

S1 - Supplementary Material

This document summarizes all Supplementary Material for Kiang *et al.* (2026), "Ent Köppen-Geiger v1.0, a software tool for generating Earth System Model global vegetation boundary conditions for alternative climates."

Supplementary Material files are numbered with "S#". This document is numbered "S1". Tables and figures in this document that summarize the contents of these files as well as plots provided in this file are numbered with "SM#".

General shorthand for referring to the vegetation boundary condition variables (VBCs) is:

lc=land cover fraction, height=canopy height, laimax=annual maximum LAI, and lai=monthly LAI

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1 Supplementary Material I - Details of the Ent Köppen-Geiger Lookup Table v1.0

This section lists files that provide detailed plots and tables of all vegetation boundary condition (VBC) values. The Köppen-Geiger biome classes are as listed in the Appendix in Table A1. The Ent plant functional types (PFTs) are listed in Table SM 1, below. The Ent PFTs list some types that are not represented in the current Ent Global Vegetation Structure dataset v1.0: early vs. late successional types are not distinguished, so the evergreen broadleaf tree, evergreen needleleaf tree, and cold deciduous broadleaf tree types are all lumped into the "late successional" PFT bin, and there is zero cover for the "early successional" types; the Ent GVSD v1.0 also does not distinguish different crop types, so all crops are represented as a C3 grass, and the cover fraction for crops broadleaf woody is zero. There are two purely bare soil cover types to represent bare soil albedo only, "bare soil bright" with a shortwave albedo of 0.5 and "bare soil dark" with a shortwave albedo of 0.0. These two types are a legacy of how land surface albedos were assigned in the early NASA GISS GCM (Hansen et al., 1983; Matthews, 1983, 1984), in which bare soil albedo was a cover-weighted average of the bright and dark fractions, and these soil types are unrelated to specification of soil texture.

Table SM 1. Ent Terrestrial Biosphere Model plant functional types and bare soil albedo types.

Ent PFT	netcdf name label in plots	Notes
evergreen broadleaf early successional	ever br early	early successional not used
evergreen broadleaf late successional	ever br late	
evergreen needleleaf early successional	ever nd early	early successional not used
evergreen needleleaf late successional	ever nd late	
cold deciduous broadleaf early successional	cold br early	early successional not used
cold deciduous broadleaf late successional	cold br late	
drought deciduous broadleaf	drought_br	

deciduous needleleaf	decid nd	
cold adapted shrub	cold shrub	
arid adapted shrub	arid shrub	
C3 grass perennial	c3 grass per	
C4 grass	c4 grass	
C3 grass - annual	c3 grass ann	
arctic C3 grass	c3 grass arct	
crops herb (C3)	crops herb	
crops broadleaf woody	crops woody	not used
bare soil bright	bare bright	
bare soil dark	bare dark	

35 1.1 Histograms of observed vegetation boundary condition (VBC) values by biome and cover type, with kernel density estimation (KDE) fits

40 The following files are PDF files that plot the observationally-derived vegetation boundary condition (VBC) values by biome and cover type, with kernel density estimation (KDE) fits. Each file has 1-2 pages each for each biome type, with plots by Ent cover types. The hashtag "fc9fd9b" was generated from the particular call of the scripts to identify the "EntKGLUT" default published lookup table.

45 **S2_Figures_biomes-pft_lc_bs_histogram_EntKGLUT_HXH_fc9fd9b.pdf:** Histograms of observed land cover fraction by Köppen-Geiger biome and Ent cover type (plant functional types, PFTs, and bare soil albedo classes). The LUT value is given in the text box in the plot.

S3_Figures_biomes-pft_hgt_histogram_EntKGLUT_HXH_fc9fd9b.pdf: Histograms of observed canopy heights by Köppen-Geiger biome and Ent PFT, with kernel density estimation (KDE) fits. The LUT value is given in the text box in the plot.

50 **S4_Figures_biomes-pft_laimax_histogram_EntKGLUT_HXH_fc9fd9b.pdf:** Histograms of observed maximum annual leaf area index by Köppen-Geiger biome and Ent PFT, with kernel density estimation (KDE) fits. The LUT value is given in the text box in the plot.

55 **S5_Figures_biomes-pft_lai_monthly_regression_raw_EntKGLUT_HXH_fc9fd9b.pdf:** Plots of regressions of monthly leaf area index by Köppen-Geiger biome and Ent cover type, raw values with means and standard deviation envelopes. The maximum annual LAI (LAI_{max}) obtained from S3 is overlaid for comparison. The number pixels for each regression line is provided for the Northern and Southern hemispheres (NH, SH).

60 **S6_Figures_biomes-pft_lai_monthly_EntKGLUT_HXH_fc9fd9b.pdf:** Plots of final values of monthly leaf area index by Köppen-Geiger biome and Ent cover type for the EntKGLUT default lookup table. Values are weighted by cover fraction, with Northern and Southern Hemispheres distinct, except with biome Af attributed only one seasonality.

65 **S7_Tables_EntKGLUT_lc.xlsx:** Ent KGLUT tables of land cover fractions, canopy heights, and annual maximum leaf area index by PFT and KG biome. These are the values in the netcdf file EntKGLUT_HXH_fc9fd9b-2025-05-29_default.nc, in the Supplementary Material for Code and Data, below.

2 **Supplementary Material II - Codes and Data**

All Supplementary Material in this section are made available on zenodo.org [path to be provided upon publication]. All data input files downloadable from NASA Center for Climate Simulation (NCCS) data portal, URL paths provided below.

70 **S8_ent_kglut_codes.tar.gz:** gzip file of repository scripts and data files for the "EntKGLUT" tool. Snapshot of code on Zenodo.com. Repository on github.com: ent-tbm/ent_kglut

Table SM 2. Contents of gzip file S8_ent_kglut_codes.tar.gz.

Subdirectory	Description
	Scripts for KDE analyses and plots
ent_kglut-0017864.tar.gz ent_kglut_modelE/	All R and python scripts for Köppen-Geiger classification
ent_kglut_modelE/Rfiles/	R scripts for utilities and Köppen-Geiger classification
ent_kglut_modelE/kglut_modelE	R and python scripts and sample configuration files for: generating the EntKGLUT; applying it to other climates to generate vegetation boundary condition files; cpt tables for color schemes for visualization of Köppen-Geiger classification and Ent cover types. Includes: - KGbiomes_720x360_fc9fd9b-2025-05-29.nc: netcdf file of Köppen-Geiger biomes for 2001-2009 climatology. - EntKGLUT_HXH_fc9fd9b-2025-05-29_default.nc : netcdf file of default Ent Köppen-Geiger Lookup Table (EntKGLUT). - README files on how to run the scripts.

75 **S9:** Data input files. Input 0.5°.x0.5° Ent Global Vegetation Structure Dataset v1.0 and climate data files for generating the EntKGLUT. These files are held in the URL paths given in Table SM 3; all files are posted in two locations, the NASA Center for Climate Simulation (NCCS) data portal and Zenodo.com.

80 **Table SM 3. Netcdf data files in S9 Data input files. ts=surface temperature, prec=precipitation, lc=land cover fraction, height=canopy height, laimax=maximum annual LAI, lai=monthly LAI.**

0.5° x 0.5° files fetched by script data_get_HXH.sh: NASA Center for Climate Simulation (NCCS) data portal: https://portal.nccs.nasa.gov/datashare/GISS/Ent_TBM/Ent_utils/kglut_modelE/data/HXH Zenodo.com	
Climate observations at 0.5° x 0.5° used to generate the EntKGLUT	ts="cru_ts3.22_TS_means_2001-2010_HXH.nc"
	prec="GPCC_v6_PREC_means_2001-2010_HXH.nc"
Ent Global Vegetation Structure Dataset v1.0 files at	lc="V720x360_EntGVSD16_MM_lc_max_trimmed_scaled_v1.0b.nc"
	height="V720x360_EntGVSD16_MM_height_trimmed_scaled_v1.0b.nc"
	laimax="V720x360_EntGVSD16_MM_lai_max_trimmed_scaled_v1.0b.nc"

0.5° x 0.5° used to generate the EntKGLUT	lai="V720x360_EntGVSD16_MM_lai_trimmed_scaled_v1.0b.nc"
2.5° x 2.0° files fetched by script data_get_2HX2.sh: NASA Center for Climate Simulation (NCCS) data portal: https://portal.nccs.nasa.gov/datashare/GISS/Ent_TBM/Ent_utils/kglut_modelE/data/2HX2 Zenodo.com:	
Climate observations at 2.5° x 2.0° used to evaluate ModelE simulated climate	ts="cru_ts3.22_TS_means_2001-2010_2HX2.nc"
	prec="GPCC_v6_PREC_means_2001-2010_2HX2.nc"
Ent Global Vegetation Structure Dataset v1.0 files at 2.5° x 2.0° used to evaluate the EntKGLUT-generated VBCs	V144x90_EntGVSD_v1.0_MM16_lc_max_trimmed_scaled.nc
	V144x90_EntGVSD_v1.0_MM16_height_trimmed_scaled.nc
	V144x90_EntGVSD_v1.0_MM16_lai_max_trimmed_scaled.nc
	V144x90_EntGVSD_v1.0_MM16_lai_trimmed_scaled.nc
2.5° x 2.0° VBC input files used in ModelE experiment "E0". Available from NASA GISS CMIP6 input files in two places: https://portal.nccs.nasa.gov/GISS_modelE/modelE_input_data/ https://portal.nccs.nasa.gov/datashare/GISS/Ent_TBM/EntGVSD/entgvsd_v1/entgvsd_v1.0/2HX2/modelE_CMIP6/	
Ent Global Vegetation Structure Dataset v1.0 "extended" files at 2.5° x 2.0° used to conduct ModelE control experiment "E0" (standard files for ModelE CMIP6 experiments)	V144x90_EntMM16_lc_max_trimmed_scaled_nocrops.ext.nc
	V144x90_EntMM16_height_trimmed_scaled_ext.nc
	V144x90_EntMM16_lai_max_trimmed_scaled_ext.nc
	V144x90_EntMM16_lai_trimmed_scaled_ext.nc
2.5° x 2.0° historical crop cover ModelE input file used in experiment "E0". https://portal.nccs.nasa.gov/datashare/GISS/Ent_TBM/EntGVSD/entgvsd_v1/entgvsd_v1.0/2HX2/modelE_CMIP6/	
Historical crop cover ModelE input file at 2.5° x 2.0°	CROPS+PASTURE_LUH-GCB_historical_2HX2_850-2020_ext.nc

3 Supplementary Material III - Study Results

Generated codes and diagnostics from the study are provided here. All Supplementary Material in this section are made available on zenodo.org [path to be provided upon publication].

- 85 **S10_kglut_fc9fd9b_2025-06-05.tar.gz:** Results for output vegetation boundary condition (VBCs) files (netcdf files) for simulations in this study. Contents are summarized in Table SM 4.

90 **Table SM 4. Contents of S10_kglut_fc9fd9b_2025-06-05.tar.gz containing Köppen-Geiger predictions in this study. Each subdirectory includes the configuration file for running the Ent KGLUT scripts, intermediate generated scripts and outputs, and map plots of Köppen-Geiger biomes and of land cover-weighted VBCs. Hash tag "fc9fd9b" is a unique identifier for the EntKGLUT v1.0 default lookup table.**

Subdirectory	Description
EntKGLUTv1.0/	Default EntKGLUT v1.0 from Modern (2001-2009) climate data: EntKGLUT HXH fc9fd9b-2025-05-29 default.nc. Includes:

	configuration file; generated python and R scripts; map plot and netcdf file of the generated Köppen-Geiger biome classification from 0.5° x 0.5° climate data; intermediate CSV files of the VBC monthly raw regression results; CSV file of final cover fraction table after rules to trim off tiny fractions and round to two decimal places; netcdf file of final EntKGLUTv1.0; time plots of monthly LAI in the LUT.
ModernRepHXXH_KGLUTv1.0/	Reproduction of VBCs at 0.5°x0.5°, from applying the EntKGLUT v1.0 observed climate data for 2001-2010.
ModernRep_KGLUTv1.0/	Reproduction of modern natural-only VBCs at 2.5°x2.0°, from applying the EntKGLUT v1.0 observed climate data for 2001-2010.
ModernRep_fc9fd9b_2025-06-05cr_ext/	Modern (2004) VBCs at 2.5°x2.0°, from scaling in MODIS 2004 cropland cover fractions, heights, LAI max, and monthly LAI, and "extending" ModernRep_KGLUTv1.0 across coastlines.
Cretaceous85Mya_0bare/	Estimated Cretaceous VBCs at 4° x 5°, from applying the default EntKGLUT v1.0 to a bare soil ROCKE-3D simulated climatology and replacing modern vegetation with time-relevant types.
Cretaceous85Mya_1veg/	Estimated Cretaceous VBCs at 4° x 5°, from prescribing VBCs generated from climatology of Cretaceous85Mya_0bare (above), asynchronously re-equilibrating climate, applying the default EntKGLUT v1.0 to the updated climatology and replacing predicted modern vegetation with time-relevant types.

95 **S11_ModelE_code_rundecks.tar.gz:** ModelE code, rundecks for experiments E0, E1. Contains modelE2.1_86g.tar.gz (code date April 3, 2018, same as used for the Coupled Model Intercomparison Project 6 (CMIP6). Also contains modelE2.1_86g_AIC.tar.gz, restart files from preindustrial soil carbon spinups for initial conditions for E0 and E1. For details about running ModelE, see documentation at the NASA GISS website at: <https://www.giss.nasa.gov/tools/modelE/>

100 **S12_ROCKE-3D_code_rundecks.tar.gz:** ROCKE-3D planet 2.0 code, and rundeck for Cretaceous_0bare experiment. The Cretaceous_1veg experiment uses the same rundeck, continuing the run after updating the VBC input files. The user edits a generated configuration file (the "I" file) to change the VBCs (input files VEG, HITEent, LAImax, LAI) to the *_paleo.nc files generated in S10_kglut_fc9fd9b_2026-07-14/Cretaceous85Mya_0bare, edits the run parameter YEARE to extend the last year of the run, and then continues the run with these new VBCs.

105 **S13_ModelE_ROCKE3D_diags.tar.gz:** Output ModelE diagnostics files for experiments E0, E1, and for the ROCKE-3D -simulated Cretaceous85Mya_0bare soil and Cretaceous85Mya_1veg climatologies. Output diagnostics files for ROCKE-3D Cretaceous climatology. Contents are described in Table SM 5.

110 **Table SM 5. Contents of S13_ModelE_ROCKE3D_runs.tar.gz. Output ModelE diagnostics files for experiments E0, E1, and for the ROCKE-3D -simulated Cretaceous 85 Mya bare soil climatology**

File or Folder Name	Item
rsfjl_E151F40t1C.tar.gz	Initial conditions file for experiments E0 and E1 preindustrial spinups.
Modern_2000-2009_jl_E151F40t1C_CTLsst	Experiment E0, Control run, netcdf files of ModelE diagnostics
Modern_2000-2009_jl_E151F40t1C_KTLsst	Experiment E1, Köppen-Geiger reproduced modern VBCs, netcdf files of ModelE diagnostics

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Cretaceous_0bare_3506-3516_P2SAoM40_Phan85Ma1500_2	Experiment Cretaceous85Mya_0bare climatology, netcdf files of ROCKE-3D planet 2.0 diagnostics
Cretaceous_1veg_3861-3870_P2SAoM40_Phan85Ma1500_2_Veg1_O3d	Experiment Cretaceous85Mya_1veg climatology, netcdf files of ROCKE-3D planet 2.0 diagnostics

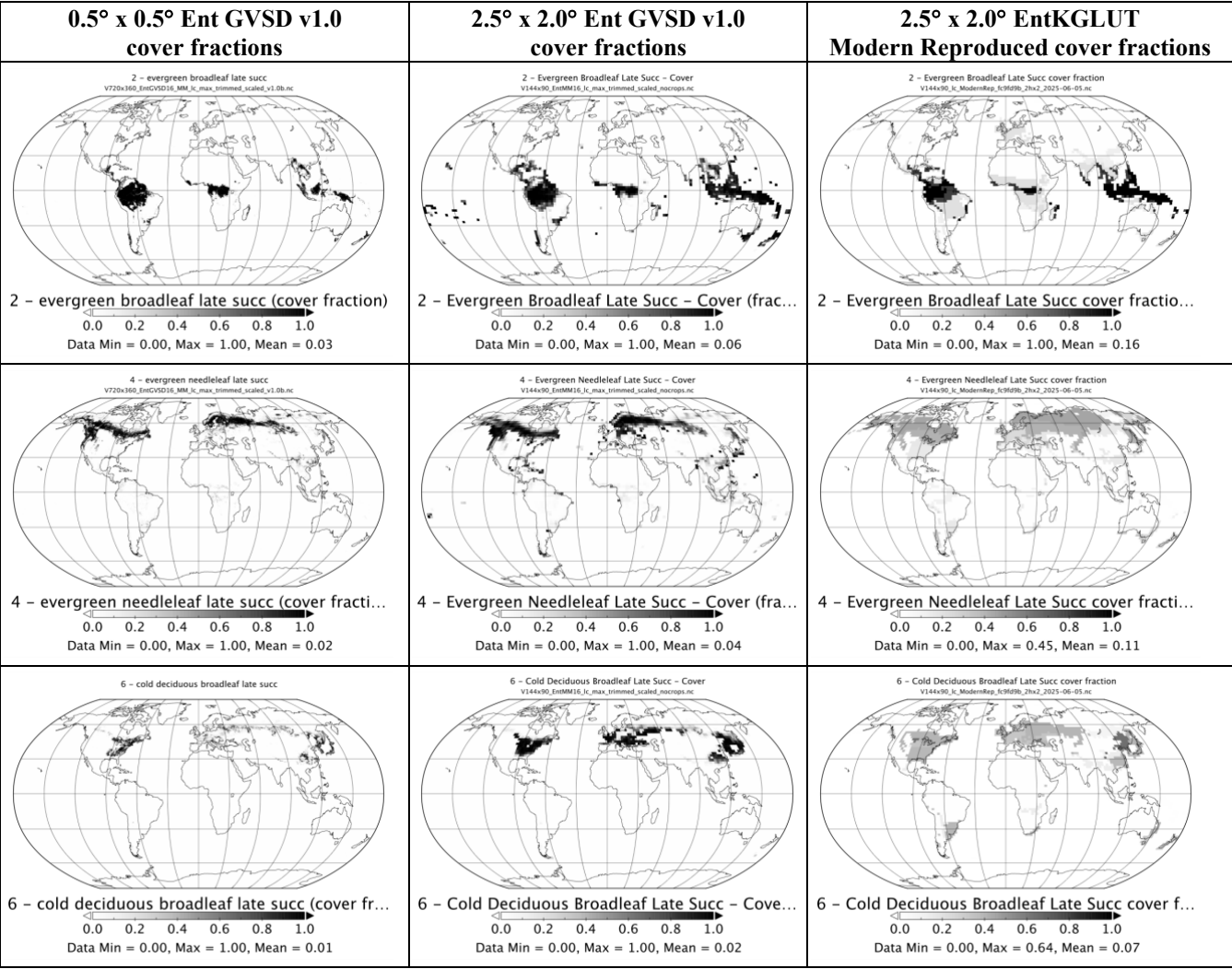
S14_Panoply_plotting.tar.gz: To easily plot maps of the netcdf files, download the application Panoply from www.giss.nasa.gov. This folder contains various useful graphical utility files, as listed in Table SM 6, including *.cpt color tables, land masks, continental outlines for the Cretaceous.

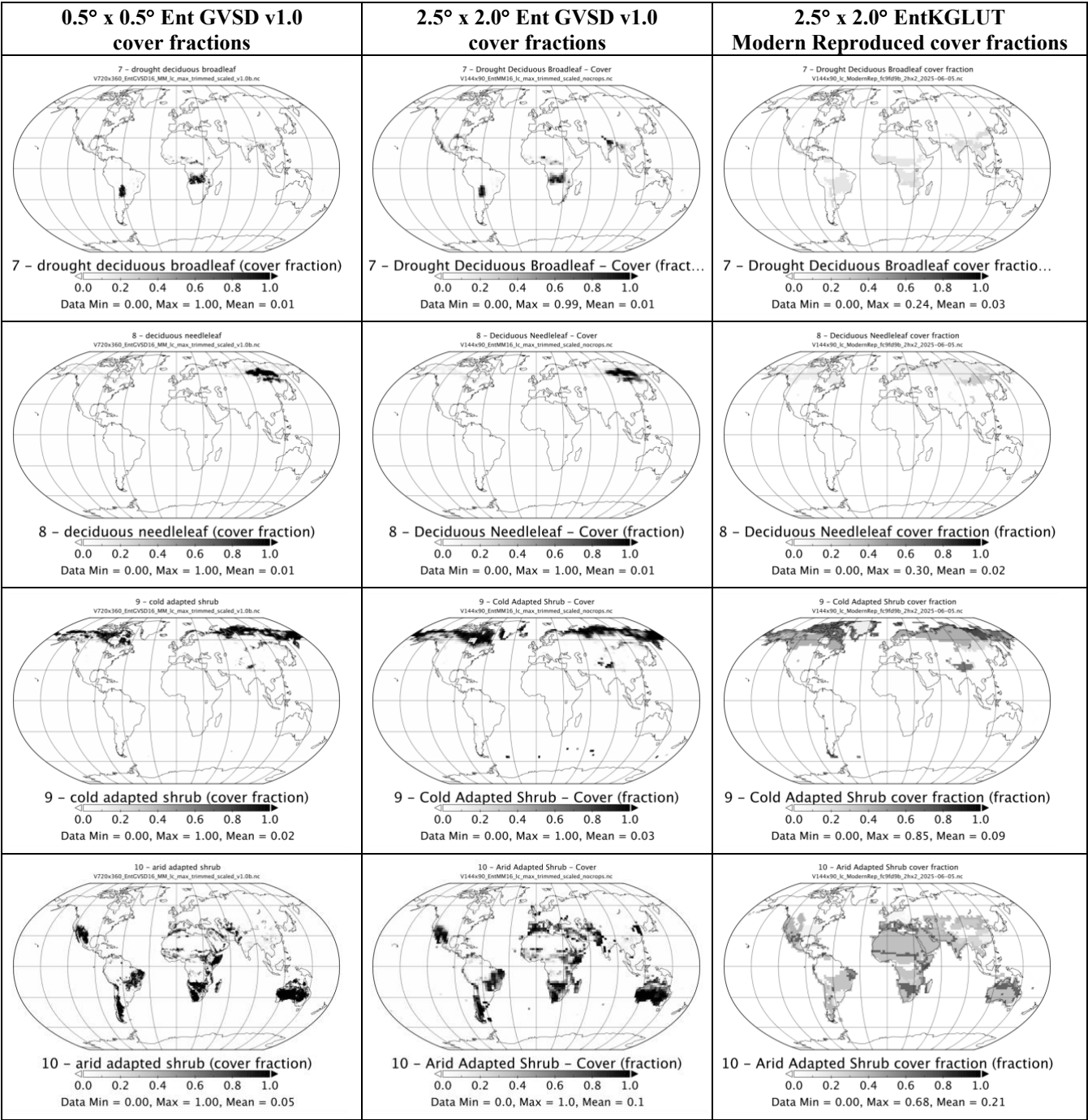
Table SM 6. Contents of S14_Panoply_plotting.tar.gz. Map plotting graphical utilities for use with the Panoply application, downloadable from www.giss.nasa.gov.

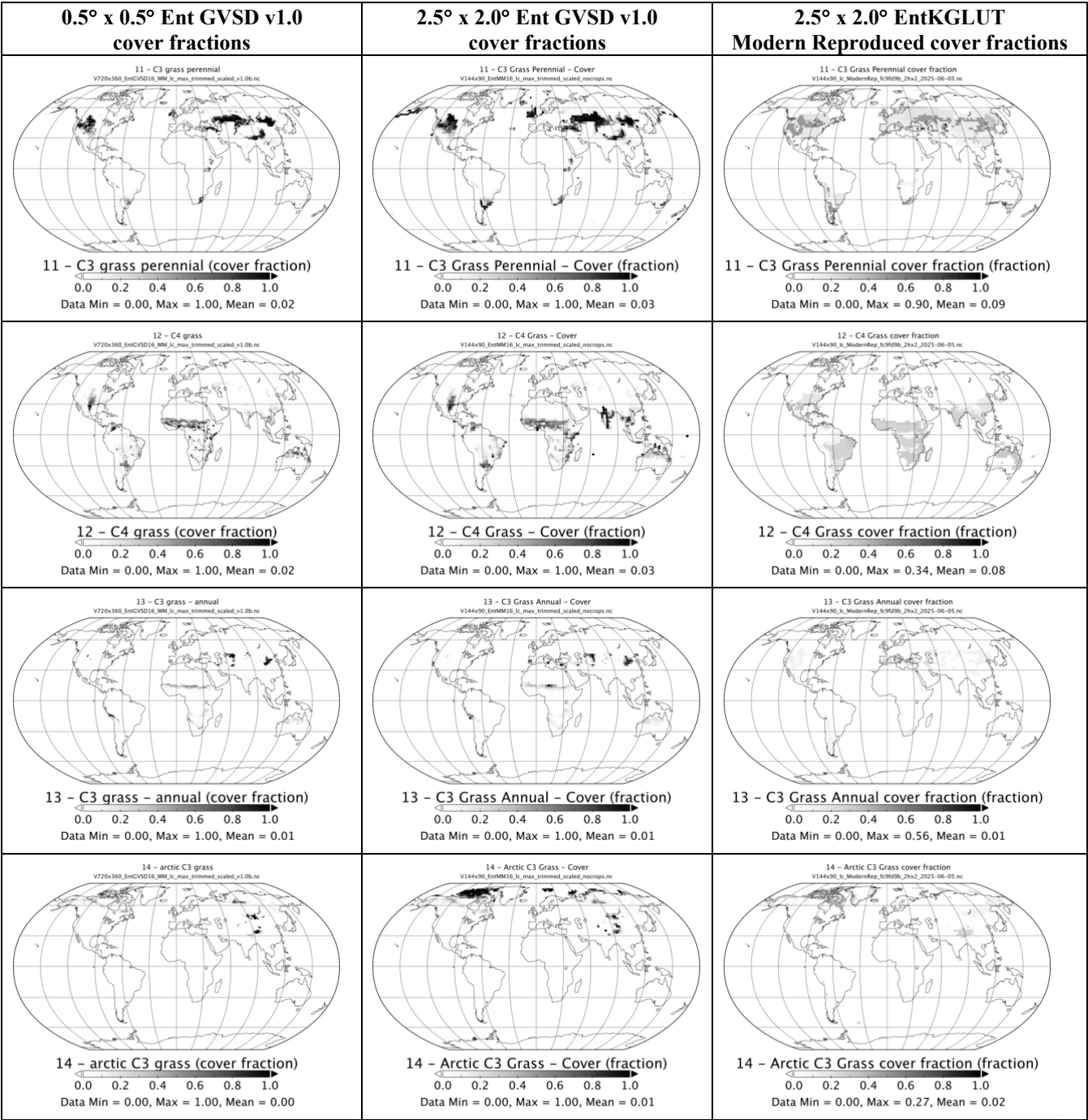
Item	
EntPFTs16_colorbar4.cpt	*.cpt color table for plotting maps of Ent cover types
KoeppenGeiger_colorbar3.cpt	*.cpt color table for plotting maps of Köppen-Geiger classes
Z2HX2fromZ1QX1N.BS1_landmask.nc	Land mask for the Modern Earth
Z4x5_TOPO_Phan85Ma[87]_landmask.nc	Land mask for the Cretaceous
Paleo_85Ma_clean.cno	Continental outline overlay for the Cretaceous 85 Mya

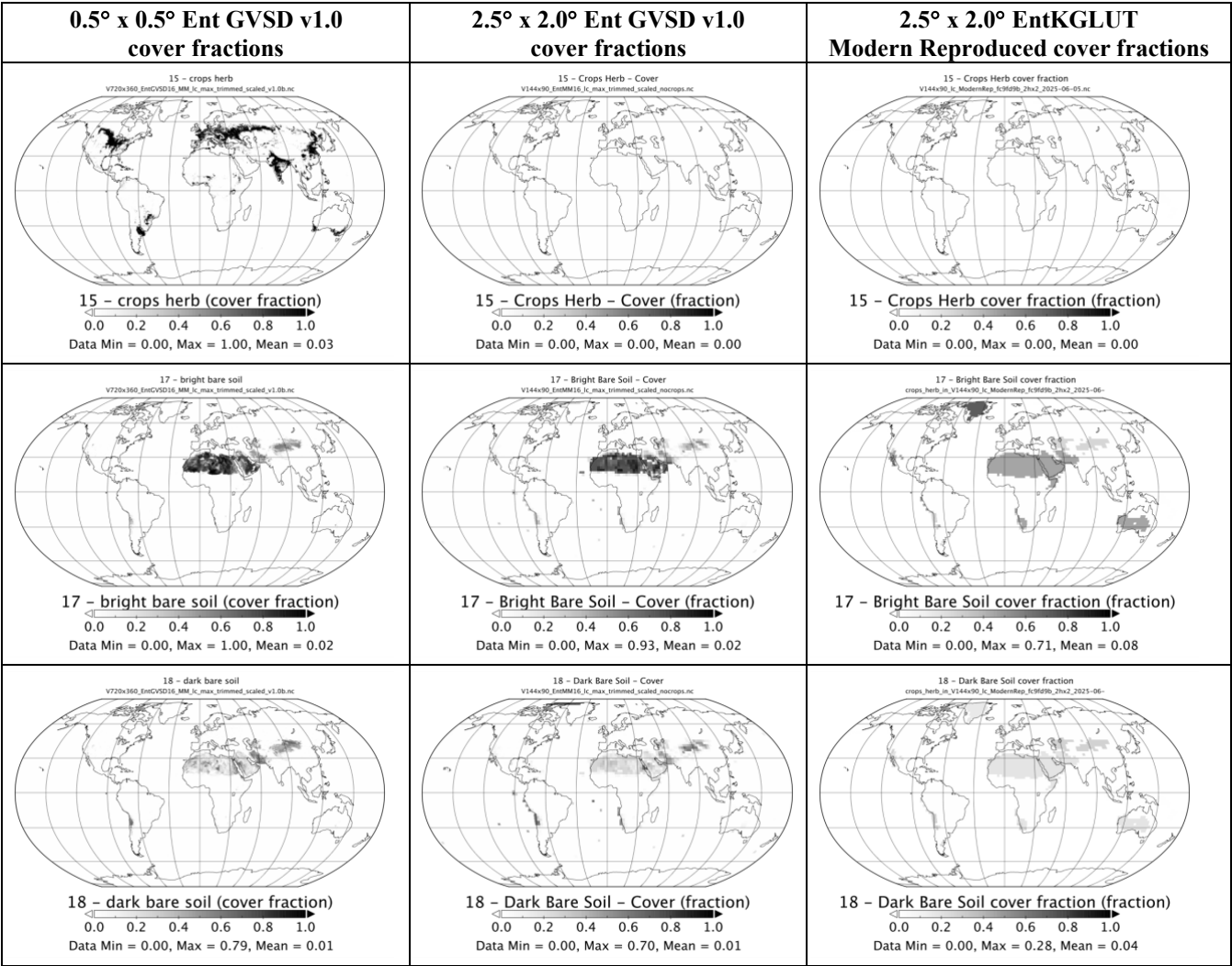
120

Figure SM 1. Subgrid land cover fractions in: (left column) the Ent GVSD v1.0 at 0.5° x 0.5°, used to generate the EntKGLUT, (middle column) the natural vegetation Ent GVSD v1.0 at 2.5° x 2.0°, used in ModelE experiment E0, and (right column) the EntKGLUT-generated natural vegetation values for the Modern climatology of 2001-2009. The following Ent cover types are skipped because early and late successional types are not distinguished or they are not present in the data: 1 - evergreen broadleaf early successional, 3 - evergreen needleleaf early successional, 5 - cold deciduous broadleaf early successional, 16 - crops woody.









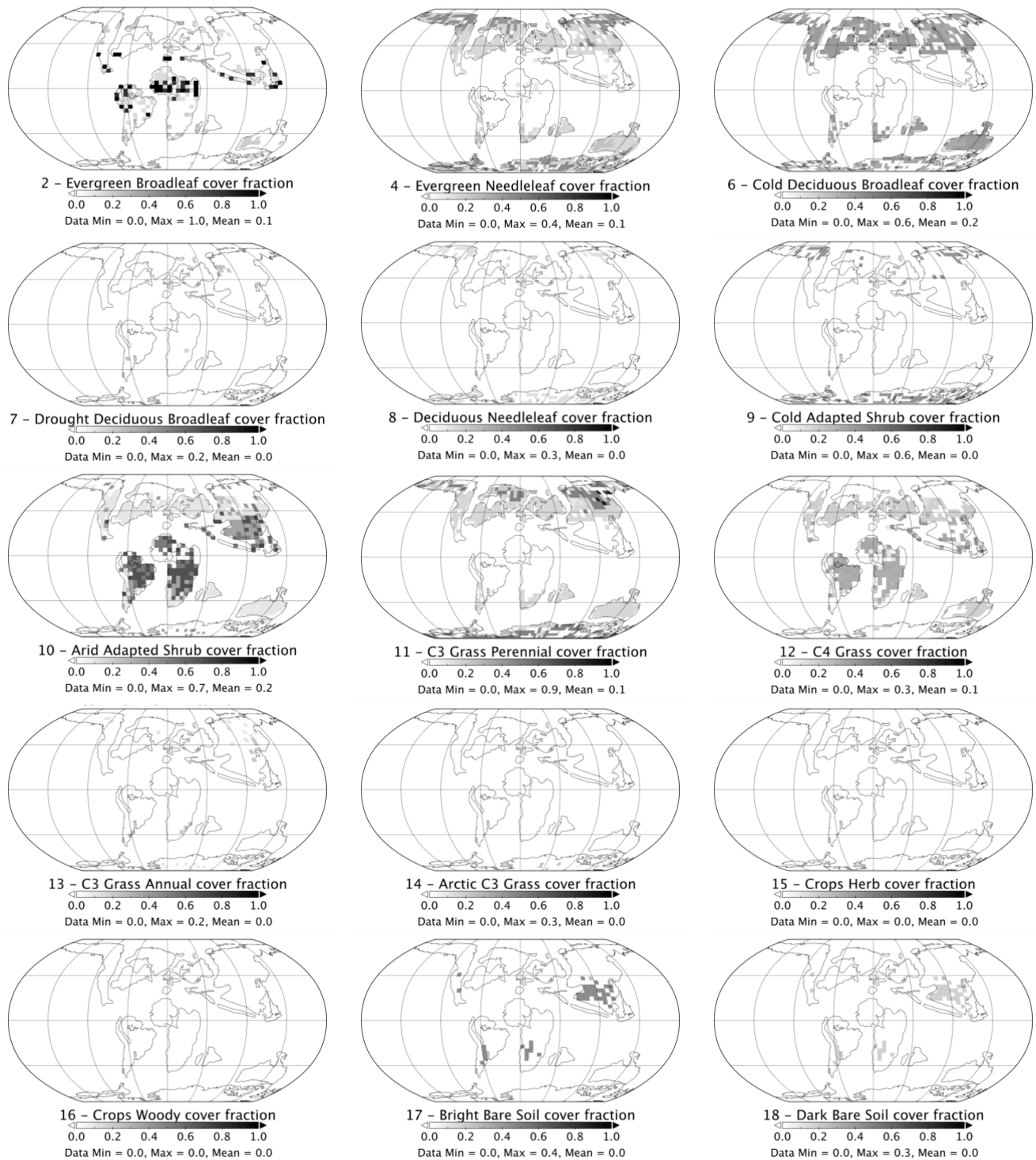
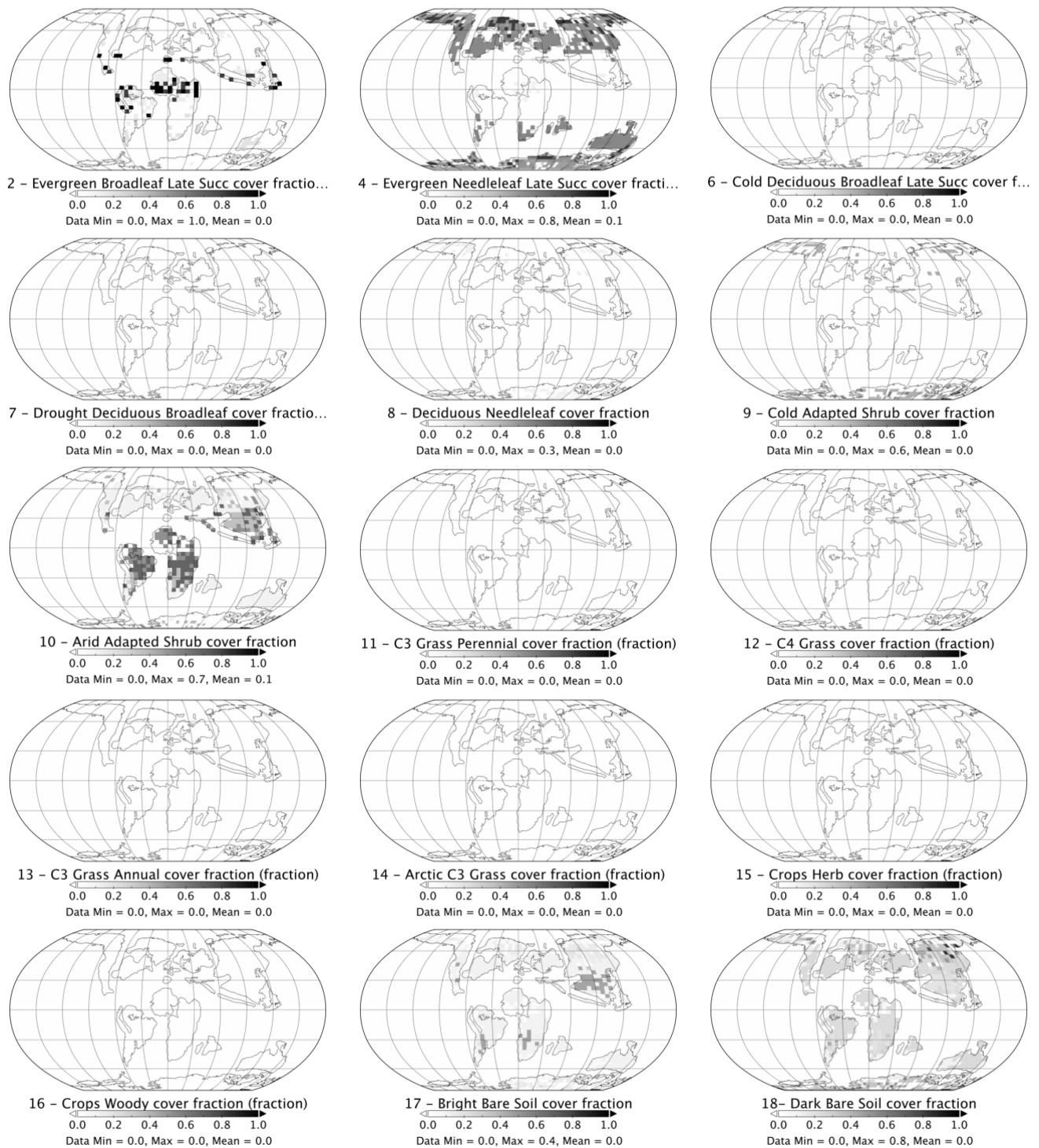


Figure SM 2. Modern vegetation subgrid cover fractions of Ent cover types predicted by the Ent Köppen-Geiger LUT scheme for a Cretaceous climate at 85 Mya with bare soil conditions, simulated with the ROCKE-3D climate model.



135 **Figure SM 3. Paleo-vegetation subgrid cover fractions of Ent cover types predicted by the Ent Köppen-Geiger LUT scheme for a Cretaceous climate at 85 Mya with bare soil conditions, simulated with the ROCKE-3D climate model.**

4 References

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- Matthews, E. (1983). Global vegetation and land use: new high-resolution data bases for climate studies. *Journal of Climate and Applied Meteorology*, 22, 474–487.
- 145 Matthews, E. (1984). Prescription of land-surface boundary conditions in GISS GCM II: A simple method based on fine-resolution data bases [NASA Technical Memo](86096). (NASA Technical Memo, Issue.