Technical documentation of REMO-iMOVE

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REMO-iMOVE v10 - August 2011

Inhaltsverzeichnis

Kapitel 1

Introduction

This document serves the purpose to explain the steps needed before REMO-iMOVE can be run with full functionality. REMO-iMOVE needs some additional data to the standard data REMO needs. REMO-iMOVEs' land surface scheme operates on plant functional types, this information is extracted out of a current satelite land cover retrieval. Further more it needs information about soil types to allocate background albedo parameters.

- First dataset needed is the Globcover 2000 landcover data (GLC2000), on which the plant functional types and the land use information is based.
- Second dataset needed is the Harmonized World Soil Database data on soil types (HWSD) on which the background albedo values are based
- Third dataset is the IPCC AR5 harmonized land use change szenario if you want to run with past land cover change.

The first two datasets in their original form are geographical information system (GIS) readable GEOTIFF files which have been converted to .netcdf using GDAL 1.3.2.0. and NCL.

The GLC2000 raw data are converted globally and accessible on the archive
/hpss/arch/mh0140/m300068/REMO_iMOVE The HWSD data are converted worldwide and also accessible on the archive
/hpss/arch/mh0140/m300068/REMO_iMOVE

Since the performance of REMO-iMOVE was tested for Europe, data for other regions need to be compiled and the model - especially the phenological module - needs to be tested in these regions. For performance issues of the phenological module it is a good advice to ask C. Reick and T. Raddatz from the land department - these are the main developers of JSBACH - which is integrated into REMO.

Kapitel 2

Preprocessing: preparation of GLC2000 and HWSD data for REMO-iMOVE

2.1 Plant functional type information

GLC2000: The raw data are processed (see Appendix), ready to use and available on the archive: /bm0545/m300068/GLC_DATA/GLC2000_global_data.tar

For the simulation region for which the landcover information is needed, the GLC2000 data are needed. Because of the large data amount, GLC2000 data are cut into regions. Select the regions you need and be sure that they cover the whole area the REMO-iMOVE simulation region lays in. The files are named:

GLOBCOVER_200412_200606_V2.2_(REGION_NAME)_Glob_inverted_newgrid.nc

Further things needed are:

- Grid description of target grid
- variable 614 and 615 of target grid in .srv format
- script: remap_GLC_box_by_box_squall_various_GLC_files

Customize the script remap_GLC_box_by_box_squall_various_GLC_files:

- adjust x_end and y_end following the target grid description
- put GLOBCOVER region names into the variable 'GLC_org_data=()' list (you can put all, if you are not sure where your area lies the program searches for the right location)

- put name of target grid to 'grid='
- adjust resolution in 'res='
- rename and create empty service file 'outdata='
- put variable 614 to 'lats='
- put variable 615 to 'lons='
- put variable 172 to 'lsm_data='
- adjust the locations in the script where numbers are cut out of changing textfiles

The information in grid shoud look somthing like that:
#
grid 01
#
gridtype = ...
gridsize = ...
xname = ...
xlongname = ...
xunits = ...
yname = ...
ylongname = ...
yunits = ...
xsize = ...
ysize = ...
xfirst = ...
xinc = ...
yfirst = ...
yinc = ...

All input data need to be '.srv' files 'SERVICE FORMAT'. You can check that by typing 'cdo sinfo FILENAME'. And convert via 'cdo -f srv copy INPUT OUTPUT'.

Please run for only one gridbox, exit the script and check whether the 'cut -c' commands cut out the right information - this can be different from one platform to the other. So it is recommended to check all cursor locations after all 'cut -c' commands.

Then start the script. The procedure will take very long, because for every box of the target grid the GLC2000 data (1km) are processed. If the script stops because squall collapses, you can restart the script, by setting 'rerun=' to 1 and adjusting 'xx' and 'yy' according to the last box the script computed (use ncview on land a processed land cover file (named: 'outdata'_11 ... 230)). This information can be seen in the jobs' output and error files.

Having run the script you have the aggregated information on how much (in percent) of the target's area grid boxes is filled with the GLC2000 land cover classes. This information has to be translated into the PFT cover needed which is read into REMO-iMOVE. This is done by using: GLC2PFT_Holdridge_16_PFTS.ksh.

To provide the plant functional type data to the script, all single pft-class files should be aggregated into one file via 'cdo merge'. We will call this file GLC2000_DATA_ON_TARGET_GRID further down.

When running the script GLC2PFT_Holdridge_16_PFTS.ksh you will get:

- the distribution of the 16 PFTS used in REMO-iMOVE:

  GLC_2_PFT_translate_Holdridge_16_classes.srv

- a file which contains the root length of every PFT and climatic region:

  ROOT_DEPTH_FOR_PFTS_16_classes.srv

- a file containing the biotemperature: Biotemperture.srv

- a file containing the Holdridge classes: Holdridge_classes.srv

The script GLC2PFT_Holdridge_16_PFTS.ksh needs to be adjusted:

- xsize, ysize
- line 111: 'OPEN(5,FILE=' ' state the REMO land sea mask (var172) in .srv
- line 122: 'OPEN(10,FILE=' ' state the GLC2000_DATA_ON_TARGET_GRID in .srv
- line 213: 'OPEN(20,FILE=' ' state REMO var 614 in .srv
- line 219: 'OPEN(30,FILE=' ' state REMO var 615 in .srv
- line 225: 'OPEN(40,FILE=' ' state the observed climatological monthly mean temperatures (12 values per gridbox) on the target grid resolution (e.g. CRU)
- line 233: 'OPEN(50,FILE=' ' state the observed climatological annual precipitation sum (1 value per gridbox) on the target grid resolution (e.g. CRU)

2.1.1 The script functions as followed:

The classes and the according variable names of the GLC2000 data are:

raw GLC number	variable names	class name	used in conversion
1	11	Post-flooding or irrigated cr(or aquatic)	X
2	14	Rainfed croplands	X
3	20	Mosaic cropland (50-70%) / vegetation (grassland/shrubland/forest) (20-50%)	X
4	30	Mosaic vegetation (grassland/shrubland/forest) (50-70%) / cropland (20-50%)	X
5	40	Closed to open (>15%) broadleaved evergreen or semi-seciduous forest (>5m)	X X
6	50	Closed (>40%) broadleaved deciduous forest (>5m)	X
7	60	Open (15-40%) broadleaved deciduous forest/woodland (>5m)	X
8	70	Closed (>40%) needleleaved evergreen forest (>5m)	X
9	90	Open (15-40%) needleleaved deciduous or evergreen forest (>5m)	X
10	100	Closed to open (>15%) mixed broadleaved and needleleaved foreest (>5m)	X
11	110	Mosaic forest or shrubland (50-70%) / grassland (20-50%)	X
12	120	Mosaic grassland (50-70%) / forest or shrubland (20-50 %)	X
13	130	Closed to open (>15%) (broadleaved or needleleaved, evergreen or deciduous) shrubland (<5m)	X
14	140	Closed to open (>15%) herbaceouse vegetation (grassland, savannas or lichens/mosses)	X
15	150	Spare (<15%) vegetation	X
16	170	Closed to open (>40%) broadleaved forest or shrubland permanently flooded - Saline or brackish water	X
17	180	Closed to open (>15%) grassland or woody vegetation on regularly flooded or waterlogged soil - Fresh, brackish or saline water	X
18	190	Artificial surfaces and associated urban areas (>50%)	X
19	200	Bare Areas	X
20	210	Water bodies	X
21	220	Permanent snow and ice	
22	230	No data	

The script computes first the climate classes according to Holdridge, based on the input climatologies (observations) and the biotemperature computed from these observations. Then the GLC2000 land cover classes are allocated and aggregated to the sixteen PFTs, which will be read into REMO. The REMO-iMOVE PFTs are:

1. Tropical broadleave evergreen forest
2. Tropical broadleave deciduous forest
3. Temperate broadleave evergreen forest
4. Temperate broadleave deciduous forest
5. Evergreen coniferous
6. Deciduous coniferous
7. Evergreen shrubs
8. Deciduous shrubs
9. C3 grasses
10. C4 grasses
11. tundra

12. swamps
13. C3 crops
14. C4 crops
15. urban
16. bare

The following chapter serves the purpose to introduce the allocation of GLC2000 land use classes to PFTs to be able to change it. In the script there are three data structures which are important for this task:

1. PFT_fractions(x,y,16)
2. GLC_data(x,y,22)
3. holdridge_class(30)

The GLC_data variable stores the percentage cover of each of the GLC2000 classes at a gridcell. The PFT_fractions variable stores the percentage cover of the PFTs. The variable holdridge_class stores the information about the climate zone according to the Holdridge classification for every gridpoint. In line 419, marked by 'DO the allocation of GLC -> PFT' the allocation part begins. For every gridbox and every GLC2000 class the PFT cover is computed from the GLC2000 class' cover simply by adding up all percentage covers according to the allocation sheme.

Example:

GLC2000 class 90/9 'Open (15-40%) Needleleaved deciduous or evergreen forest (>5m)'. Whenever this class is present in a gridcell, the GLC2000 cover is translated into PFT 6,5 and 9/10 according to the following definition for all Holdride classes:

PFT_fractions(i,j,6) = PFT_fractions(i,j,6) + GLC_data(i,j,9)*0.1

PFT_fractions(i,j,5) = PFT_fractions(i,j,5) + GLC_data(i,j,9)*0.8

PFT_fractions(i,j,9) = ... GLC_data(i,j,9)*0.1

PFT_fractions(i,j,10) = ... GLC_data(i,j,9)*0.1

This means 10% of the GLC2000 cover goes into the cover of PFT 6, 80% goes to PFT 5 and 10% goes to PFT 9 and 10. The float numbers at the lines' ends have to sum up to one. The allocation to C3 and C4 grasses is desidgned in a way that given a maximum temperature for the box, a certain percentage is allocated to C3 or C4, therefore the percentage of GLC2000 cover which goes into the formulation has to be the same.

Let's assume the box is covered by 40% GLC2000 class 90/9, the PFTs look the following, assuming 80% goes to C3 and 20% goes to C4 :

PFT 6:	0.1 * 0.4 =	0.04
PFT 5:	0.8 * 0.4 =	0.32
PFT 9:	0.8 * 0.1 * 0.4 =	0.032
PFT 10:	0.2 * 0.1 * 0.4 =	0.008
	Sum =	0.4

At the end of this part you created the servive file to read into REMO-iMOVE, be sure the ENDIAN encoding matches your machine specifications.

If the model should be run with C4 crops in addition to C3 crops, there is the possibility to state a fixed fraction of cropland to be C4 crops. This is then valid for the whole domain and cannot be specified for certain regions. So if you want to have e.g. a fixed fraction of 15% C4 crops in all your domain, look in script GLC2PFT_Holdridge_16_PFTS.ksh. Past line 2951 after 'AGGREGATE PFTS AND ROOT DEPTH TO MODFEL PFTS' you will find a comment called: 'C3 / C4 crop ratio 15%'. If you uncomment the two folowing lines, simply by deleting the ” at the front you get the ratio of 15% C4 crops written to 'PFT_fractions_model(i,j,14)'. You also need to put comment marks in fron of the next lines, otherwise the ratio of 15% will be overwritten.

2.2 Background albedo

The next thing to do is to provide the background albedo information. The global soil types are given in different regional coverage - therefore variable 9 and 13 of the HWSD information is used.

For this purpose you need:

- the two scripts remap_HWSD_soil_data_var_9 and remap_HWSD_soil_data_var_13
- The HWSD soil data variable 9 and 13
  (/hpss/arch/bm0545/m300068/SOIL_DATA/soil_data_var???_glob.nc)
- Variable 614
- Variable 615
- Variable 172

Adjust the script parameters:

- 'x_end=' and 'y_end=': number given in the grid definition

- 'grid=': targets regions' grid
- 'soil_grid=': global_HWSD_grid
- 'outdata=': Here you need a file for every soil type variable in the HWSD file called for HWSD var 9 like:

  HWSD_9_TO_TARGET.srv_001,...,HWSD_9_TO_TARGET.srv_152 and

  for HWSD var 13 like:

  HWSD_13_TO_TARGET.srv_001,...,HWSD_13_TO_TARGET.srv_205

  This can be done with the script called 'set_outdata.ksh',

  there you just need to give your target regions destination grid for YOUR_GRID.
- 'lats=': variable 614
- 'lons=': variable 615
- 'lsm_data=': vaiable 172
- 'res=': resolution information given in the grid definition

The information in global_HWSD_grid should be somthing like that:
#
gridID 0
#
gridtype = lonlat gridsize = 933120000 xname = lon xlongname = longitude xunits = degrees yname = lat ylongname = latitude yunits = degree xsize = 43200 ysize = 21600 xfirst = -180.0 xinc = 0.008333 yfirst = -90.0 yinc = 0.008333

All input data need to be '.srv' files 'SERVICE FORMAT'. You can check that by typing 'cdo sinfo FILENAME'. And convert via 'cdo -f srv copy INPUT OUTPUT'.

Please run for only one gridbox, exit the script and check whether the 'cut -c' commands cut out the right information - this can be different from one platform to the other. So it is recommended to check all cursor locations after all 'cut -c' commands.

You may want to speed up the whole procedure of calculating the soil types, because it will need days to weeks for big domains. One thing you can do is cut your region out of the global HWSD files via 'cdo sellatlonbox' and state this file in 'soil_org_data='. Don't forget to adjust the 'soil_grid=' variable according to your new file.

The two scripts will populate all soil type files HWSD_9_TO_TARGET.srv_??? and HWSD_13_TO_TARGET.srv_??? so these need to be merged after the scripts have finished via 'cdo merge '.

After this step you produced two files containing the percentage cover of the different soil types for the model grid. This has to be translated now into dry soil albedo values. For that you use the script 'compute_soil_albedo_from_HWSD.ksh'

Adjust 'compute_soil_albedo_from_HWSD.ksh' like that:

- xsize, ysize
- line 43: OPEN(10,FILE=" to the filename of the HWSD var9 merged file
- line 56: OPEN(20,FILE=" to the filename of the HWSD var13 merged file
- line 68: OPEN(30,FILE=" to the filename of REMO land sea mask .srv file

When you run the script you will get a file called: 'REMO_iMOVE_backgrd_albdeo.srv'

2.3 Land use change

To perform land use change studies REMO-iMOVE can run in land-use-change-mode. In this mode the model reads in precompiled geographic distribution of PFTs every 1st January. To create quasi-realistic land cover change information it is recommended to use the IPCC AR5 land cover change szenarios. These comprise 5 land use types and the resulting changes from one type to another on a yearly basis from 1700 to 2100. For the land cover computation scripts (compute_landcover_16_PFTs.ksh and compute_landcover_16_PFTs_future.ksh) you need the following data on your model grid in .srv format!

- land sea mask code 172
- PFT fractions
- land use change information: 'gflvc' (virgin land to cropland)
- land use change information: 'gflsc' (secondary land to cropland)
- land use change information: 'gfsh1' (wood harvested from mature secondary forest)
- land use change information: 'gfsh2' (wood harvested from young secondary forest)
- land use change information: 'gfsh3' (wood harvested from non-forested (shrub))
- land use change information: 'gfvh1' (wood harvested from primary forested land)
- land use change information: 'gfvh2' (wood harvested from primary non-forested land)

Adjust the following parameters:

- xsize (integer)
- ysize (integer)
- years (integer)
- start_year (integer)

  contains the start year of the luc change if past luc is computed

  must equal 2000 if future land use change is computed
- Path to land sea mask code 172: OPEN(5, FILE='
- Path to PFT fractions: OPEN(40, FILE='
- Path to 'gflvc' : OPEN(60, FILE='
- Path to 'gflsc' : OPEN(50, FILE='
- Path to 'gfsh1' : OPEN(70, FILE='
- Path to 'gfsh2' : OPEN(80, FILE='
- Path to 'gfsh3' : OPEN(90, FILE='
- Path to 'gfvh1' : OPEN(100, FILE='
- Path to 'gfvh2' : OPEN(110, FILE='

When computing land cover change information you need a reference point in time onto which you base the land cover change, since this information is given in %. When using the GLC2000 land cover distribution this reference point is the year 2000.

Use script 'compute_landcover_16_PFTs.ksh' when doing land cover changes until 2000 and the script 'compute_landcover_16_PFTs_future.ksh' when computing land cover changes beginning in 2000 into future time periods. The year 2000 must always be used as reference point - it is not possible with the GLC2000 distribution and these scripts to compute the periode 1950 tzo 2010. There you have to compute first 1950 to 2000 using 'compute_landcover_16_PFTs.ksh' and the periode 2000 to 2010 using 'compute_landcover_16_PFTs_future.ksh'.
The difference is that in script 'compute_landcover_16_PFTs.ksh', land cover changes are performed backwards in time, so a deforestation from 1950 to 2000 is computed as a afforestatuion from 2000 back to 1950. In the future land use change szenario this is not needed.
The 'years' variable in both cases must be equal to the timesteps in the input land cover change information files, e.g. 301 for changes beginning in 1700 reaching until 2000.
When using 'compute_landcover_16_PFTs.ksh', the 'start_year' variable gives the first (earliest) year of the land cover change information files e.g. 1700 for changes 1700

to 2000.
When using 'compute_landcover_16_PFTs_future.ksh', the 'start_year' variable has to be 2000, since the GLC2000 file gives the land cover state of 2000.

After running the .ksh scripts you will get an executable (.exe), called landcover_szenario.exe or landcover_szenario_future.exe, which need to be executed.

Output of both scripts is a file called 'landcover_szenario_pfts.srv' or 'landcover_szenario_pfts_future.srv' which contains 'years'-timesteps with the geographic land cover distribution for each PFT.

This file needs to be split up into one file for every year called like: 'NameOfPft-File_YYYY.srv', these files are then read into REMO-iMOVE (see below).

Kapitel 3

Running REMO-iMOVE

3.1 ...without land use szenarios

Running REMO-iMOVE is roughly the same procedure as running REMO2009, you just need to give to the namelist the PFT distribution, root depth (even if it is not used yet), roughness length of the topography and albedo information and two switches to let REMO know it should run in REMO-iMOVE mode.

In the &PHYCTL namelist part you should add this if you want to run without land use change

- LIMOVE=.TRUE., LIMOVELUC=.FALSE.

ALL information of the standard NAMELIST is mandatory also the surface fields even if they are not used!

Additionally you have to set three paths:

- YNAMPFT='NameOfPftFile' (16 PFTs, .srv format, BIG ENDIAN, variable names 801-816)
- YNAMZ0='NameOfRoughnessLengthFile'(topography roughness out of the soil library called ..._rle.srv, variable name 173)
- YNAMSALB='NameOfAlbedoFile' (1 var, .srv format, BIG ENDIAN, variable name 444)
- YNAMROOT='NameOfRootDepthFile' (16 var, .srv format, BIG ENDIAN, variable name 901-916)

IT IS MANDATORY THAT THE PFT FILE 'NameOfPftFile_YYYY.srv' ends exactly like '_YYYY.srv'. But that you only give 'NameOfPftFile' to the YNAMPFT variable.

'YYYY' in this framework specifies the start year of the model run. If you run with 'LIMOVELUC=.TRUE.' then you have to read in a new PFT distribution every 1st of January of the year. So when you run 10 years with landcover change from 1950 to 1959 you need ten files called 'NameOfPftFile_1950.srv',...,'NameOfPftFile_1959.srv'

3.2 ...with land use szenarios

The first thing in the namelist which is differenet is the switch 'LIMOVELUC', which should be set to .TRUE. .

- LIMOVE=.TRUE., LIMOVELUC=.TRUE.

When running REMO-iMOVE with land use change, for every year you need a PFT distribution. So when you run 10 years with landcover change from 1950 to 1959 you need ten files called 'NameOfPftFile_1950.srv',...,'NameOfPftFile_1959.srv'. The PFT distribution can be created in any way, one is the use of the IPCC AR5 harmonized land use change szenarios (Hurtt et al. 2009) (mentioned above).

3.3 ...in restart mode

REMO-iMOVE has the need of a new part for doing a restart. Besides the normal f- and g-files in /remo/xf you need two additional files called:

- v_rst_2d_{USR}{EXP}_{YEAR}{MON}
- v_rst_3d_{USR}{EXP}_{YEAR}{MON}

These two files contain information about the actual vegetation state (phenology ...) at the beginning of the actual month. This is different to the information of the normal REMO restart files. The files for the REMO-iMOVE restart need to sit in /remo/xe.

When you want to perform a restart for February 1959, REMO-iMOVE has written the files at the end of January 1959 and called them:

- v_rst_2d_{USR}{EXP}_1959_02
- v_rst_3d_{USR}{EXP}_1959_02

These files need to be present in the /remo/xe folder when the model is restarted.

The 2D restart files contain the following variables:

1. AGRPHSG/AGPSG: growth phase of summer green phenology
2. AGRPHEG/AGPEG: growth phase of evergreen phenology
3. AGRPHCR/AGPCRP: growth phase of crop phenology
4. ADSGBEG: days since growth begin evergreen
5. ADSGBEG: days since growth begin summergreen
6. APST: pseudo soil temperature
7. APDT: previous day temperature
8. APDTMIN: previous day min temperature
9. APDTMAX: previous day max temperature
10. ADTSUM/ADTS: day temperature sum
11. ADTMIN: day min temperature
12. ADTMAX: day min temperature
13. AHSUMEG/AHSEG: heat sum evergreen
14. AHSUMSG/AHSSG: heat sum summergreen
15. AHSUMCR/AHSCR: heat sum crops
16. AHSUMWI/AHSWI: heat sum winter
17. ACHDEG/ACDEG: chill days evergreen
18. ACHDSG/ACDSG: chill days summergreen
19. AGRPHCRC4/AGPCRPC4: growth phase of C4 crop phenology

The 3D restart files contain the following variables for each PFT (therefore 3D) :

1. APDNPP: previous day NPP rate
2. ADNPPSUM: day NPP sum
3. AYNPPSUM: year NPP sum
4. APFTS: fraction of PFT cover
5. ALAI_PFT: LAI
6. AGDD: growing degree days

3.4 New output variables

REMO-iMOVE writes 2 new 2D-output variables and 10 new 3D-output variables.

The 2D variable are (grib format with grid description):

- code 291 (AJSB1) = box weighted mean stomatal conductance [m/s] of vegetated fraction of REMO-iMOVE (used in the model)
- code 292 (AJSB2) = old ECHAM3 stomatal conductance [m/s] computed in vdiff.f (not used in the model)
- code 293 (AJSB3) not used
- code 294 (AJSB4) not used
- code 295 (AJSB5) = paremeter ZHUM of vdiff.f (fraction of bare soil that is allowed to evaporate)

The 3D variable are (.srv format without grid description):

For every of the 16 PFTs, hourly, found in /remo/xe:

- vp_APAR_{USR}{EXP}_{YEAR}{MON} = fAPAR (fraction of absorpt photosynthetically active radiation) [mol(photons) / m^2 / s]
- vp_DRS_{USR}{EXP}_{YEAR}{MON} = plant dark respiration (maintenance respiration) [gC / m^2 / s]
- vp_FPFT_{USR}{EXP}_{YEAR}{MON} = fraction of PFTs [% gridbox]
- vp_GAS_{USR}{EXP}_{YEAR}{MON} = plant gross assimilation (photosynthesis rate) [gC / m^2 / s]
- vp_LAI_{USR}{EXP}_{YEAR}{MON} = leaf area index [m^2 / m^2]
- vp_NPP_{USR}{EXP}_{YEAR}{MON} = plant net primary productivity (GAS-DRS) [gC / m^2 / s]
- vp_PAR_{USR}{EXP}_{YEAR}{MON} = PAR (photosynthetically active radiation) [mol(photons] / m^2 / s]
- vp_STCO_{USR}{EXP}_{YEAR}{MON} = stomatal conductance for the vegetated part of each PFT [m/s]
- vp_WSTF_{USR}{EXP}_{YEAR}{MON} = water stress factor (water between 0.35*WS and 0.75*WS) [% pl. available water]

For the four phenological types (evergreen, summergreen, raingreen, crops):

- vp_GRPA_{USR}{EXP}_{YEAR}{MON} = state of vegetation

3.5 Questions you may answer with these variables

3.5.1 What's the vegetations NPP per year

There are two ways of expressing this: either on a grid box weighted mean, or on a PFT leaf basis.

For a gridbox weighted mean you take all monthly files of one year for NPP, their unit is [gC / m^2 s]. You have to multiply by 3600 to perform the conversion from second to hourly values. Then you sum all timesteps up. You result in one value for each PFT which has the unit [gC / m^2 / year] - a common format for NPP. When you build the sum over all PFTs you end up with the weighted grid box mean NPP. The equation for that is:

$$NPP_{gridbox} = \sum output_{hourly} * 3600 \tag{3.1}$$

When you want this information for each PFT on leaf basis - this may be needed if you want to compare the NPP rate of grass in the Meditteranean to the rate in High Northern Latitudes - you need to divide the NPP by the fraction of the PFTs.

$$NPP_{PFT_{leafbased}} = \frac{\sum output_{hourly} * 3600}{frac.PFT} \tag{3.2}$$

3.5.2 How much PAR do I have?

This can be expressed per PFT or per gridbox as weighted mean.

When multiplying [mol(photons) / m^2 s] times 220000, it is converted to [W/m^2], with this flux you can easily compute the gridbox weighted mean of PAR. When dividing by the fraction of PFTs you arrive at PAR on leaf level.

Kapitel 4

Technical changes in REMO-iMOVE

Here I wanted to explain the changes made to REMO to arrive at REMO-iMOVE on a source code basis, to increase the insigths into modelling results. All new implemented or changed subroutines will be listed and the changes explained briefly. To see the changes made you can use >grep -in 'ccw' *<. This command will list all changes I did (CommentChristofWilhelm) to REMO to make it run with the iMOVE extention.

Impotant overarching parameters are set in /CBS/parorg.h. Here the number of PFTs 'IPFTS', the number of layers taken into account for the computation of radiation in the canopy 'NCANO' and the number of vegetation related parameters 'VEGPARAMS' is set. Whenever a different number of PFTs or a new vegetation related parameter should be integrated - these parameters are to change. For the explanation of 'VEGPARAMS' see 'set_veg_constants.f'.

4.1 ec4org.f

This is the overarching organisation routine in REMO. Here, all new variables, their in- and output and their distribution in the model are organized.

- INCLUDE time_components.h (time dependent variables needed in the vegetation physics)
- AJSB1 to AJSB5
- WSMOLD (old ws for land cover changes)
- APFTS (cover fraction of pfts)
- ALAI_PFTS (LAI per pft)
- APAR_PFT (fraction of absorpt photosynthetically active radiation per pft)

- PPAR_PFT (photosynthetically active radiation per pft)
- AOROZ0 (orographic roughness length)
- ASOILALB (soil albedo per gridbox)
- AROOTD (root depth per pft and climatic zone)
- ANPP_ACC (net primary production - accumulated in the code, but written out in [gC/m^2/s] in an hourly intervall)
- AGAS_ACC (gross primary productivity - dito)
- DRS_ACC (dark respiration - dito)
- PINSTSWDWN (instantaneouse value of shortwave downward radiation)
- PINSTSW (instantaneouse value of net surface shortwave radiation)
- AGRPHSG (growth phase of summer green phenology)
- AGRPHEG (growth phase of evergreen phenology)
- AGRPHCR (growth phase of crop phenology)
- AGRPHCRC4 (growth phase of C4 crop phenology)
- ADSGBEG (days since growth begin evergreen)
- ADSGBSG (days since growth begin summergreen)
- APST (pseudo soil temperature)
- APDT (previous day temperature)
- APDTMIN (previous day min temperature)
- APDTMAX (previous day max temperature)
- ADTSUM (day temperature sum)
- ADTMIN (day min temperature)
- ADTMAX (day max temperature)
- AHSUMEG (heat sum evergreen)
- AHSUMSG (heat sum summergreen)
- AHSUMCR (heat sum crops)
- AHSUMWI (heat sum winter)

- ACHDEG (chill days evergreen)
- ACHDSG (chill days summergreen)
- APDNPPR (previous day NPP rate)
- ADNPPS (day npp sum)
- AGDD (growing degree days)
- ASTCON (stomatal conductance per pft)
- AWSTF (water stress factor per pft)
- LFTSD (flag if it is the first timestep of the day)
- LPFTOK (flag to see is a land grid point has no pft distribution)

If ec4org.f is running in iMOVE mode, the following subroutines are called:

- MANAGE_TIME
- PHENO_RESTART
- READPFTS
- READSALB
- READOROZ0
- WRITE_PHENO_RE
- WRITE_VEG_PARAMS

4.2 manage_time.f

In manage_time.f the values of LFTSD and IYEARDAY is computed out of NZT and the start date.

4.3 pheno_restart.f

In this routine the restart for the phenological variables is performed. Here the vegetation two and three dimensional restart files (v_rst_2d_... / v_rst_3d_...) are read in.

4.4 readpfts.f / readsalb.f / readoroz0.f

In these three routines the PFT distribution, the new soil albedo (or background albedo) and the roughness length of orography is read is.

4.5 write_pheno_restart.f

In this routine the restart files for the phenological restart is written out. The description of the content of the files is stated before.

4.6 write_veg_params.f

In this routine the ten new vegetation parameters on a output-intervall basis are written out. (see section 'New output variables')

4.7 progec4.f, phyec.f

In these routines the new variables are passed to reach phyorg.f.

4.8 phyorg.f

New variables here are used to compute the solar zenith angle, the saturated surface humidity and the average of upper soil temperatures (not used).

- ZDUM1 (dummy for sending pressure at last halflevel to vegphy.f)
- ZDUM2 (dummy for sending humidity at last level to vegphy.f)
- ZSATSURF (saturated surface specific humidity)
- ZZENITH
- ZCZEN (cosine of solar zenith angle)
- ZES
- ZCOR
- ZTDMEAN (mean of upper soil temperatures TD3, TD4, TD5)

- NSOIL (# soil layers)

ZSATSURF is computed in vdiff.f style. ZSCEN is computed after JSBACH with the REMO inherent solar parameters.

The new subroutine vegphy.f is called to account for the PFT related changes.

4.9 vegphy.f

This is the new central steering routine, the idea for that comes from JSBACH (there is is called mo_jsbach_interface.f90). Here the following steps are done:

- setting vegetation constants for the 16 PFTs: SET_VEG_CONSTANTS
- rearranging arrays for radiation, diffuse radiation (usual constants put of ECHAM3 and JSBACH), solar zenith angle, CO_2 concentration, available water
- computing the maximum vegetated fraction
- if first time step: initializing LAI
- set forest fraction
- update the surface variables (roughness length, albedo): UPDATE_SURFACE
- call the bethy model for the first time (non water stressed): UPDATE_BETHY_REMO
- compute the plant water stress and the stomatal closing: UPDTAE_SOIL_REMO
- call the bethy model for the second time (water stressed): UPDATE_BETHY_REMO
- computing phenology: UPDATE_PHENOLOGY
- setting output variables: NPP, GAS, DRS, VLT, AJSB1, FOREST, AWSTF, ASTCON

4.10 set_veg_constants.f

This is a very important subroutine since here all vegetation related parameters are set. The routine sets the variable ZLCTLIB which is called ZVEGLIB in vegphy.f. ZVEGLIB is a 3d array build up by the number of PFTs 'IPFTS' (set in parorg.h) and the number of vegetation related parameters 'VEGPARAMS' (set in parorg.h)

Whenever a vegetation related parameter in the model is used ZVEGLIB is called with the index of the parameter first, followed by the number of the specific PFT.

The following parameters are contained in ZVEGLIB/ZLCTLIB:

- Position 1: index number of landcover type: 1-16
- Position 2: natural land cover(1) or not(0)
- Position 3: crop land cover (1) or not (0)
- Position 4: phenological type
- Position 5: C3 (0) or C4 (1) photosythetic pathway
- Position 6: maximum carboxylation rate at 25 deg C
- Position 7: maximum electron transport at 25 deg C
- Position 8: maximum LAI
- Position 9: if Nitrogen scaling is needed (1)
- Position 10: carbon content per leaf area
- Position 11: vegetation albedo
- Position 12: roughness length
- Position 13: forest fraction
- Position 14: litter albedo to fit formula (albedo_soil + litteralbedo / l_factor)
- Position 15: l_factor for above stated formula

If you want to run REMO-iMOVE with the latest parameters for the photosynthetic scheme, you can copy 'set_veg_constants_lctlib21.f' to the subroutine name. In this file the carboxylation and electron transport rate are derived by J. Kattge out of a plant trait database. Please contact C. Reick and T. Raddatz for further information. Short time testruns showed a huge overestimation of plant productivity when using these paramters.

4.11 update_surface.f

Computes the new surface albedo and roughness length out of the PFT distribution and LAI.

NOTE: if iMOVE is switched on this is the routine which changes the surface albedo!

4.12 mo_bethy_2.f90

This is the bethy module, here the radiative pathway, photosynthesis and stomatal control is computed. It is documented up to now in the land department's documentation about JSBACH (C. Reick, T. Raddatz, or dissertation W. Knorr)

4.13 mo_soil_2.f90

In this routine the plant water stress factor for the second run of UPDATE_BETHY_REMO is computed in ECHAM3 style. Here it would be nice to have multi soil layers and root depth for each PFT included - the infrastructure on PFT side is already there (AROOTD).

4.14 mo_phenology_2.f90

This is the interactive phenological routine. It generally follows the JSBACH documentation mentioned above.

4.15 vdiff.f

Here, the connection to the new part of the model takes place. In vegphy.f the plant stomatal conductance for the gridbox was computed and saved in AJSB1, this now substitutes ZWET. ZWET in turn is saved into another output variable (AJSB2) to have the possibility to check the difference.

4.16 prerad.f

In this routine the ZCLOCK parameter is extracted for the computation of the zenith angle. It is save to ZCCOM in the COMCON header file.

4.17 aorad.f, aoradint.f, rad.f, radheat.f

In radheat.f the instantaneouse values of shortwave downward and net surface shortwave radiation are determined and given to the corresponding variables.

4.18 orbit.f

Pass declination to COMCON

4.19 COMCON

Here new variables are put, to pass important information to different subroutines.

1. ZCCOM: ZCLOCK of prerad.f
2. ZDECOM: declination of orbit.f
3. LIMOVE: logical if iMOVE module is used
4. LIMOVELUC: logical if LUC is used in iMOVE

Kapitel 5

Appendix

5.1 Conversion of GLC2000 and HWSD data has been achived due to the following conversion chain:

GLC2000:

- from GEOTIFF to HDF4Image via GDAL 1.3.2.0: gdal_translate -of HDF4Image INPUT OUTPUT
- from HDF4Image to .netcdf via NCL script: output_netcdf_GLC2000
- invert data by latitudes using 'cdo invertlat'
- Grid settings: either the grid is known, then create a gridfile (without pole definition!!) and put it on the .netcdf file via the CDOs or grid is unknown: then open raw data with SAGA GIS tool and open the GEOTIFF file. The grid is shown via the 'show grid' button.

5.2 Allocation scheme of GLC2000 classes to PFTs according to Holdridge

Definition of the Holdridge climate classes:

Computation of biotemperature:

$$Biotemp = [\sum_{i=1}^{12} monthly\_mean\_temp(i)]/12 \tag{5.1}$$

Biotemp [°]	Precipitation [mm]					
	<125	125 - <250	250 - <500	500 - <1000	1000 - <2000	>2000
<3	dry tundra(1)	moist tundra(2)	wet tundra(3)	rain tundra(4)	-(5)	-(6)
3 - <6	desert(7)	dry shrub(8)	moist forest(9)	wet forest(10)	rain forest(11)	-(12)
6 - <12	desert(13)	desert shrub(14)	steppe(15)	moist forest(16)	wet forest(17)	rain forest(18)
12 - <24	desert(19)	desert shrub(20)	thorn steppe/ woodland(21)	dry forest(22)	moist forest(23)	wet forest/ rain forest(24)
>24	desert(25)	desert shrub(26)	thorn steppe/ woodland(27)	very dry forest (28)	dry forest(29)	moist,wet,rain forest(30)

Examples of allocation tables GLC2000 to raw PFT classes (rest can be found in GLC2PFT_Holdridge_16_PFTS.ksh):

1. Tropical broadleave evergreen forest
2. Tropical broadleave deciduous forest
3. Temperate broadleave evergreen forest
4. Temperate broadleave deciduous forest
5. Evergreen coniferous
6. Deciduous coniferous
7. Evergreen shrubs
8. Deciduous shrubs
9. C3 grasses
10. C4 grasses
11. tundra
12. swamps
13. managed land non-irrigated
14. managed land irrigated
15. urban
16. bare
17. water

GLC2000 class 11/1:

Biotemp [°]	Precipitation [mm]					
	<125	125 - <250	250 - <500	500 - <1000	1000 - <2000	>2000
<3	PFT 14: 100%	PFT 14: 100%	PFT 14: 100%	PFT 14: 100%	PFT 14: 100%	PFT 14: 100%
3 - <6	PFT 14: 100%	PFT 14: 100%	PFT 14: 100%	PFT 14: 100%	PFT 14: 100%	PFT 14: 100%
6 - <12	PFT 14: 100%	PFT 14: 100%	PFT 14: 100%	PFT 14: 100%	PFT 14: 100%	PFT 14: 100%
12 - <24	PFT 14: 100%	PFT 14: 100%	PFT 14: 100%	PFT 14: 100%	PFT 14: 100%	PFT 14: 100%
>24	PFT 14: 100%	PFT 14: 100%	PFT 14: 100%	PFT 14: 100%	PFT 14: 100%	PFT 14: 100%

GLC2000 class 14/2:

Biotemp [°]	Precipitation [mm]					
	<125	125 - <250	250 - <500	500 - <1000	1000 - <2000	>2000
<3	PFT 13: 100%	PFT 13: 100%	PFT 13: 100%	PFT 13: 100%	PFT 13: 100%	PFT 13: 100%
3 - <6	PFT 13: 100%	PFT 13: 100%	PFT 13: 100%	PFT 13: 100%	PFT 13: 100%	PFT 13: 100%
6 - <12	PFT 13: 100%	PFT 13: 100%	PFT 13: 100%	PFT 13: 100%	PFT 13: 100%	PFT 13: 100%
12 - <24	PFT 13: 100%	PFT 13: 100%	PFT 13: 100%	PFT 13: 100%	PFT 13: 100%	PFT 13: 100%
>24	PFT 13: 100%	PFT 13: 100%	PFT 13: 100%	PFT 13: 100%	PFT 13: 100%	PFT 13: 100%

GLC2000 class 20/3: Mosaic cropland (50-70%) / vegetation(grassland/shrubland/forest) (20-50%)

Biotemp [°]	Precipitation [mm]					
	<125	125 - <250	250 - <500	500 - <1000	1000 - <2000	>2000
<3	PFT 13: 60% PFT 12: 20% PFT 11: 20%	PFT 13: 60% PFT 12: 20% PFT 11: 20%	PFT 13: 60% PFT 12: 20% PFT 11: 20%	PFT 13: 60% PFT 12: 20% PFT 11: 20%	PFT 13: 60% PFT 12: 20% PFT 11: 20%	PFT 13: 60% PFT 12: 20% PFT 11: 20%
3 - <6	PFT 13: 60% PFT 9/10: 40%	PFT 13: 60% PFT 9/10: 40%	PFT 13: 60% PFT 9/10: 40%	PFT 13: 60% PFT 9/10: 30% PFT 5: 10%	PFT 13: 60% PFT 9/10: 10% PFT 5: 30 %	PFT 13: 60% PFT 9/10: 10% PFT 5: 30%
6 - <12	PFT 13: 60% PFT 9/10: 40%	PFT 13: 60% PFT 9/10: 40%	PFT 13: 60% PFT 4: 5% PFT 5: 5% PFT 8: 20% PFT 9/10: 10%	PFT 13: 60% PFT 4: 7.5% PFT 5: 7.5% PFT 8: 10% PFT 9/10: 15%	PFT 13: 60% PFT 4: 20% PFT 8: 10% PFT 9/10: 10%	PFT 13: 60% PFT 4: 20% PFT 8: 10% PFT 9/10: 10%
12 - <24	PFT 13: 60% PFT 9/10: 40%	PFT 13: 60% PFT 7: 20% PFT 9/10: 20%	PFT 13: 60% PFT 4: 10% PFT 5: 10% PFT 7: 10% PFT 9/10: 10%	PFT 13: 60% PFT 4: 10% PFT 5: 10% PFT 7: 10% PFT 9/10: 10%	PFT 13: 60% PFT 4: 10% PFT 5: 10% PFT 7: 20%	PFT 13: 60% PFT 4: 10% PFT 5: 10% PFT 7: 20%
12 - <24	PFT 13: 60% PFT 9/10: 40%	PFT 13: 60% PFT 7: 20% PFT 9/10: 20%	PFT 13: 60% PFT 2: 20% PFT 7: 10% PFT 9/10: 10%	PFT 13: 60% PFT 2: 10% PFT 7: 15% PFT 9/10: 15%	PFT 13: 60% PFT 1: 15% PFT 7: 10% PFT 9/10: 15%	PFT 13: 60% PFT 1: 20% PFT 8: 10% PFT 9/10: 10%

GLC2000 class 30/4: Mosaic vegetation (grassland/shrubland/forest) (50-70%) / cropland (20-50%)

Biotemp [°]	Precipitation [mm]					
	<125	125 - <250	250 - <500	500 - <1000	1000 - <2000	>2000
<3	PFT 13: 35% PFT 12: 30% PFT 11: 35%	PFT 13: 35% PFT 12: 30% PFT 11: 35%	PFT 13: 35% PFT 12: 30% PFT 11: 35%	PFT 13: 35% PFT 12: 30% PFT 11: 35%	PFT 13: 35% PFT 12: 30% PFT 11: 35%	PFT 13: 35% PFT 12: 30% PFT 11: 35%
3 - <6	PFT 13: 40% PFT 9/10: 60%	PFT 13: 40% PFT 9/10: 60%	PFT 13: 40% PFT 9/10: 60%	PFT 13: 40% PFT 9/10: 45% PFT 5: 15%	PFT 13: 40% PFT 9/10: 40% PFT 5: 20%	PFT 13: 40% PFT 9/10: 40% PFT 5: 20%
6 - <12	PFT 13: 40% PFT 4: 10% PFT 5: 10% PFT 8: 10% PFT 9/10: 30%	PFT 13: 40% PFT 4: 20% PFT 5: 20% PFT 8: 10% PFT 9/10: 10%	PFT 13: 40% PFT 4: 20% PFT 5: 20% PFT 8: 10% PFT 9/10: 10%	PFT 13: 40% PFT 4: 25% PFT 5: 20% PFT 9/10: 15%	PFT 13: 40% PFT 4: 25% PFT 5: 25% PFT 9/10: 10%	PFT 13: 40% PFT 4: 30% PFT 5: 30%
12 - <24	PFT 13: 40% PFT 9/10: 60%	PFT 13: 40% PFT 7: 35% PFT 9/10: 25%	PFT 13: 40% PFT 4: 20% PFT 5: 15% PFT 7: 15% PFT 9/10: 10%	PFT 13: 40% PFT 4: 25% PFT 5: 10% PFT 7: 15% PFT 9/10: 10%	PFT 13: 40% PFT 4: 20% PFT 5: 20% PFT 7: 20%	PFT 13: 60% PFT 4: 20% PFT 5: 20% PFT 7: 20%
12 - <24	PFT 13: 40% PFT 7: 30% PFT 9/10: 30%	PFT 13: 40% PFT 7: 30% PFT 9/10: 30%	PFT 13: 40% PFT 2: 10% PFT 7: 50%	PFT 13: 40% PFT 2: 40% PFT 7: 20%	PFT 13: 40% PFT 1: 40% PFT 7: 20%	PFT 13: 40% PFT 1: 50% PFT 8: 10%