	6	7	8	9	10	11	12
Needle Leaf Evergreen Temperate Tree	4.1	4.2	4.6	4.8	4.9	5.0	4.8	4.7	4.6	4.2	4.0	4.0
Needle Leaf Evergreen Boreal Tree	4.1	4.2	4.6	4.8	4.9	5.0	4.8	4.7	4.6	4.2	4.0	4.0
Needle Leaf Deciduous Boreal Tree	0.0	0.0	0.0	0.6	1.2	2.0	2.6	1.7	1.0	0.5	0.2	0.0
Broad Leaf Evergreen Tropical Tree	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5
Broad Leaf Evergreen Temperate Tree	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5
Broad Leaf Deciduous Tropical Tree	0.8	0.7	0.4	0.5	0.5	0.7	1.7	3.0	2.5	1.6	1.0	1.0
Broad Leaf Deciduous Temperate Tree	0.0	0.0	0.3	1.2	3.0	4.7	4.5	3.4	1.2	0.3	0.0	0.0
Broad Leaf Deciduous Boreal Tree	0.0	0.0	0.3	1.2	3.0	4.7	4.5	3.4	1.2	0.3	0.0	0.0
Broad Leaf Evergreen Shrub	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Broad Leaf Deciduous Temperate Shrub	0.9	0.8	0.2	0.2	0.0	0.0	0.0	0.2	0.4	0.5	0.6	0.8
Broad Leaf Deciduous Boreal Shrub	0.0	0.0	0.0	0.0	0.0	0.2	1.4	1.2	0.0	0.0	0.0	0.0
C3 Artic Grass	0.4	0.5	0.6	0.7	1.2	3.0	3.5	1.5	0.7	0.6	0.5	0.4
C3 Non-Artic Grass	0.0	0.0	0.0	0.0	0.0	0.2	1.4	1.2	0.0	0.0	0.0	0.0
C4 Grass	0.4	0.5	0.6	0.7	1.2	3.0	3.5	1.5	0.7	0.6	0.5	0.4
Corn	0.0	0.0	0.0	0.0	1.0	2.0	3.0	3.0	1.5	0.0	0.0	0.0
Wheat	0.0	0.0	0.0	0.0	1.0	2.0	3.0	3.0	1.5	0.0	0.0	0.0

Table S3: MODIS-IGBP Land Cover Category Description (Friedl et al., 2002)

MODIS-IGBP Land Cover Category	Description
Evergreen Broad Leaf Forests	Lands dominated by broad leaf woody vegetation with a percentage cover >60% and height exceeding 2m. Almost all trees and shrubs remain green year round. Canopy is never without foliage.
Closed Shrubland	Lands with woody vegetation less than 2 m tall and with shrub cover >60%. The shrub cover be either evergreen or deciduous.
Open Shrubland	Lands with woody vegetation less than 2 m tall and with shrub canopy cover between 10% and 60%. The shrub foliage can be either evergreen or deciduous.
Woody Savanna	Lands with herbaceous and other understory systems, with forest canopy cover between 30% and 60%. The forest cover height exceeds 2 m.
Savanna	Lands with herbaceous and other understory systems, with forest and canopy cover between 10 and 30%. The forest cover exceeds 2 m.
Grasslands	Land with herbaceous types of cover. Tree and shrub cover is less than 10%.
Cropland	Lands covered with temporary crops followed by harvest and bare soil periods (e.g., single and multiple cropping systems). Note that perennial woody crops will be classified as the appropriate forest of shrub land cover type.
Mosaic Cropland	Lands with a mosaic of croplands, forests, shrubland, and grasslands in which no one component comprises more than 60% of the landscape.

Table S4: Updated CLM Monthly Leaf Area Index Profiles for Broad Leaf Evergreen Tropical Trees

Region	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
EW	4.4	4.5	4.7	5.1	5.4	5.3	5.2	5.2	5.3	5.4	5.2	4.7
WW	4.9	5.2	5.3	5.6	5.6	5.7	5.7	5.8	5.7	5.6	5.4	5.0
CW (N,S,SA)	5.3	5.7	5.8	5.9	5.6	5.1	5.0	5.2	5.7	5.8	5.7	5.4
WWN	3.3	3.5	3.7	4.2	4.3	4.2	4.3	4.5	4.5	4.3	4.3	3.9
CM (S)	5.4	4.9	5.0	5.6	6.0	5.7	5.2	5.2	5.5	5.7	5.9	5.7
LVW	4.8	4.5	4.6	5.1	5.4	5.3	5.0	5.0	5.2	5.2	5.3	5.2
EM[60]	3.1	3.2	3.3	3.4	3.4	2.9	2.6	2.6	2.6	2.5	2.5	2.8
MAD	5.8	5.8	5.7	5.1	4.6	4.3	4.3	4.7	5.4	5.7	5.7	5.7

[60]: Profile generated using 60% of grid cell threshold

Table S5: Updated CLM Monthly Leaf Area Index Profiles for Broad Leaf Evergreen Temperate Trees

Region	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
EW	4.4	4.6	4.9	5.3	5.4	5.2	5.2	5.3	5.4	5.4	5.2	4.7
CM (S)	3.3	3.4	3.4	3.4	3.3	3.2	3.0	2.9	2.8	2.8	3.0	3.2
LVW	5.0	4.9	5.0	5.2	5.2	5.0	4.9	5.0	5.0	5.0	5.1	5.0
EM	3.5	3.6	3.5	3.3	3.0	2.5	2.2	2.3	2.5	2.4	2.7	3.1
MAD	5.0	5.1	4.8	4.3	3.9	3.6	3.6	3.7	4.4	4.9	5.0	4.9
SSD	2.3	2.1	2.0	1.6	1.5	1.4	1.4	1.5	1.8	2.1	2.3	2.3
SM[60]	2.9	2.9	2.6	2.2	1.7	1.5	1.3	1.4	1.5	1.7	2.2	2.7

[60]: Profile generated using 60% of grid cell threshold

Table S6: Updated CLM Monthly Leaf Area Index Profiles for Broad Leaf Deciduous Tropical Trees

Region	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
WSD	0.6	0.6	0.5	0.6	0.7	1.1	1.6	1.9	1.9	1.6	1.0	0.7
NESD (N)	0.7	0.7	0.7	0.7	0.9	1.2	1.7	1.9	1.9	1.5	1.1	0.8
NESD (S, SH)[60]	2.1	2.0	1.9	2.2	2.3	2.1	2.0	1.8	1.5	1.4	1.8	2.1
EW	0.3	0.3	0.3	0.3	0.3	0.4	0.8	1.1	1.2	0.9	0.6	0.4
WM	1.3	1.3	1.5	1.8	2.0	2.3	2.6	2.8	2.8	2.6	2.1	1.7
WW	2.3	2.2	2.2	2.3	2.5	3.0	3.4	3.6	3.6	3.6	3.3	2.6
CW (N)	3.1	3.3	3.4	3.6	3.6	3.6	3.6	3.8	3.9	3.7	3.5	3.3
CW(S,SA)	2.9	2.9	3.0	2.7	1.8	1.3	1.0	1.1	1.6	2.1	2.7	2.9
SESD	2.6	2.7	2.7	2.7	2.3	1.9	1.8	1.6	1.5	1.6	1.9	2.4
MAD	1.9	2.1	2.1	1.7	1.2	0.8	0.7	0.7	0.7	0.7	0.8	1.3
SSD[60]	1.5	1.5	1.4	1.1	0.7	0.4	0.3	0.4	0.4	0.5	0.8	1.2
SM[60]	3.5	3.7	3.6	3.3	3.1	2.9	2.7	2.7	2.8	3.0	3.2	3.4

[60]: Profile generated using 60% of grid cell threshold

Table S7: Updated CLM Monthly Leaf Area Index Profiles for Broad Leaf Deciduous Temperate Shrub

Region	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
ED[60]	0.3	0.2	0.2	0.4	0.5	0.4	0.2	0.2	0.2	0.4	0.5	0.5
WSD[60]	0.4	0.4	0.4	0.4	0.4	0.7	1.3	1.7	1.7	1.3	0.7	0.5
NESD (N)	0.3	0.2	0.3	0.3	0.6	1.2	1.7	1.9	2.0	2.0	1.5	0.7
NESD (S)	0.4	0.4	0.4	0.9	1.2	0.7	0.5	0.4	0.4	0.9	1.1	0.8
NESD (SH)[60]	0.3	0.3	0.3	0.4	0.6	0.4	0.3	0.3	0.3	0.4	0.5	0.4
CW (S)[60]	0.5	0.6	0.7	0.7	0.5	0.4	0.3	0.3	0.3	0.3	0.3	0.4
CW (SA)[60]	0.8	1.0	1.1	1.1	0.9	0.7	0.5	0.5	0.5	0.5	0.6	0.8
SESD[60]	0.7	0.7	0.6	0.6	0.4	0.3	0.2	0.2	0.2	0.3	0.4	0.6
MAD[60]	1.0	1.1	1.1	1.0	0.8	0.6	0.5	0.4	0.4	0.4	0.5	0.7
SD[60]	0.3	0.3	0.2	0.2	0.2	0.3	0.3	0.4	0.4	0.4	0.3	0.3
SSD[60]	0.5	0.6	0.6	0.5	0.3	0.2	0.2	0.2	0.2	0.3	0.4	0.5
SM[60]	0.9	0.9	0.8	0.6	0.4	0.3	0.3	0.3	0.3	0.4	0.6	0.8

[60]: Profile generated using 60% of grid cell threshold

Table S8: Updated CLM Monthly Leaf Area Index Profiles for C3 Non-Artic Grass

Region	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
WSD[60]	0.6	0.5	0.5	0.5	0.8	1.2	1.6	1.8	1.9	1.6	0.9	0.7
NESD (N)	0.4	0.4	0.4	0.6	0.8	0.9	1.3	1.6	1.6	1.2	0.8	0.5
NESD (S)	1.4	1.6	1.6	1.6	1.2	0.8	0.6	0.6	0.5	0.5	0.6	0.9
NESD (SH)[60]	1.0	0.9	0.8	1.2	1.3	1.0	0.8	0.9	0.9	0.9	1.2	1.2
EW	0.5	0.4	0.4	0.5	0.6	0.8	1.3	1.8	1.9	1.5	1.0	0.6
WW[60]	1.0	1.0	1.1	1.4	1.6	2.1	2.4	2.5	2.6	2.4	1.8	1.2
CW (N)[60]	1.4	1.3	1.5	2.1	2.6	2.7	2.7	2.7	2.6	2.6	2.3	1.8
CW (S)	1.8	1.8	1.8	1.8	1.7	1.3	1.1	1.2	1.5	1.8	1.9	1.9
CW (SA)	1.4	1.5	1.6	1.5	1.2	0.8	0.6	0.6	0.6	0.8	1.1	1.3
WWN[60]	0.5	0.5	0.7	1.3	2.0	2.3	2.3	2.3	2.3	2.2	1.5	0.8
CM (N)[60]	1.0	0.9	0.9	1.3	1.6	1.7	1.7	1.7	1.6	1.4	1.4	1.2
CM (S)	1.6	1.6	1.7	1.8	1.6	1.1	0.8	0.8	0.8	0.7	0.9	1.3
LVW	1.4	1.2	1.3	1.5	1.8	1.7	1.6	1.5	1.5	1.4	1.5	1.5
EM	1.5	1.6	1.6	1.5	1.2	1.0	0.8	0.7	0.7	0.7	0.9	1.2
SESD	1.6	1.6	1.6	1.3	1.0	0.7	0.6	0.5	0.6	0.6	0.8	1.3
MAD	1.3	1.6	1.6	1.5	1.1	0.9	0.7	0.6	0.6	0.6	0.8	1.0
SD[60]	0.3	0.3	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
SSD	1.0	1.2	1.1	0.9	0.6	0.4	0.4	0.3	0.3	0.4	0.6	0.8
SM	1.8	1.9	1.6	1.2	0.7	0.5	0.4	0.4	0.5	0.8	1.2	1.6

[60]: Profile generated using 60% of grid cell threshold

Table S9: Updated CLM Monthly Leaf Area Index Profiles for C4 Grass

Region	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
ND[60]	0.2	0.1	0.1	0.1	0.1	0.2	0.3	0.4	0.5	0.3	0.2	0.2
WSD	0.4	0.4	0.4	0.4	0.5	0.9	1.3	1.7	1.7	1.3	0.8	0.5
NESD (N)	0.4	0.3	0.3	0.4	0.6	1.0	1.5	1.9	1.9	1.5	0.9	0.6
NESD (S)	1.2	1.0	1.0	1.3	1.4	1.2	1.1	0.9	0.8	0.9	1.2	1.3
NESD (SH)[60]	0.3	0.3	0.2	0.4	0.4	0.3	0.4	0.5	0.4	0.4	0.4	0.4
EW	0.6	0.4	0.5	0.8	1.4	2.0	2.3	2.6	2.5	2.2	1.6	1.0
WM	0.5	0.6	0.6	0.9	1.2	1.5	1.8	2.0	2.0	1.9	1.2	0.7
WW	0.7	0.7	0.9	1.1	1.4	1.8	2.1	2.2	2.3	2.1	1.4	0.9
CW (N)	0.5	0.5	0.6	0.8	1.1	1.7	2.2	2.3	2.4	2.0	1.2	0.6
CW (S)	2.1	2.1	2.2	2.3	2.0	1.4	1.1	1.2	1.4	1.6	1.9	2.1
CW (SA)	1.5	1.7	1.8	1.7	1.3	0.9	0.7	0.7	0.7	0.8	1.1	1.5
WWN	0.5	0.6	0.7	1.0	1.5	1.8	2.0	2.1	2.1	2.1	1.4	0.8
CM (N)	0.6	0.6	0.6	0.9	1.4	2.0	2.3	2.5	2.2	1.7	1.1	0.7
CM (S)	1.7	1.7	1.7	1.7	1.6	1.2	1.1	0.9	0.8	0.8	1.1	1.5
LVW[60]	0.8	0.7	0.8	1.1	1.3	1.3	1.3	1.3	1.2	1.2	1.2	0.9
EM	1.9	2.1	2.2	2.2	1.8	1.3	1.0	0.8	0.7	0.7	0.8	1.2
SESD	1.8	1.9	1.9	1.6	1.1	0.8	0.7	0.6	0.6	0.6	0.8	1.4
MAD	1.5	1.6	1.6	1.3	1.0	0.7	0.6	0.6	0.6	0.6	0.7	1.1
SSD	1.1	1.2	1.1	1.0	0.7	0.5	0.4	0.4	0.4	0.4	0.6	0.9

[60]: Profile generated using 60% of grid cell threshold

Table S10: Updated CLM Monthly Leaf Area Index Profiles for Corn

Region	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
ND	0.1	0.1	0.1	0.1	0.1	0.2	0.2	0.3	0.3	0.2	0.1	0.1
WSD	0.2	0.2	0.1	0.2	0.2	0.3	0.4	0.6	0.6	0.5	0.3	0.2
NESD (N)	0.2	0.2	0.3	0.5	0.6	0.5	0.5	0.6	0.6	0.5	0.5	0.3
NESD (S, SH)	0.4	0.4	0.4	0.7	1.0	1.0	0.9	1.0	0.9	0.7	0.6	0.5
EW[60]	0.4	0.5	0.5	0.6	0.6	0.6	0.8	1.2	1.3	1.1	0.7	0.5
WM	0.6	0.6	0.7	0.9	1.1	1.4	1.7	1.8	1.9	1.7	1.3	0.9
WW	0.6	0.8	1.1	1.6	1.9	2.0	2.2	2.2	2.2	2.3	1.5	0.8
CW (N)[60]	0.9	1.0	1.2	1.7	2.3	2.6	2.7	2.6	2.6	2.5	1.8	1.1
WWN	0.7	0.8	1.0	1.3	1.7	1.9	2.0	2.1	2.1	2.0	1.6	1.0
CM (N)	0.6	0.5	0.7	1.4	2.2	2.5	2.5	2.6	2.6	2.2	1.7	1.0
CM (S)	1.6	1.4	1.4	1.7	1.9	1.4	1.0	0.9	1.1	1.5	1.8	1.8
LVW	1.1	1.0	1.1	1.5	1.8	1.7	1.6	1.6	1.5	1.5	1.5	1.2
SESD[60]	1.8	1.9	1.9	1.7	1.3	0.9	0.8	0.6	0.6	0.6	0.8	1.3
SSD	0.6	0.6	0.6	0.5	0.4	0.5	0.7	0.8	0.7	0.5	0.4	0.5
SM[60]	2.1	2.2	2.0	1.7	1.3	0.9	0.8	0.8	0.8	1.2	1.7	2.0

[60]: Profile generated using 60% of grid cell threshold

Table S11. Dinamica EGO Explanatory Variables

Type	Group	Variable	Resolution	Product Acronym	Source	
Static	Biophysical conditions	Elevation (DEM)	~ 1 km	GTOPO30	USGS	Global 30 Arc-Second Elevation (GTOPO30) Digital Object Identifier (DOI) number: /10.5066/F7DF6PQS
		Slope	~ 1 km		Derived from DEM	
		Aspect	~ 1 km		Derived from DEM	
		Bulk density	~ 1 km	BLDFIE_M_sl1	ISRIC - World Soil Information	https://soilgrids.org/
		Clay content	~ 1 km	CLYPPT_M_sl1	ISRIC - World Soil Information	https://soilgrids.org/
		Sand content	~ 1 km	SNDPPT_M_sl1	ISRIC - World Soil Information	https://soilgrids.org/
		Silt content	~ 1 km	SLTPPT_M_sl1	ISRIC - World Soil Information	https://soilgrids.org/
		Soil organic carbon content	~ 1 km	ORCDRC_M_sl1	ISRIC - World Soil Information	https://soilgrids.org/
	Land status	Protected areas		WDPA	UCN and UNEP	https://www.protectedplanet.net/
	Demography	Population density	~ 1 km	GPWv4	SEDAC	https://sedac.ciesin.columbia.edu/data/collection/gpw-v4
	Infrastructure	Roads		GPWv4	SEDAC	https://sedac.ciesin.columbia.edu/data/collection/gpw-v4
		Settlements			SEDAC	https://sedac.ciesin.columbia.edu/data/set/groads-global-roads-open-access-v1
Dynamic	Distance to LULC categories	Evergreen Broadleaf forest				
		Open shrublands				
		Woody savannas				
		Savannas				
		Grasslands				
		Croplands				
		Cropland/natural vegetation mosaic				
		Barren or sparsely vegetated				
		Waterbodies				

Table S12. Comparison of Noah and Satellite Derived Albedo values for MODIS-IGBP categories

MODIS-IGBP Category	Noah	Houldcroft et al. (2009)
1	12	9.2
2	12	13.9
3	14-15	10.3
4	16-17	13.3
5	17-25	11.2
6	25-30	13.4
7	22-30	16.1
8	25-30	13.1
9	20	15.5
10	19-23	16.8
11	14	10.2
12	17-23	16.5
13	15	14.9
14	18-23	15.8

Table S13. Noah-MP LAI Seasonal Profiles for each MODIS-IGBP Category

MODIS-IGBP Category	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
1	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
2	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5
3	0.0	0.0	0.0	0.6	1.2	2.0	2.6	1.7	1.0	0.5	0.2	0.0
4	0.0	0.0	0.3	0.9	2.2	3.5	3.5	2.5	0.9	0.3	0.0	0.0
5	2.0	2.0	2.2	2.6	3.5	4.3	4.3	3.7	2.6	2.2	2.0	2.0
6	0.0	0.0	0.3	0.9	2.2	3.5	3.5	2.5	0.9	0.3	0.0	0.0
7	0.0	0.0	0.2	0.6	1.5	2.3	2.3	1.7	0.6	0.2	0.0	0.0
8	0.2	0.2	0.4	1.0	2.4	4.1	4.1	2.7	1.0	0.4	0.2	0.2
9	0.3	0.3	0.5	0.8	1.8	3.6	3.8	2.1	0.9	0.5	0.3	0.3
10	0.4	0.5	0.6	0.7	1.2	3.0	3.5	1.5	0.7	0.6	0.5	0.4
11	0.2	0.3	0.3	0.5	1.5	2.9	3.5	2.7	1.2	0.3	0.3	0.2
12	0.0	0.0	0.0	0.0	1.0	2.0	3.0	3.0	1.5	0.0	0.0	0.0
13	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
14	0.2	0.3	0.3	0.4	1.1	2.5	3.2	2.2	1.1	0.3	0.3	0.2
15	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
16	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
17	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
18	1.0	1.0	1.1	1.3	1.7	2.1	2.1	1.8	1.3	1.1	1.0	1.0
19	0.6	0.6	0.7	0.8	1.2	1.8	1.8	1.3	0.8	0.7	0.6	0.6
20	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table S14. Noah LAI Maximum and Minimum Values for each MODIS-IGBP Category

MODIS-IGBP Category	Min.	Max.
Evergreen Needle Leaf Forest	5.00	6.49
Evergreen Broad Leaf Forest	3.08	6.48
Deciduous Needle Leaf Forest	1.00	5.16
Deciduous Broad Leaf Forest	1.85	3.31
Mixed Forest	2.80	5.50
Closed Shrubland	0.50	3.66
Open Shrubland	0.60	2.60
Woody Savanna	0.50	3.66
Savannas	0.50	3.66
Grasslands	0.52	2.90
Permanent Wetlands	1.75	5.72
Cropland	1.56	5.68
Urban and Built	1.00	1.00
Cropland/Natural Vegetation Mosaic	2.29	4.29
Ice	0.01	0.01
Barren/Sparsely Vegetated	0.10	0.75
Water	0.01	0.01
Wooded Tundra	0.41	3.35
Mixed Tundra	0.41	3.35
Barren Tundra	0.41	3.35

Table S15: Annual Average Surface Sensible Heat Flux (W m^{-2}) in WRF Grid Cells that experience LULCCs between 2001 and 2015

Transition	Noah	Noah-MP	CLM-D	CLM-AF
Agricultural Expansion*	2.35	-9.14	-3.37	0.94
10 to 12	-0.22	-1.53	0.22	0.67
2 to 14	0.51	1.29	4.67	5.18
8 to 14	5.03	-14.38	-5.85	0.12
10 to 14	-0.91	-0.90	0.42	4.42
Deforestation/Degradation*	4.08	-3.38	-2.03	-2.12
8 to 9	10.45	-3.66	-1.94	-1.45
9 to 7	-10.14	-0.19	-1.96	-5.81
9 to 10	-1.95	0.12	-5.23	-3.34
Greening*	5.65	0.12	2.16	2.13
9 to 8	-6.83	3.07	0.46	0.54
10 to 9	3.08	11.27	5.45	4.39
16 to 7	19.58	0.77	9.60	3.44
16 to 10	24.75	-2.13	4.45	11.34

*: Shows average difference for a broad class of LULCC followed by the average difference in the major MODIS LULC transitions that comprise that class. MODIS Land Use Categories: 2 – Evergreen Broad Leaf Forest; 7 – Open Shrublands; 8 – Woody Savanna; 9 – Savannas; 10 – Grasslands; 12 – Croplands; 14 –Cropland/Natural Mosaic; 16 – Barren/ Sparsely Vegetated

Table S16: Annual Average Surface Latent Heat Flux (W m^{-2}) in WRF Grid Cells that experience LULCCs between 2001 and 2015

Transition	Noah	Noah-MP	CLM-D	CLM-AF
Agricultural Expansion*	2.26	-1.67	-3.87	-3.82
10 to 12	1.01	0.30	-2.11	-2.75
2 to 14	-11.72	-18.41	-27.82	-25.57
8 to 14	9.33	0.28	-1.68	-3.80
10 to 14	1.39	0.81	-0.65	-2.28
Deforestation/Degradation*	1.61	-1.22	-1.46	-3.70
8 to 9	5.37	-0.13	-0.38	-2.93
9 to 7	-3.83	-1.85	0.37	-4.57
9 to 10	-0.29	-0.60	-1.04	-1.86
Greening*	0.14	4.76	7.81	5.83
9 to 8	-9.46	0.41	2.94	3.33
10 to 9	-0.59	-0.34	-1.05	-0.76
16 to 7	2.66	3.94	6.68	2.18
16 to 10	8.04	5.18	8.13	4.79

*: Shows average difference for a broad class of LULCC followed by the average difference in the major MODIS LULC transitions that comprise that class. MODIS Land Use Categories: 2 – Evergreen Broad Leaf Forest; 7 – Open Shrublands; 8 – Woody Savanna; 9 – Savannas; 10 – Grasslands; 12 – Croplands; 14 –Cropland/Natural Mosaic; 16 – Barren/ Sparsely Vegetated

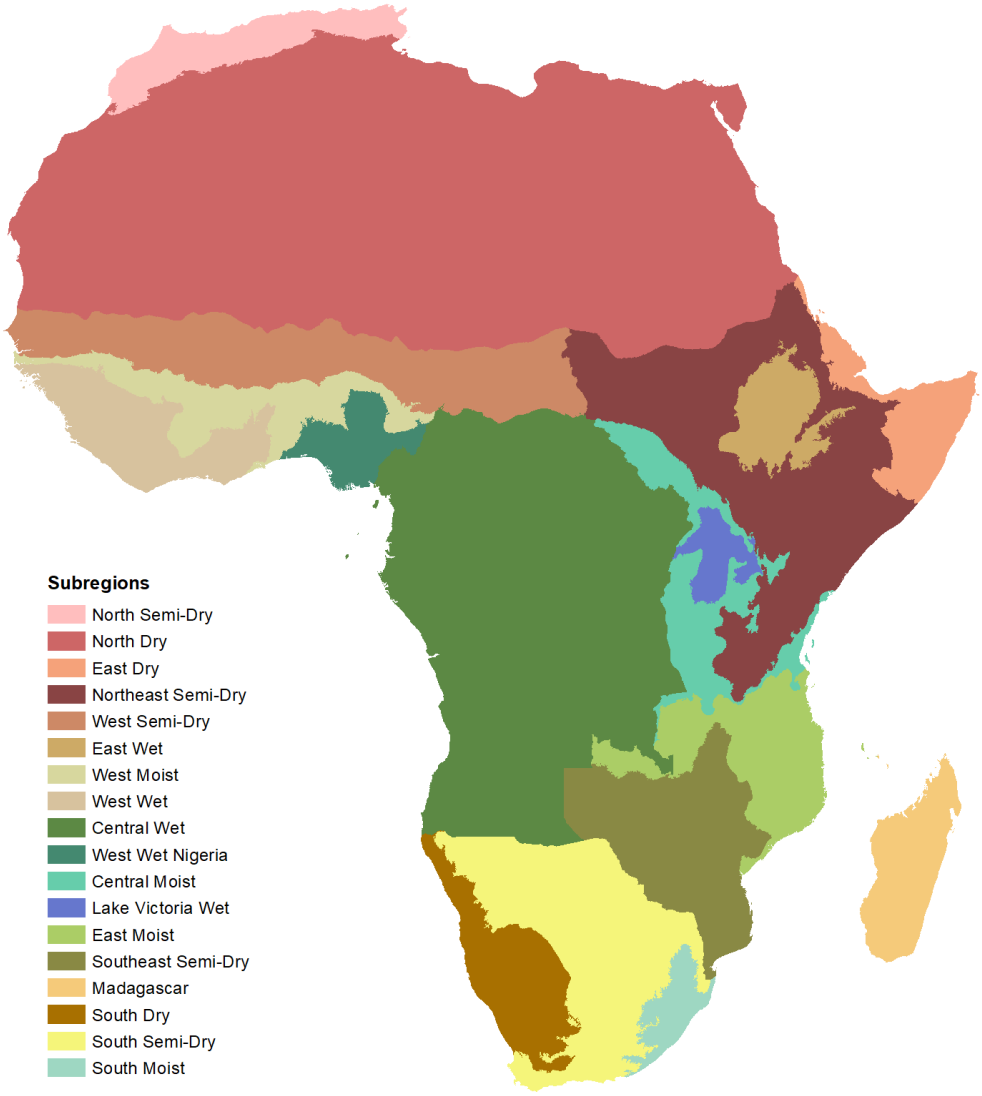

Fig S1. Regions used to model LULCC in Africa

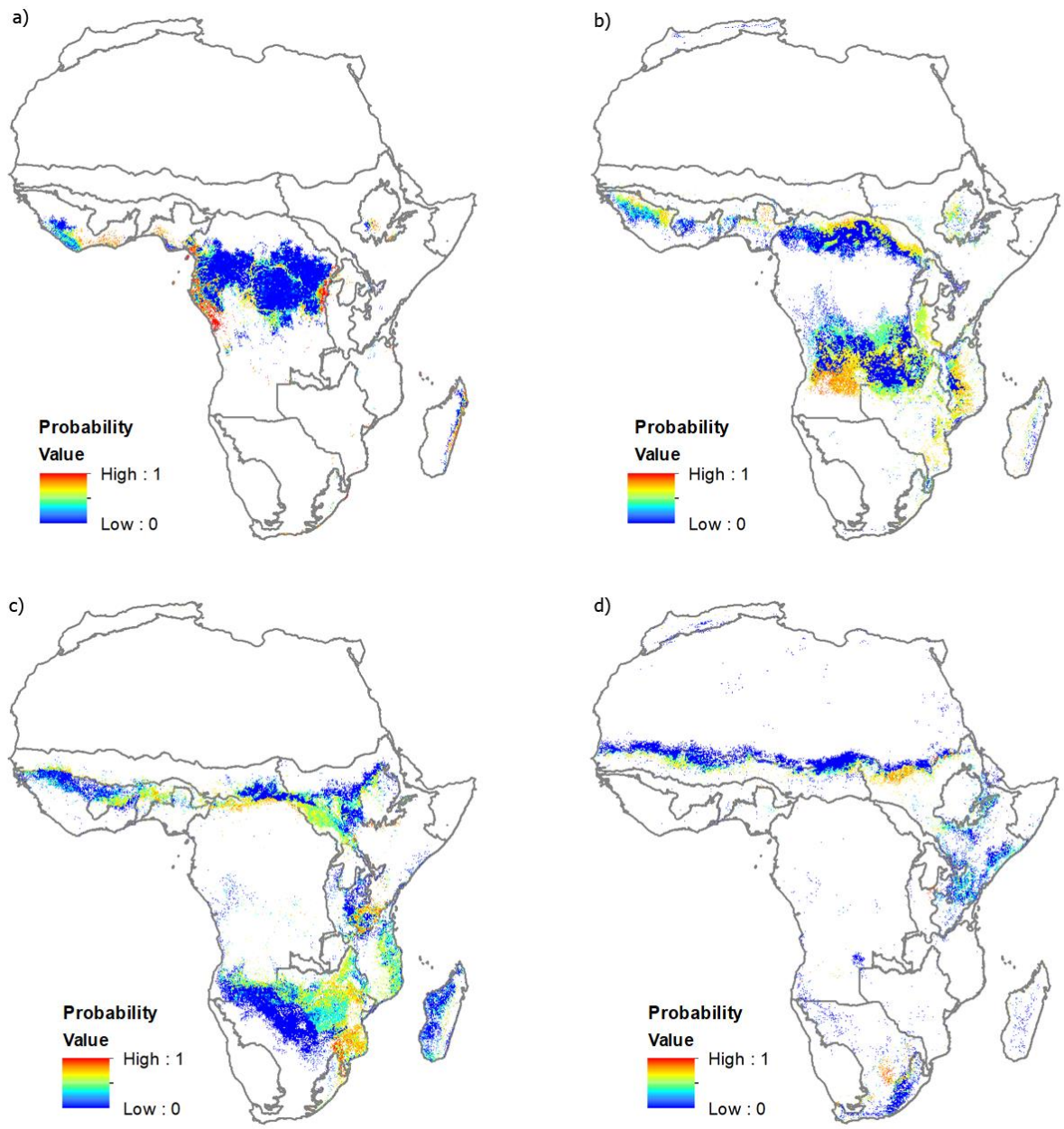

Fig S2. Probability maps for transitions a) Evergreen broadleaf forest to Cropland/Natural vegetation mosaic, b) Woody savannas to savannas, c) Savannas to woody savannas, and d) Grasslands to croplands.

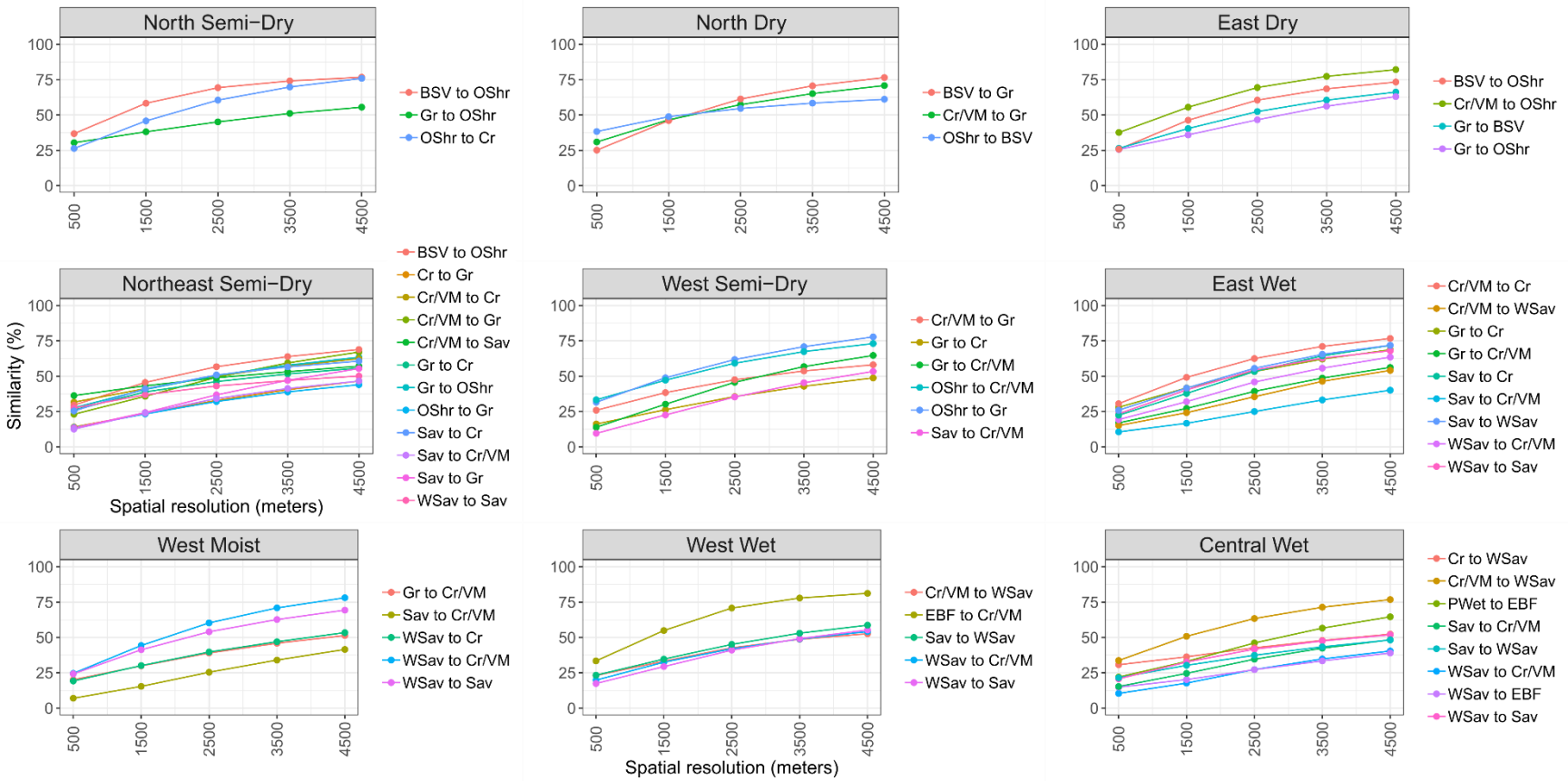

Fig S3 Part 1. Fuzzy similarity index between real and simulated changes for each transition by region.

Acronyms: EBF = Evergreen Broadleaf forest, MF = Mixed forest, CShr = Closed shrublands, OShr = Open shrublands, WSav = Woody savannas, Sav = Savannas, Gr = Grasslands, PWet = Permanent wetlands, Cr = Croplands, Cr/VM = Cropland/Natural vegetation mosaic, BSV = Barren or sparsely vegetated.

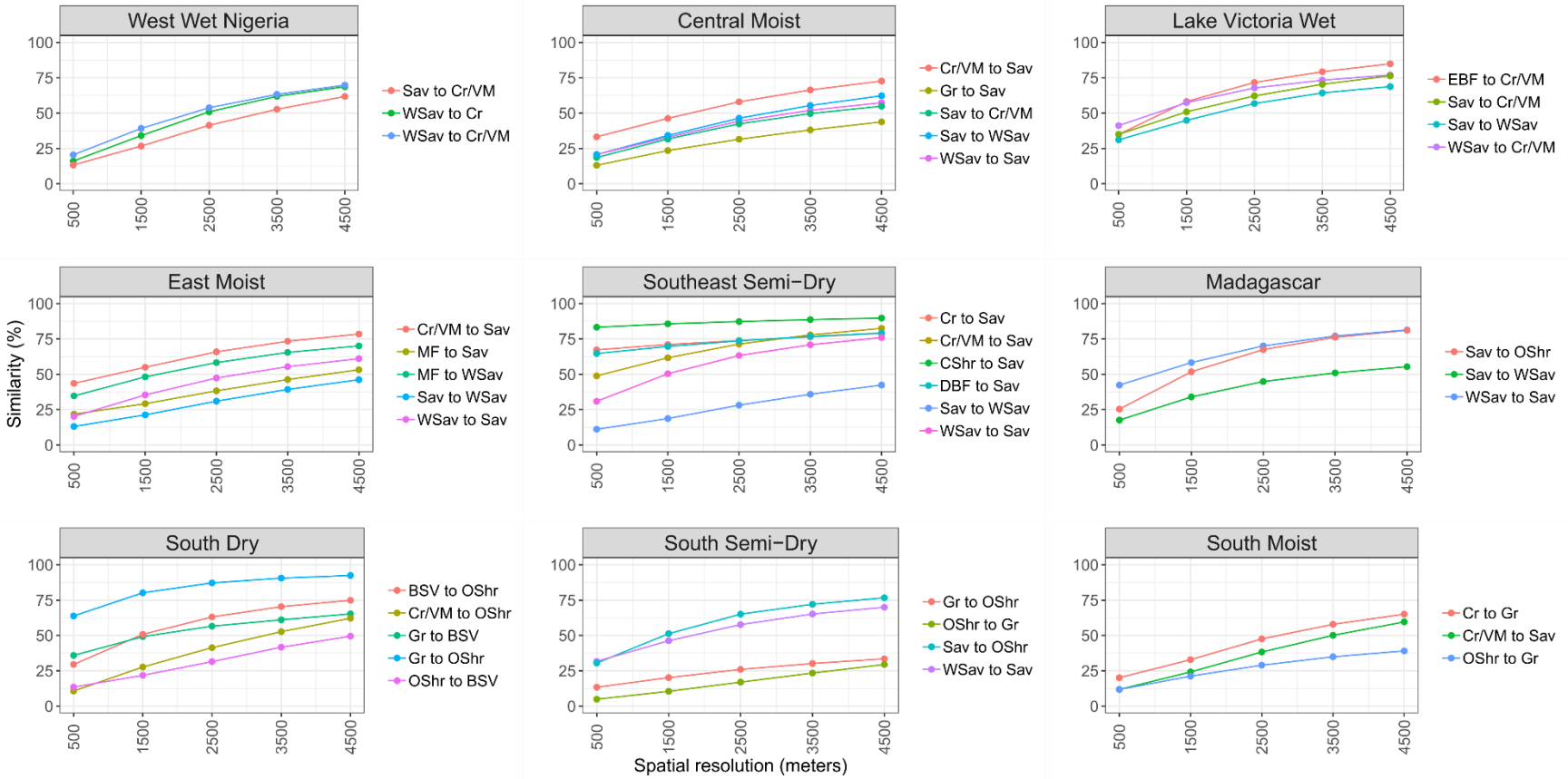

Fig S3 Part 2. Fuzzy similarity index between real and simulated changes for each transition by region.

Acronyms: EBF = Evergreen Broadleaf forest, MF = Mixed forest, CShr = Closed shrublands, OShr = Open shrublands, WSav = Woody savannas, Sav = Savannas, Gr = Grasslands, PWet = Permanent wetlands, Cr = Croplands, Cr/VM = Cropland/Natural vegetation mosaic, BSV = Barren or sparsely vegetated.

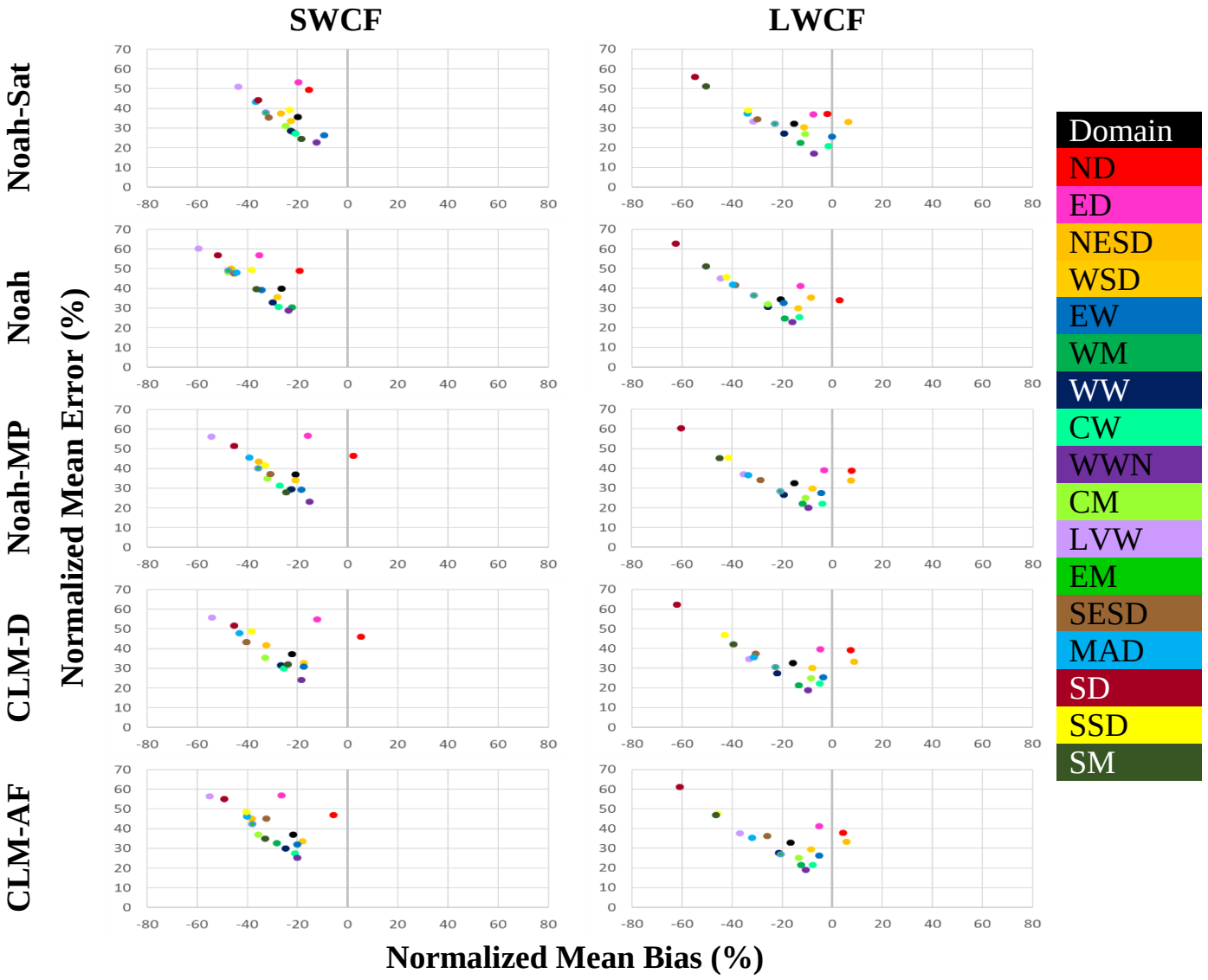

Fig S4 Soccer

plot of domain and regional WRF SWCF and LWCF model performance statistics verses CERES-EBAF estimates

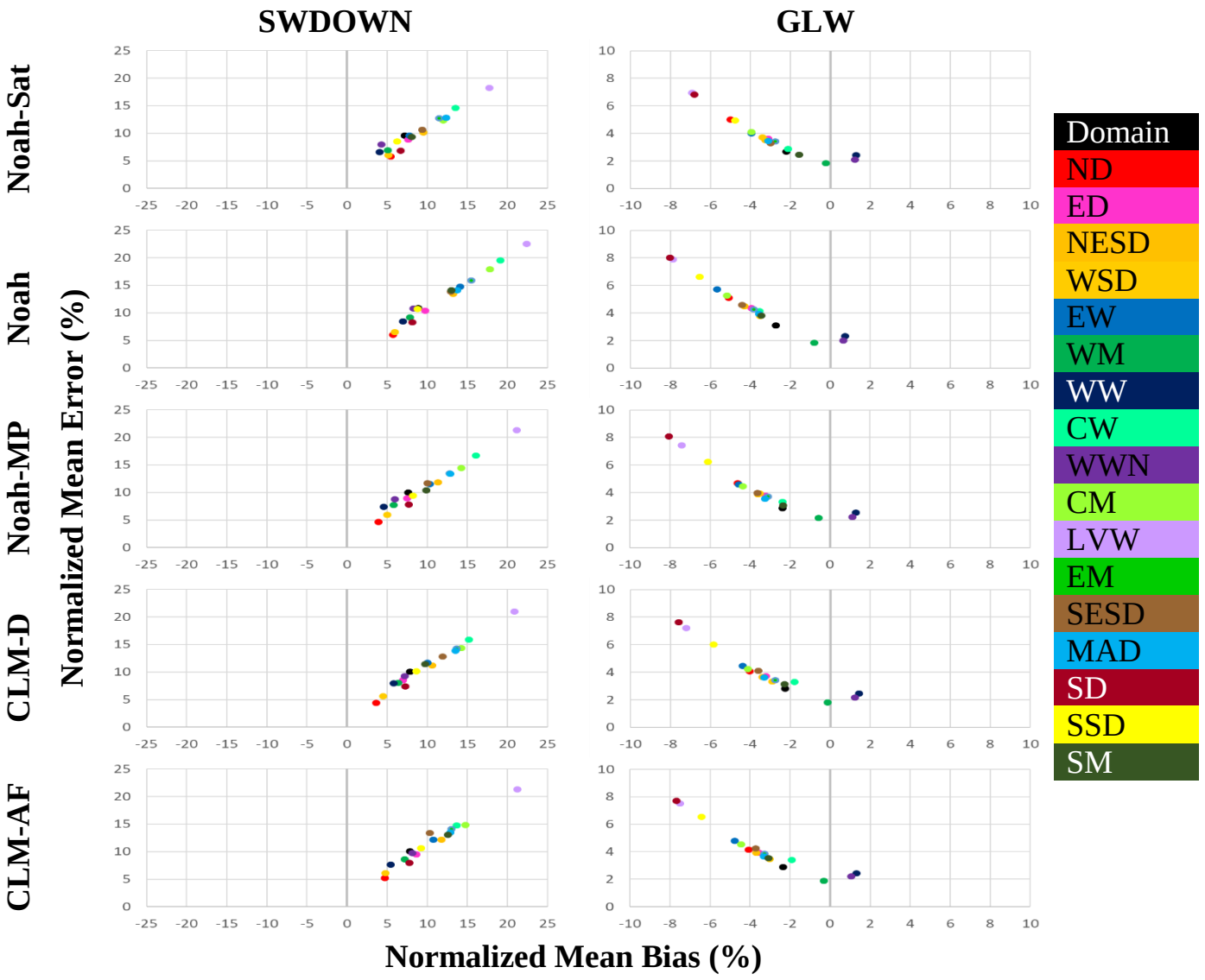

Fig S5: Soccer plot of domain and regional WRF SWDOWN and GLW model performance statistics verses CERES-EBAF estimates

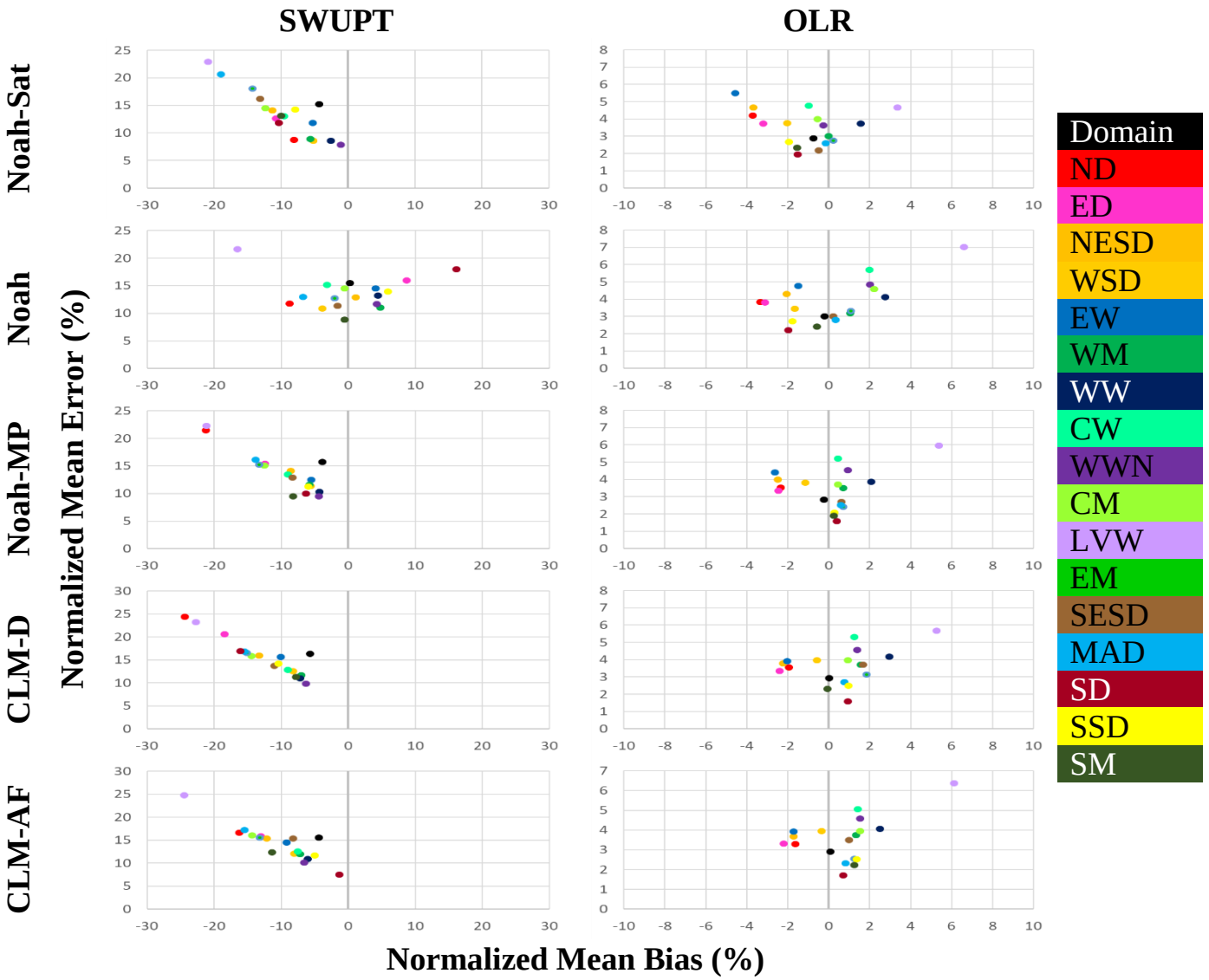

Fig S6: Soccer plot of domain and regional WRF SWUPT and OLR model performance statistics verses CERES-EBAF estimates

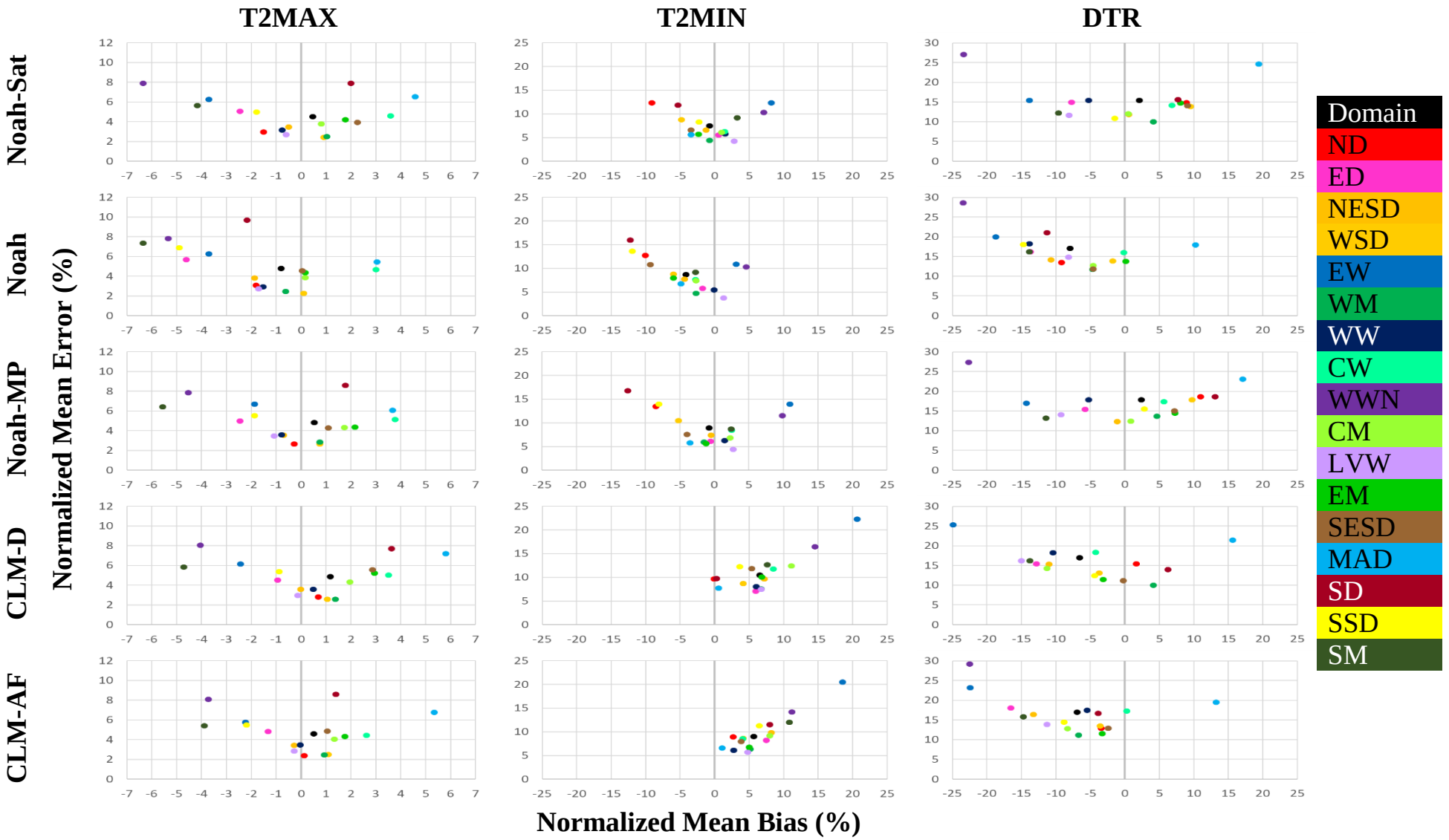

Fig S7. Soccer plots of domain and regional WRF annual average daily maximum 2-m temperature, daily minimum 2-m temperature, and diurnal temperature range compared to CRU estimates from the five WRF LSM configuration

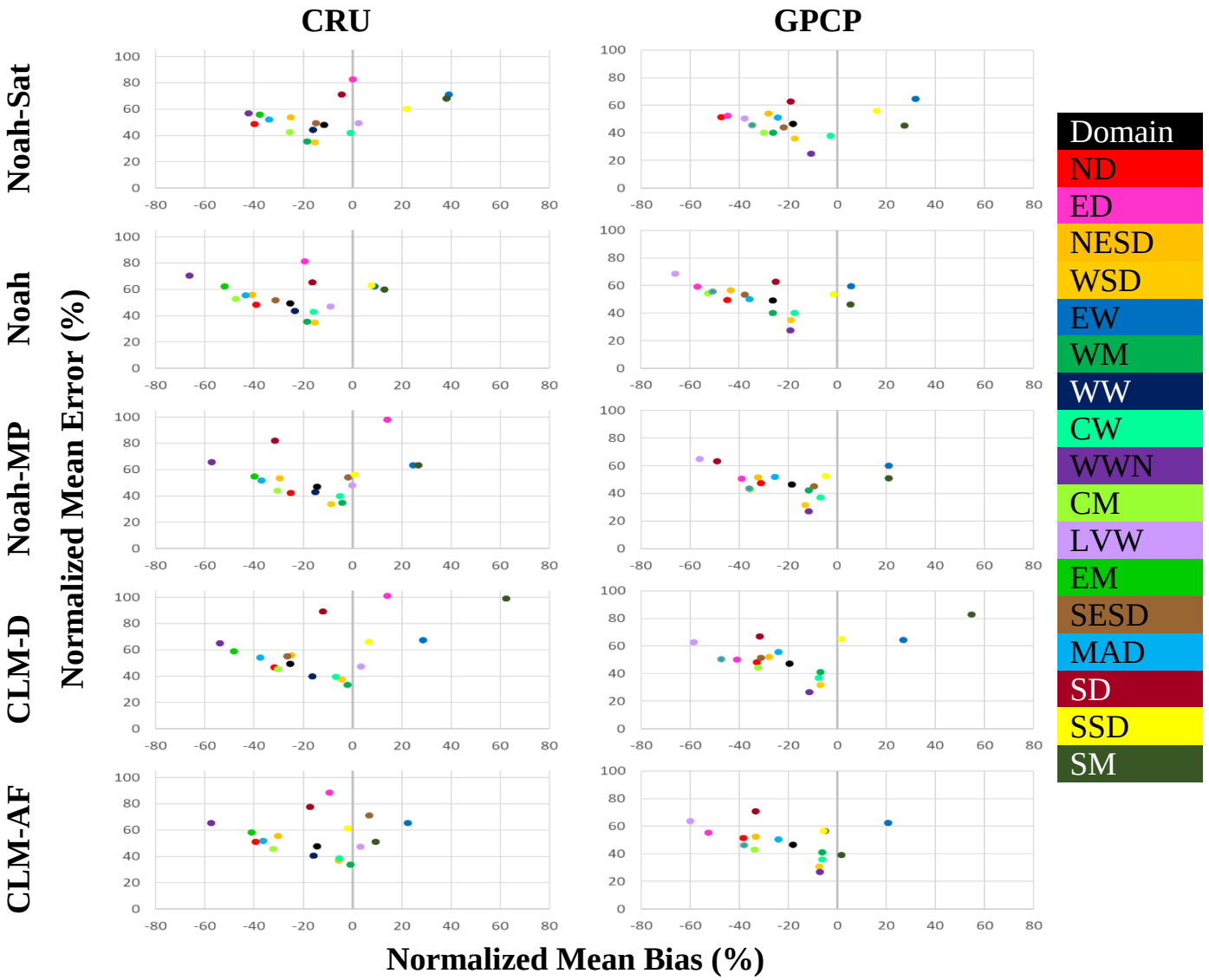

Fig S8: Soccer plot of domain and regional WRF precipitation model performance statistics verses CRU and GPCP estimates

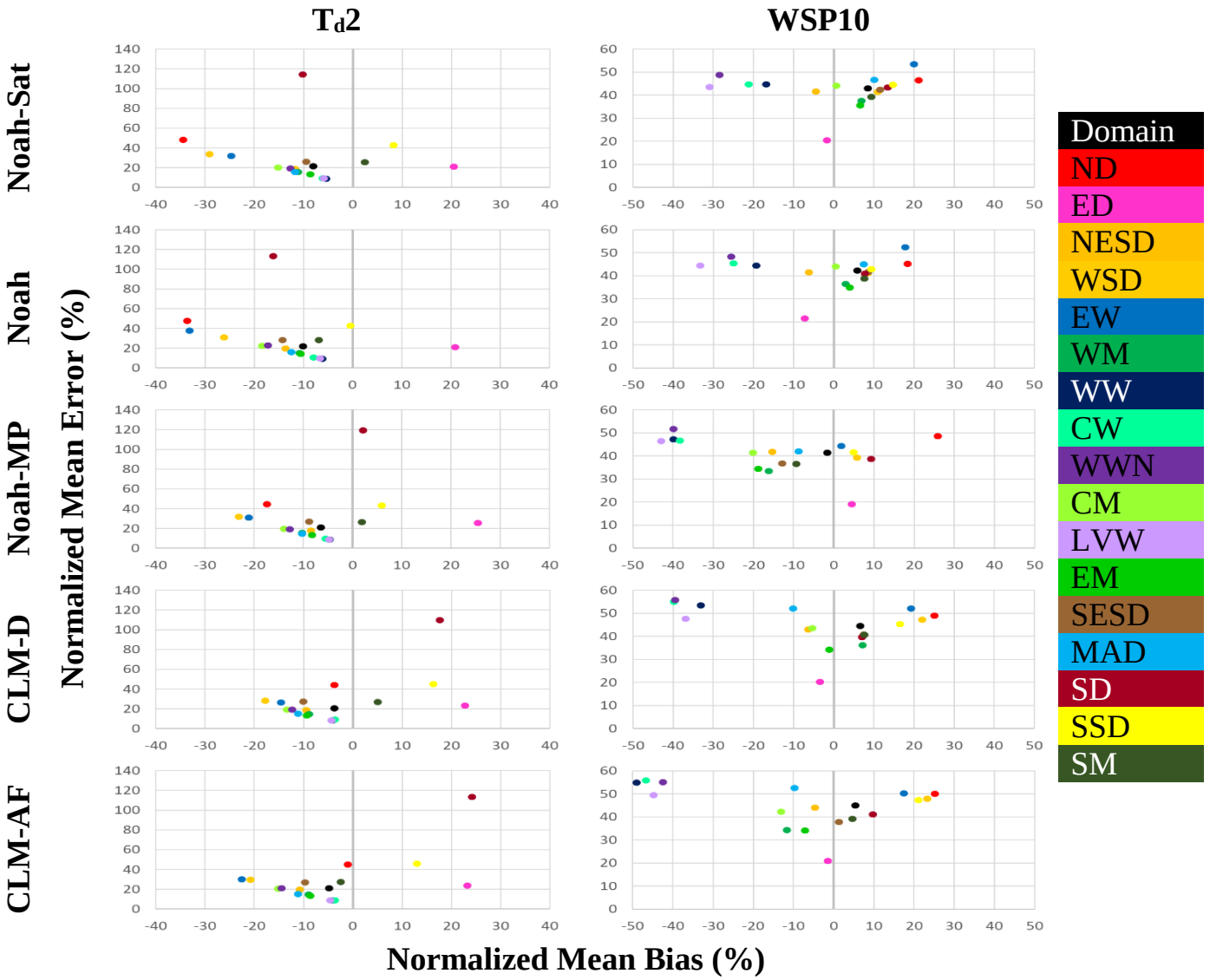

Fig S9: Soccer plot of domain and regional precipitation model performance statistics of WRF 2-m dew point temperature and 10-m wind speed verses NCDC-ISD observations

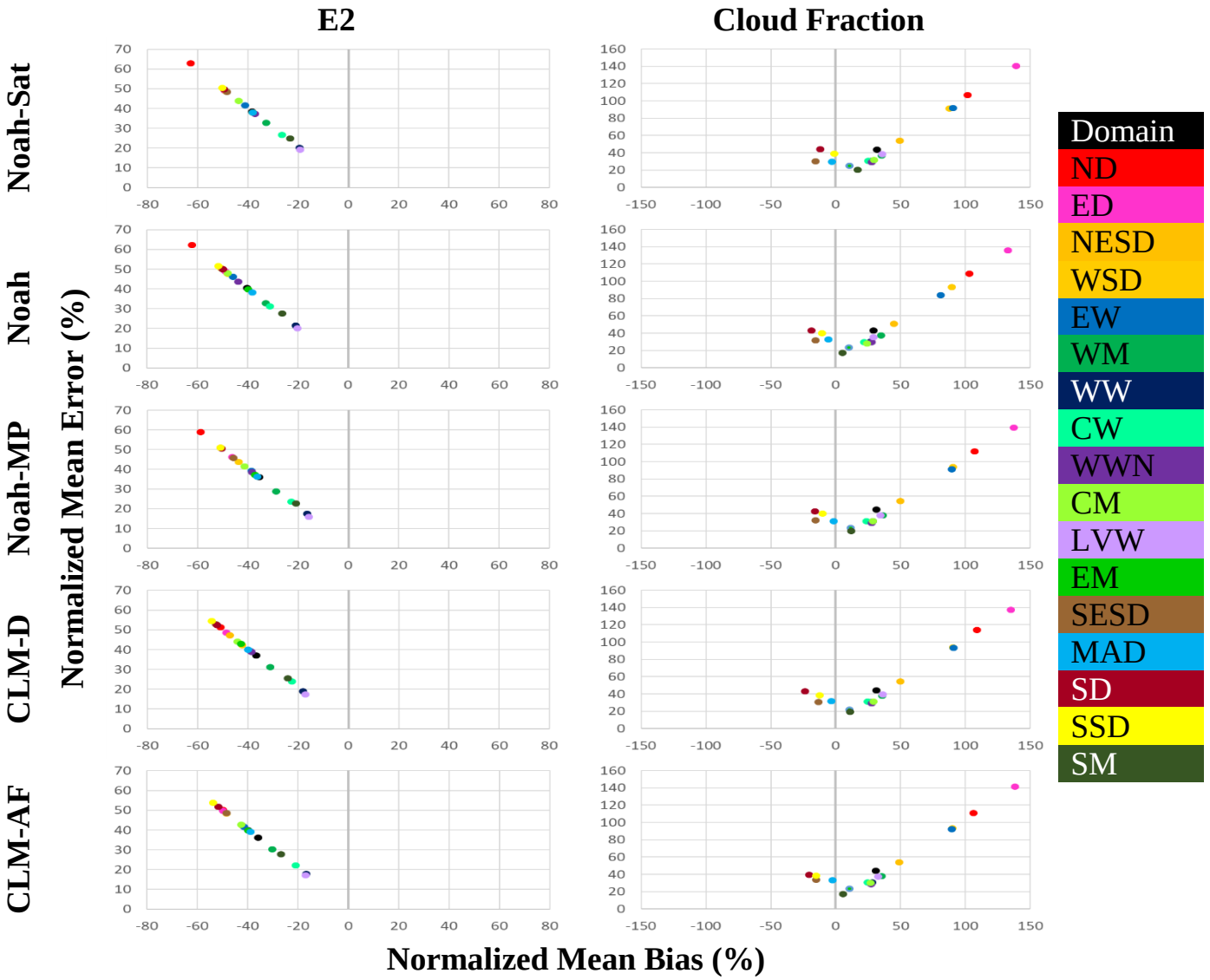

Fig S10: Soccer plot of domain and regional precipitation model performance statistics of WRF 2-m vapor pressure and cloud fraction speed verses CRU estimates

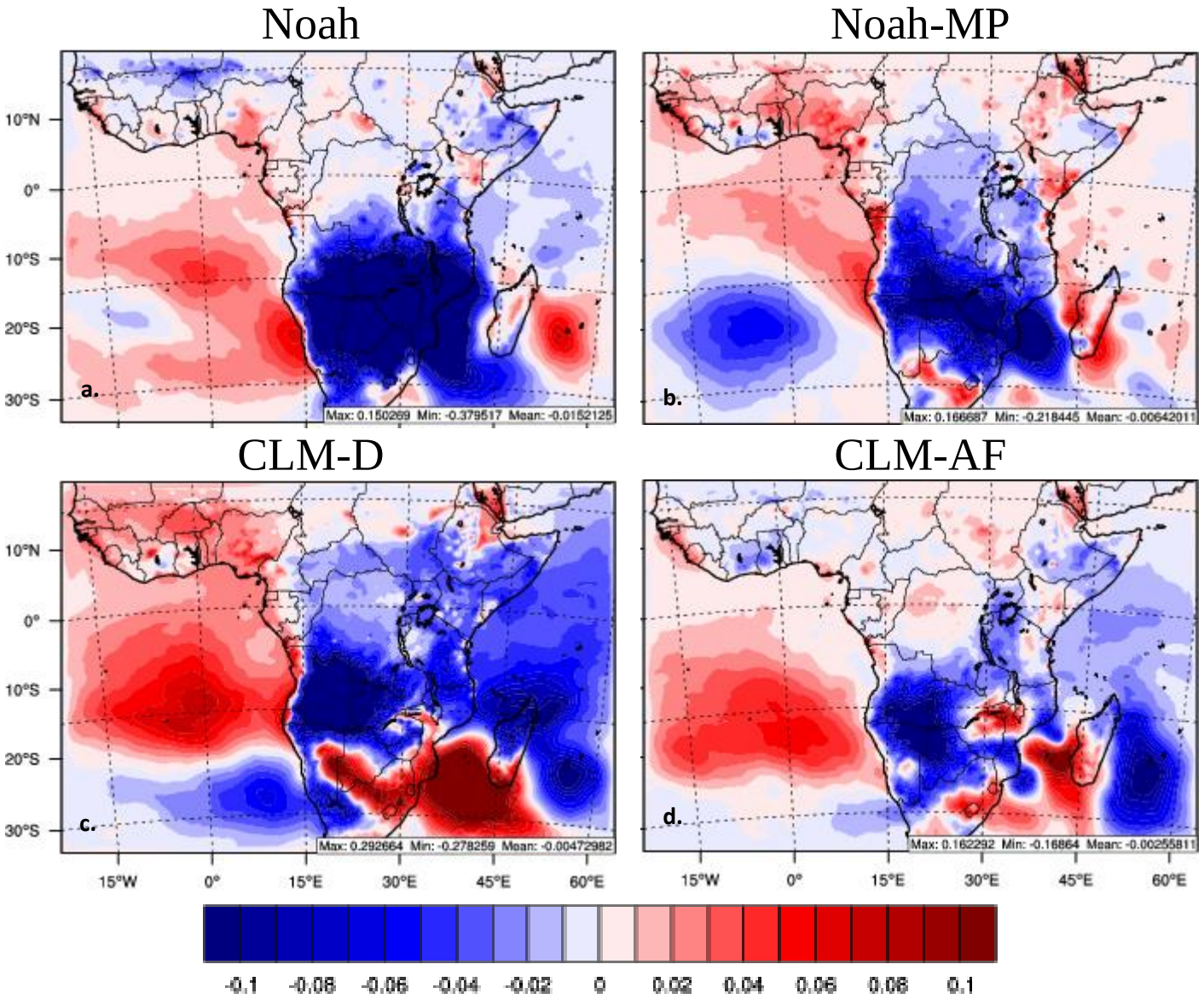

Fig S11. Differences in average JFD sea level pressure (hPa) between the dynamic and 2001 LULC simulations using (a) Noah, (b) Noah-MP, (c) CLM-D, and (d) CLM-AF

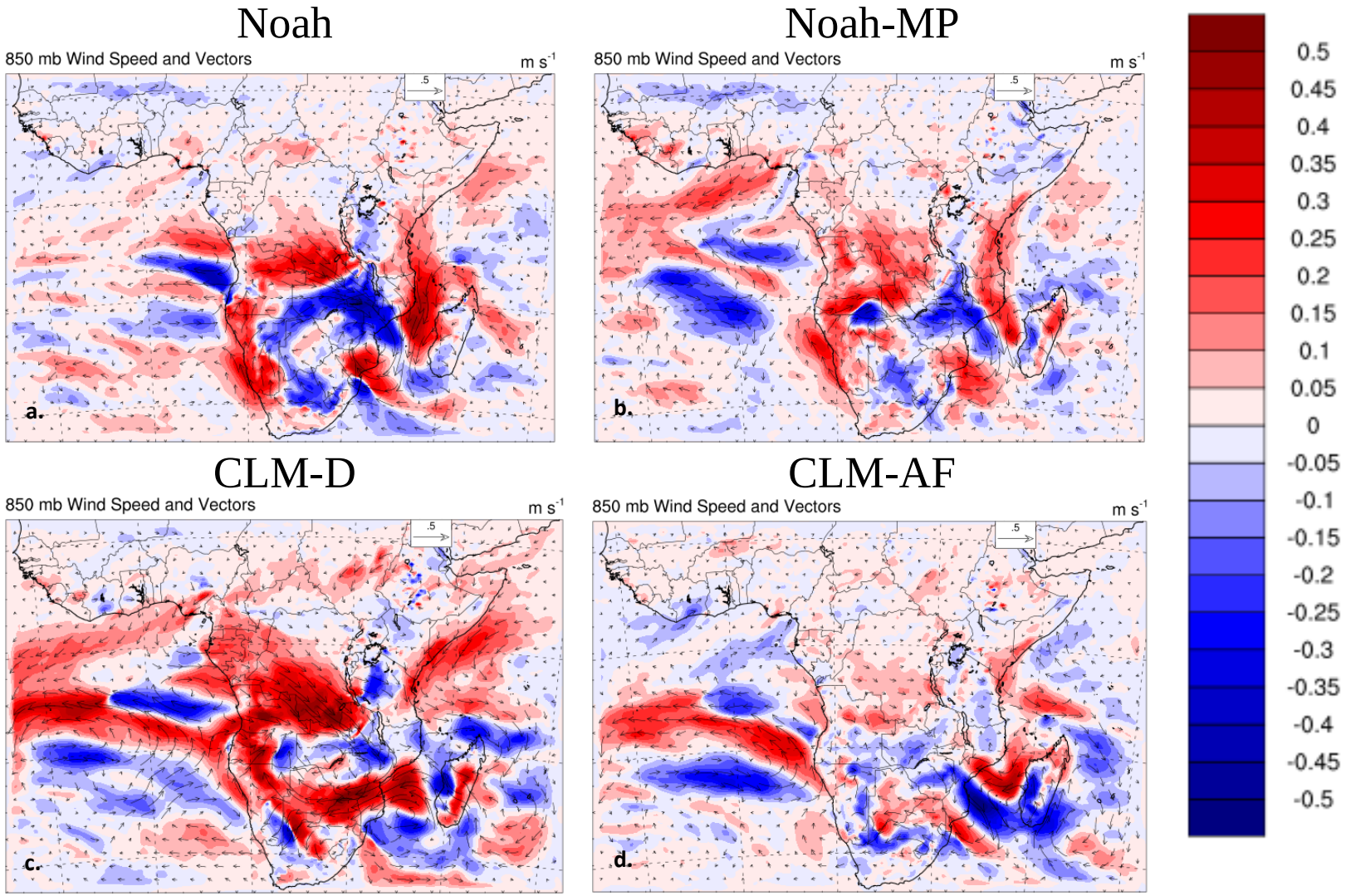

Fig S12. Differences in average JFD 850 mb wind vectors and wind speed (m s^{-1}) between the dynamic and 2001 LULC simulations using (a) Noah, (b) Noah-MP, (c) CLM-D, and (d) CLM-AF