1995_monthly_prepare_run_era5

August 20, 2025

[1]:
```python
import numpy as np
import xarray as xr
import pandas as pd
import scipy
import sys
import warnings
warnings.filterwarnings('ignore')
import time as timer
start_all = timer.time()
```

[2]:
```python
dataf ="/Volumes/ESA_F4R/era/"
datao ="/Volumes/ESA_F4R/ed_prepare/"
#datao ="/Users/ellendyer/Library/Mobile Documents/com~apple~CloudDocs/
 ↪1SHARED_WORK/Work/3_ESA_GRANT/MODEL/data/era/"
datap ="/Users/ellendyer/Library/Mobile Documents/com~apple~CloudDocs/
 ↪1SHARED_WORK/Work/3_ESA_GRANT/MODEL/plots/era/"
```

[3]:
```python
#For selection and plotting
Y1, Y2 = 1995,1995
#m1 = '03'
time_bnds = (str(Y1)+'-01-01',str(Y2)+'-12-31')
lon_bnds, lat_bnds = (15, 30), (5,-10)
#p_bnds = (1000,300) #for daily folder files
p_bnds = (30000,100000)
```

Read in ERA5 data on pressure levels (hourly in fortnightly files) - resampled to monthly MS timestep - shum multiplied by 1000 to convert from kg/kg –> g/kg - pressure levels are divided by 100 to convert from Pa to hPa (only for fortnightly files) - sort data by descending pressure levels (only for fortnightly files)

[4]:
```python
start = timer.time()
from functools import partial
def _preprocess_pres(x, lon_bnds, lat_bnds, p_bnds):
    return x.sel(lon=slice(*lon_bnds), lat=slice(*lat_bnds),
                 plev=slice(*p_bnds),drop=True)
partial_func_pres = partial(_preprocess_pres, lon_bnds=lon_bnds,␣
 ↪lat_bnds=lat_bnds, p_bnds=p_bnds)
```

```
#Reading in pressure level variables from ERA5
ds_era_pres = xr.open_mfdataset(dataf+"era5/pressure_levels/
 ↪era5_pressure_level_variables_central_africa_"+str(Y1)+"*.nc",
                                drop_variables=['r','t','w'],
                                preprocess=partial_func_pres,parallel=True).
 ↪resample(time='MS').mean(dim='time').load()
ds_era_pres = ds_era_pres.sel(time=slice(*time_bnds),drop=True)
ds_era_pres = ds_era_pres.rename({'plev':'level','q':'Shum','u':'Uwnd','v':
 ↪'Vwnd'})
ds_era_pres['Shum'] = 1000.0*ds_era_pres['Shum']
ds_era_pres['level'] = ds_era_pres['level']/100.0 #for half monthly files only
ds_era_pres = ds_era_pres.sortby('level', ascending=False) #for half monthly␣
 ↪files only
end = timer.time()
length = end - start
print("ERA5 pressure level data read in took ", length, "seconds")
```

```
ERA5 pressure level data read in took  752.2167732715607 seconds
```

Read in ERA5 land data (hourly in monthly files) - resampling to daily first because evap and prec need to be summed rather than averaged at the daily scale (mm/day) while surface pressure is averaged - prec is multiplied by 1000 to convert from m to mm - evap is multiplied by -1000 to convert from m to mm and upward fluxes in land model are considered negative - then resampled to MS monthly and also interpolated to coarser pressure level grid

[5]:
```
start = timer.time()
from functools import partial
def _preprocess_land(x, lon_bnds, lat_bnds):
    x = x.sel(longitude=slice(*lon_bnds), latitude=slice(*lat_bnds),drop=True)
    return x
partial_func_land = partial(_preprocess_land, lon_bnds=lon_bnds,␣
 ↪lat_bnds=lat_bnds)

#Reading in surface variables from ERA5 Land
ds_era_land = xr.open_mfdataset("/Volumes/ESA_F4R/era/era5_land/
 ↪era5_land_variables_central_africa_"+str(Y1)+"*.nc",
                                ␣
 ↪drop_variables=['expver','number','pev','ssr','t2m'],
                                preprocess=partial_func_land,parallel=True).
 ↪load()
ds_era_land = ds_era_land.sel(valid_time=slice(*time_bnds),drop=True)
ds_era_land = ds_era_land.rename({'valid_time':'time','latitude':'lat',
                                  'longitude':'lon','tp':'Prec','e':'Evap','sp':
 ↪'Psfc'})
ds_era_land = ds_era_land.
 ↪interp(lat=ds_era_pres['lat'],lon=ds_era_pres['lon'],method='linear',kwargs={"fill_value":
 ↪ "extrapolate"})
```

```
#print('era after int before resample',ds_era_land)
Psfc = ds_era_land['Psfc'].resample(time='D').mean(dim='time')/100.0
ds_era_land = ds_era_land.resample(time='D').sum(dim='time')
ds_era_land['Psfc'] = Psfc
ds_era_land['Prec'] = ds_era_land['Prec']*1000.0
ds_era_land['Evap'] = ds_era_land['Evap']*-1000.0
ds_era_land = ds_era_land.resample(time='MS').mean(dim='time')
end = timer.time()
length = end - start
print("ERA5 land data read in took ", length, "seconds")
```

```
ERA5 land data read in took  64.56531715393066 seconds
```

Merging the two datasets into one dataset for recyling code called ds - close both input datasets - sort everything so latitude is south to north - transpose dimensions so they run (lon,lat,level,time) as in recycling code - save input ds to file

[6]:
```
start = timer.time()
ds = xr.merge([ds_era_pres,ds_era_land])
ds_era_pres.close()
ds_era_land.close()
ds = ds.sortby('lat', ascending=True)
ds = ds.transpose("lon", "lat", "level", "time",missing_dims='ignore')
ds.to_netcdf(datao+"erads_"+str(Y1)+".nc", mode='w', format='NETCDF4',␣
 ↪engine='netcdf4')
end = timer.time()
length = end - start
print("Merging and dataset output took ", length, "seconds")
```

```
Merging and dataset output took  0.874798059463501 seconds
```

[7]:
```
#Prepping datasets near surface for recycling
import bulk_recycling_model.numerical_integration

# Integrate 10^-3 Shum Uwnd dp
# Because the integration limits are from high pressure to low pressure, we␣
 ↪need to invert the sign.
integrand = -1 * 1e-3 * ds["Shum"] * ds["Uwnd"]
Fx = bulk_recycling_model.numerical_integration.
 ↪integrate_no_extrapolation(integrand, ds["Psfc"])
# Units: mb x m/s

# Integrate 10^-3 Shum Vwnd dp
# Because the integration limits are from high pressure to low pressure, we␣
 ↪need to invert the sign.
integrand = -1 * 1e-3 * ds["Shum"] * ds["Vwnd"]
Fy = bulk_recycling_model.numerical_integration.
 ↪integrate_no_extrapolation(integrand, ds["Psfc"])
```

```
# Units: mb x m/s
```

[8]:
```
# Prepare and scale the data
from bulk_recycling_model import preprocess
from bulk_recycling_model.axis import Axis
from bulk_recycling_model.scaling import Scaling, UnitSystem

print("prepping data for recycling - scaling and flux calcs etc")

# degrees
L = ds.coords["lon"].max().item() - ds.coords["lon"].min().item()
# convert to meters
L = L * 111e3 * np.cos(np.deg2rad(ds.coords["lat"].mean().item()))
dx = L / ds.sizes["lon"]

# lon axis
lon_axis = Axis(
    ds.coords["lon"].min().item(),
    ds.coords["lon"].diff("lon").mean().item(),
    ds.sizes["lon"],
)

# degrees
H = ds.coords["lat"].values[-1] - ds.coords["lat"].values[0]
# convert to meters
H = H * 111e3
dy = H / ds.sizes["lat"]

# lat axis
lat_axis = Axis(
    ds.coords["lat"].min().item(),
    ds.coords["lat"].diff("lat").mean().item(),
    ds.sizes["lat"],
)

print(f"{L = :.2e} m")
print(f"{dx = :.2e} m")
print(f"{H = :.2e} m")
print(f"{dy = :.2e} m")

# make a scaling object to convert between unit systems
scaling = Scaling(H)

dx = scaling.distance.convert(dx, UnitSystem.SI, UnitSystem.scaled)
dy = scaling.distance.convert(dy, UnitSystem.SI, UnitSystem.scaled)
print(f"{dx = :.2e} scaled")
print(f"{dy = :.2e} scaled")
```

```python
# convert Fx and Fy to scaled units
Fx = scaling.water_vapor_flux.convert(Fx.values, UnitSystem.natural, UnitSystem.
 ↪scaled)
Fy = scaling.water_vapor_flux.convert(Fy.values, UnitSystem.natural, UnitSystem.
 ↪scaled)

# convert E to scaled units
#print('pre-scaled',ds['Evap'])
E = scaling.evaporation.convert(ds["Evap"].values, UnitSystem.natural,␣
 ↪UnitSystem.scaled)
```

```
prepping data for recycling - scaling and flux calcs etc
L = 1.66e+06 m
dx = 2.73e+04 m
H = 1.66e+06 m
dy = 2.73e+04 m
dx = 1.64e-02 scaled
dy = 1.64e-02 scaled
```

- Create recycling output array based on the shape of one of the surface input files: evap (E)
- Run through each timestep in the input files and calculate recycling ratio at each timestep across domain

[9]:
```python
import matplotlib.pyplot as plt
import logging
logging.basicConfig()
logging.getLogger("bulk_recycling_model").setLevel(logging.INFO)
from bulk_recycling_model import plotting
from bulk_recycling_model.main import run

rho_ar = np.empty((np.shape(E)[0]-1,np.shape(E)[1]-1,np.shape(E)[2]))
#Entering preprocessing and time step loop
#Run model and plot
for i,time in enumerate(ds.time):

    # preprocess E onto the secondary grid
    Ei = preprocess.prepare_E(E[:,:,i])

    # preprocess water vapor fluxes onto the secondary grid
    Fxi_left = preprocess.prepare_Fx_left(Fx[:,:,i])
    Fxi_right = preprocess.prepare_Fx_right(Fx[:,:,i])
    Fyi_bottom = preprocess.prepare_Fy_bottom(Fy[:,:,i])
    Fyi_top = preprocess.prepare_Fy_top(Fy[:,:,i])

    # compute P
    Pi = preprocess.calculate_precipitation(Fxi_left, Fxi_right, Fyi_bottom,␣
 ↪Fyi_top, Ei, dx, dy)
```

```
    # Create a quiver plot
    fig, ax = plt.subplots()
    #X, Y = np.meshgrid(lon_axis.secondary, lat_axis.secondary, indexing="ij")
    #collection = ax.pcolormesh(X[::3,::3], Y[::3,::3], Ei[::3,::3], alpha=0.5)
    #fig.colorbar(collection, label="E (scaled)")
    U,V = plotting.build_uv_fluxes(Fxi_left, Fxi_right, Fyi_bottom, Fyi_top)
    X, Y = np.meshgrid(lon_axis.half_step, lon_axis.half_step, indexing="ij")
    ax.quiver(X[::3, ::3],Y[::3, ::3],U[::3, ::3],V[::3, ::3])
    fig.suptitle("Water Vapor Fluxes on cell edges")

    # Run the model
    status = run(
        Fxi_left,
        Fxi_right,
        Fyi_bottom,
        Fyi_top,
        Ei,
        Pi,
        dx,
        dy,
        max_iter=500,
        tol=1e-3,
    )

    #Print timestep and status (converged or not) and add rho to recycling␣
↪ration array
    print(i,time.values)
    print(status['k'])
    rho_ar[:,:,i] = status["rho"]

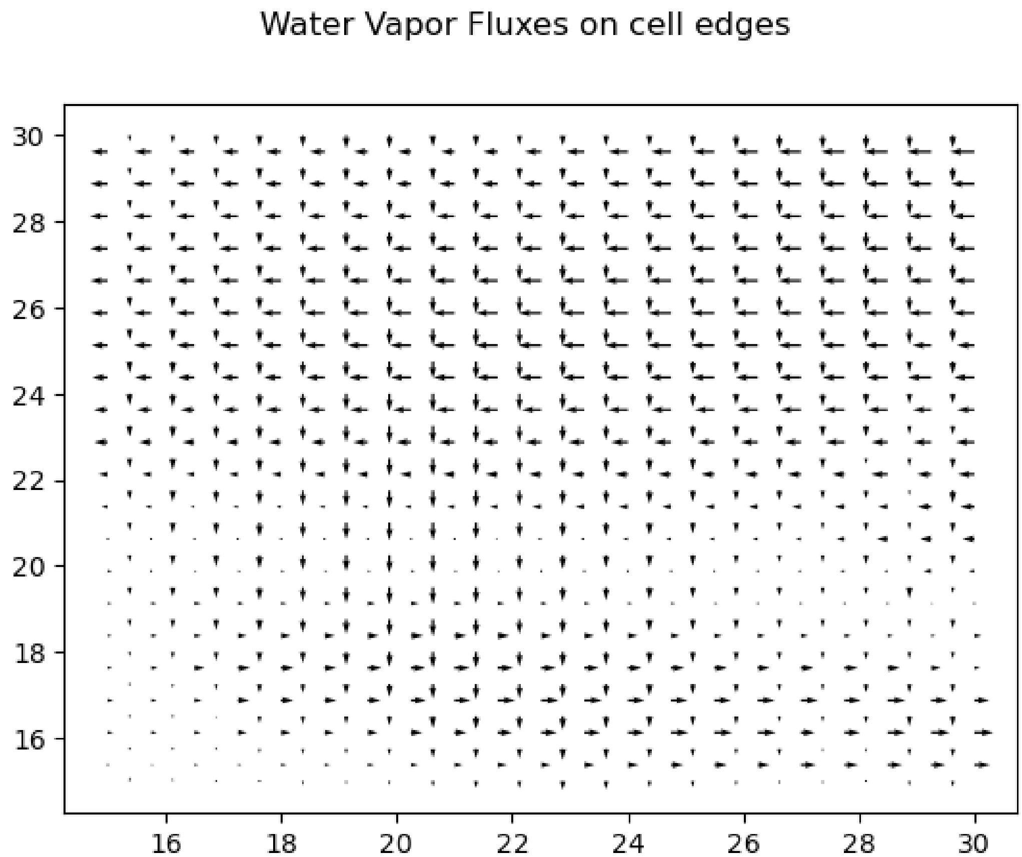
    # plot each timestep
    fig, ax = plt.subplots()
    collection = plotting.pcolormesh(ax, status["rho"], lon_axis, lat_axis)
                                    #vmin=0.0, vmax=0.8)
    fig.colorbar(collection)
    fig.suptitle(str(time.values)+" $\\rho$")
    #plt.savefig(datap+"rho_"+str(time.values)+".png")
    plt.show()
    plt.close()

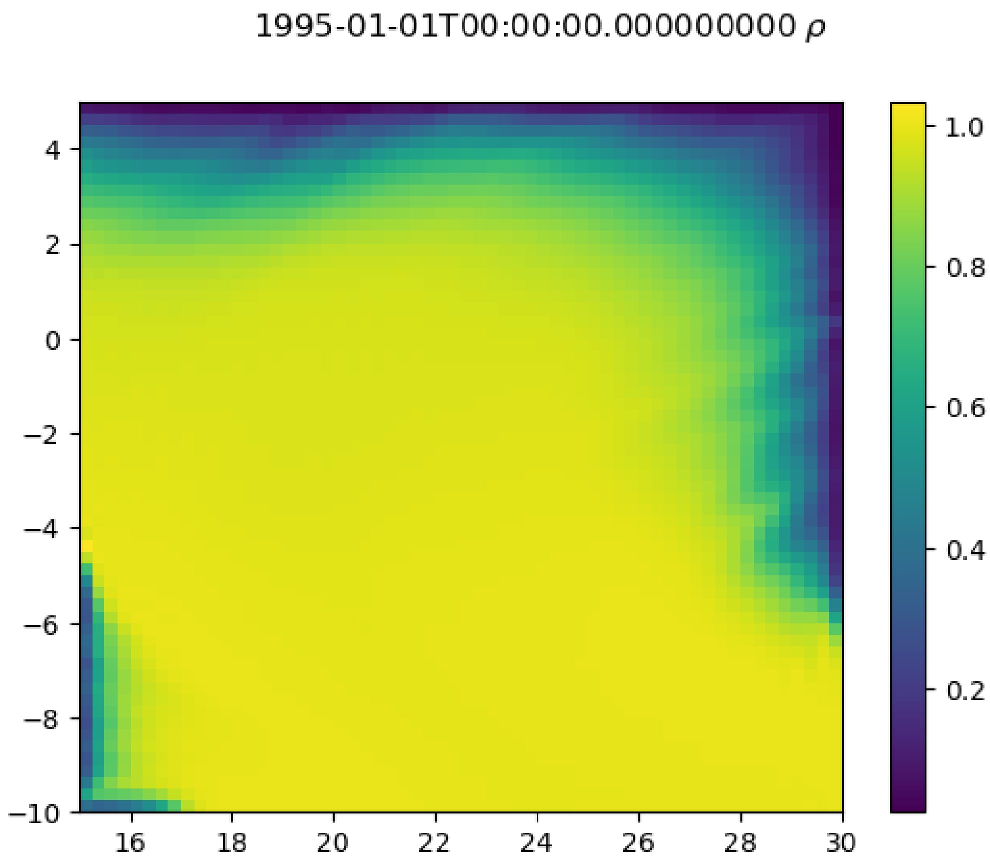
    # plot the convergence
    deltas = status["deltas"]
    fig, ax = plt.subplots()
    ax.plot(deltas)
    ax.set_title("Convergence")
    ax.set_xlabel("Iteration")
```

```
    plt.show()
    plt.close()
```

```
INFO:bulk_recycling_model.main:Converged in 123 iterations and 0:00:01.001393
```

```
0 1995-01-01T00:00:00.000000000
123
```




1995-01-01T00:00:00.000000000 ρ
4
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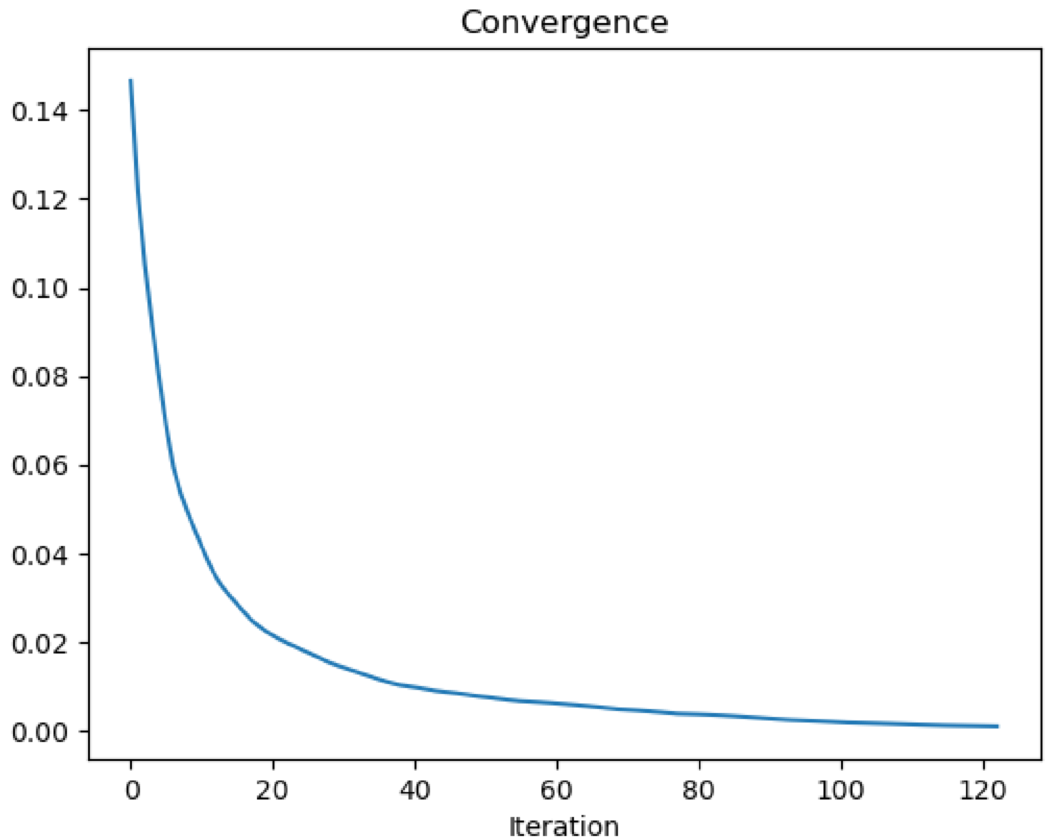
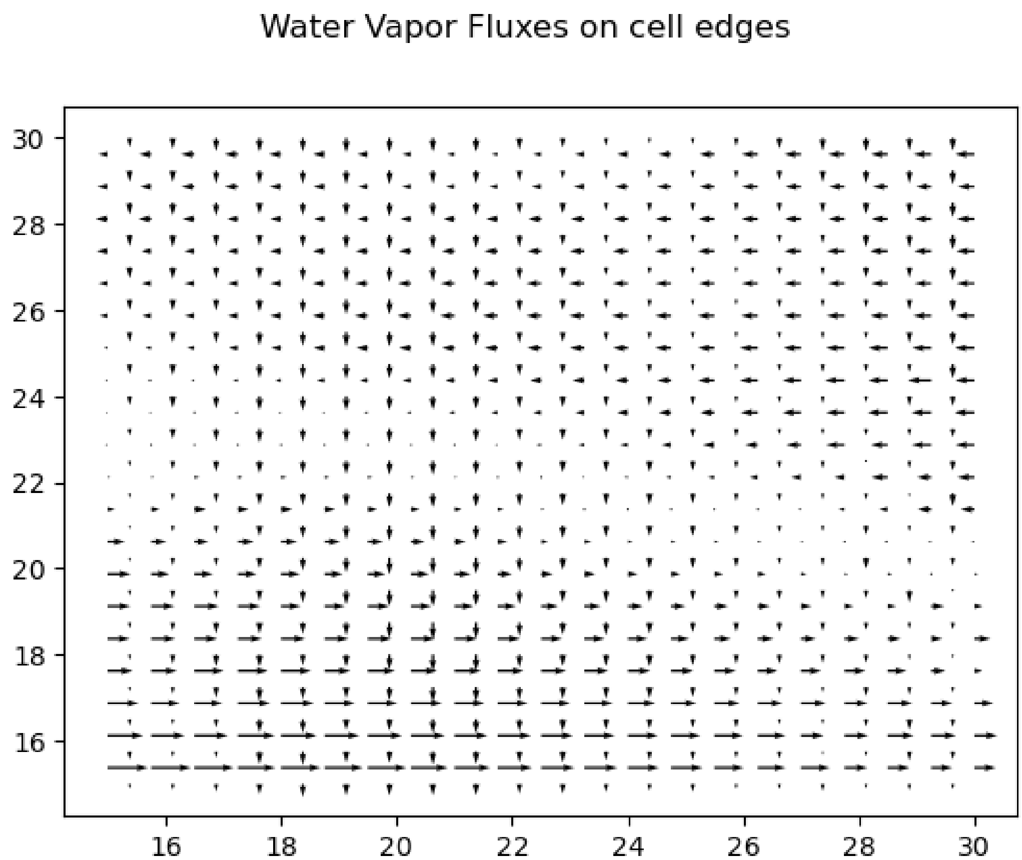
−10
16
18
20
22
24
26
28
30
1.0
0.8
0.6
0.4
0.2




```
INFO:bulk_recycling_model.main:Converged in 111 iterations and 0:00:00.910709
```

```
1 1995-02-01T00:00:00.000000000
111
```


Water Vapor Fluxes on cell edges
30
28
26
24
22
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18
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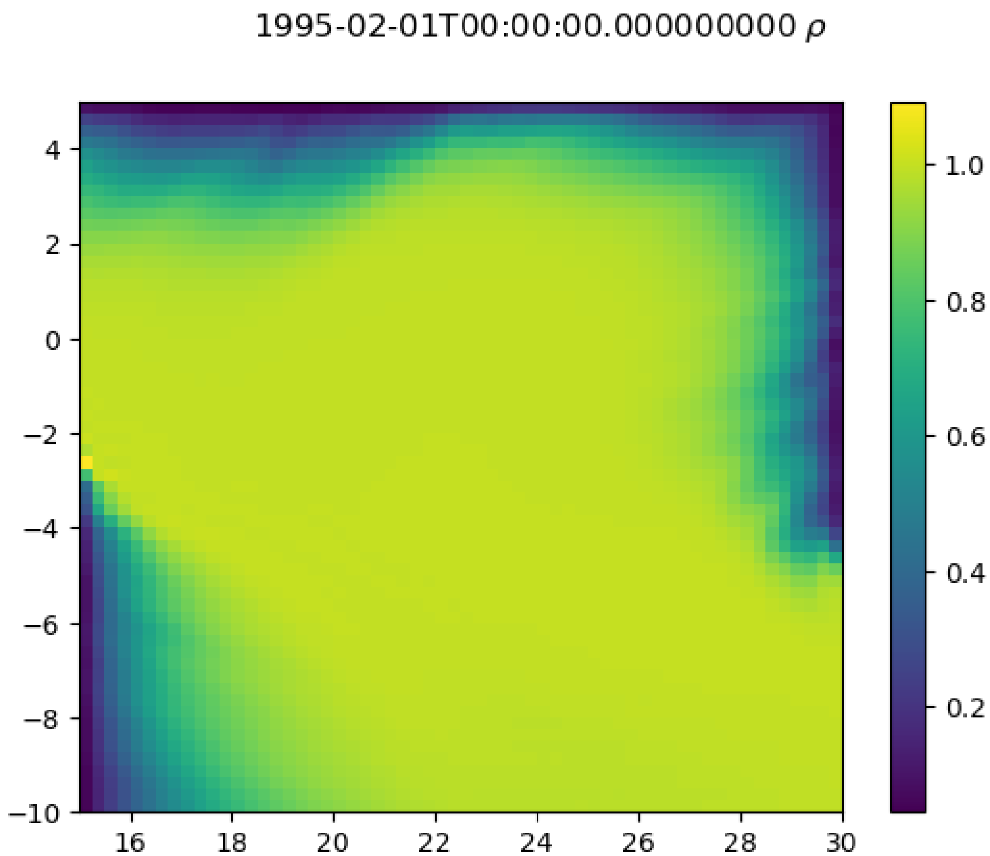
16
18
20
22
24
26
28
30


1995-02-01T00:00:00.000000000 ρ
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16
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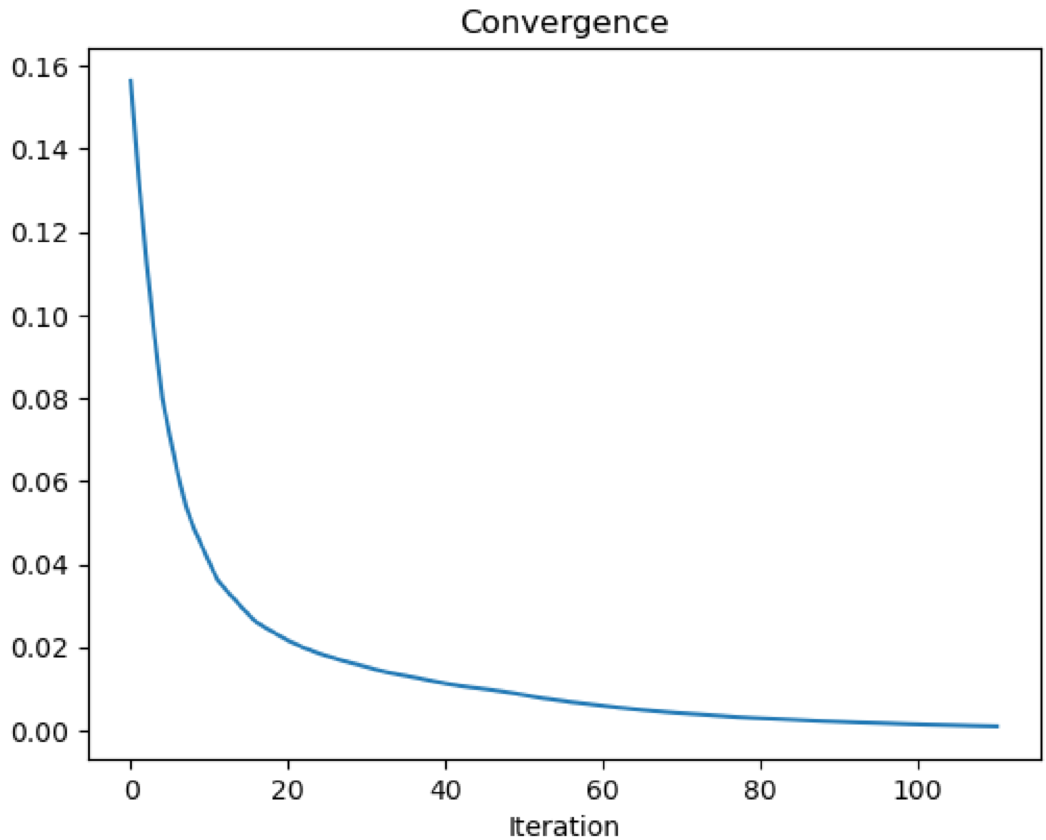
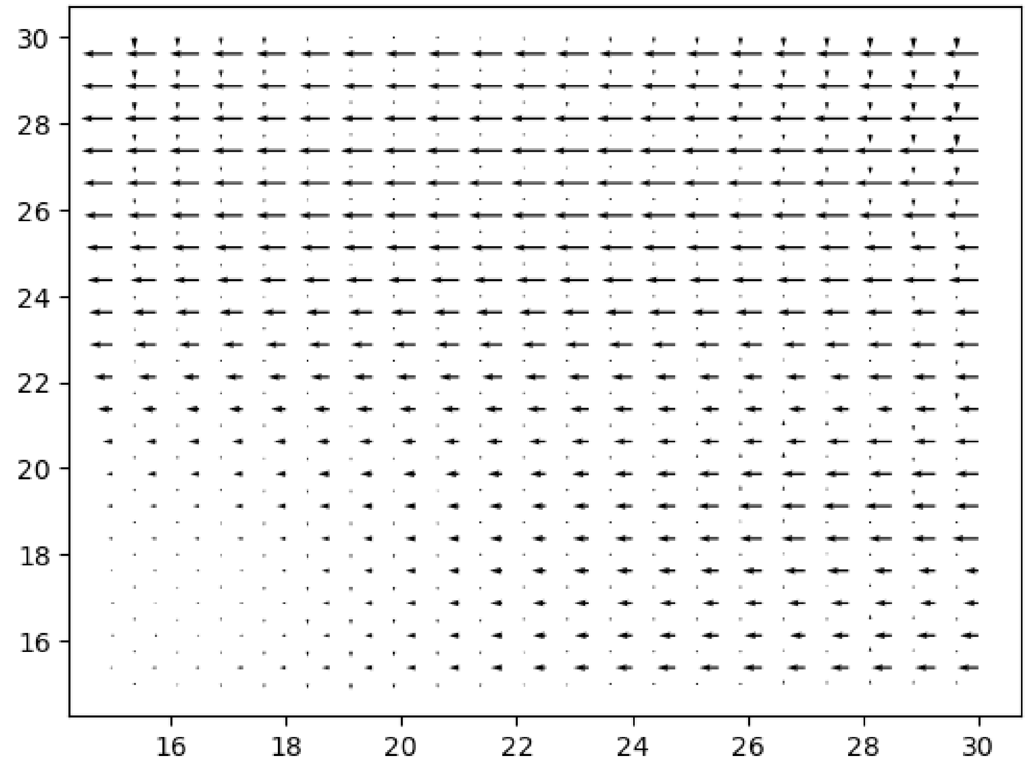
1.0
0.8
0.6
0.4
0.2

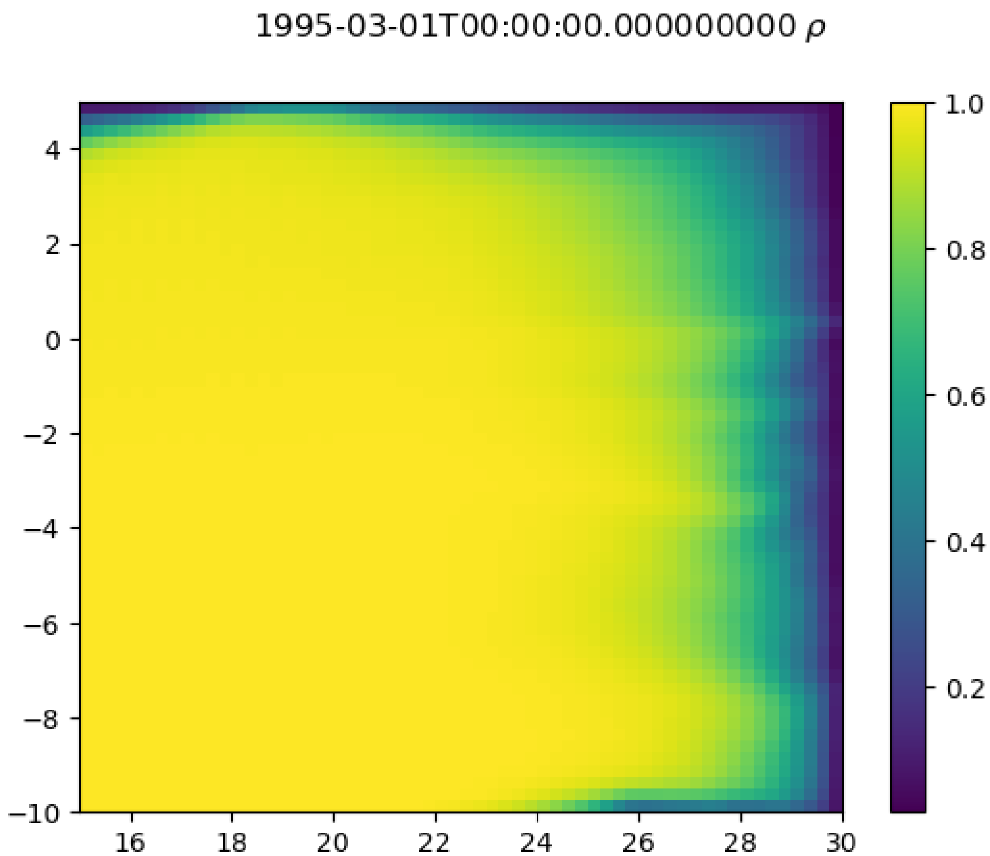



```
INFO:bulk_recycling_model.main:Converged in 124 iterations and 0:00:01.022781
```

```
2 1995-03-01T00:00:00.000000000
124
```

Water Vapor Fluxes on cell edges




1995-03-01T00:00:00.000000000 ρ
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16
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1.0
0.8
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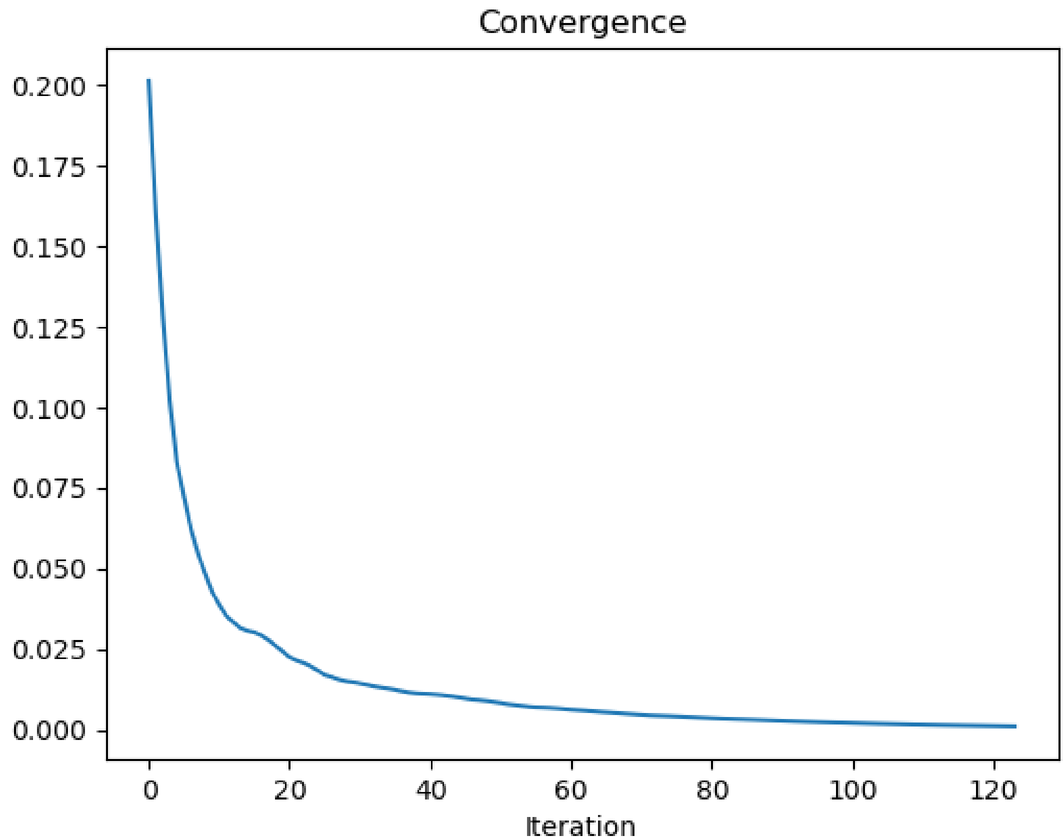
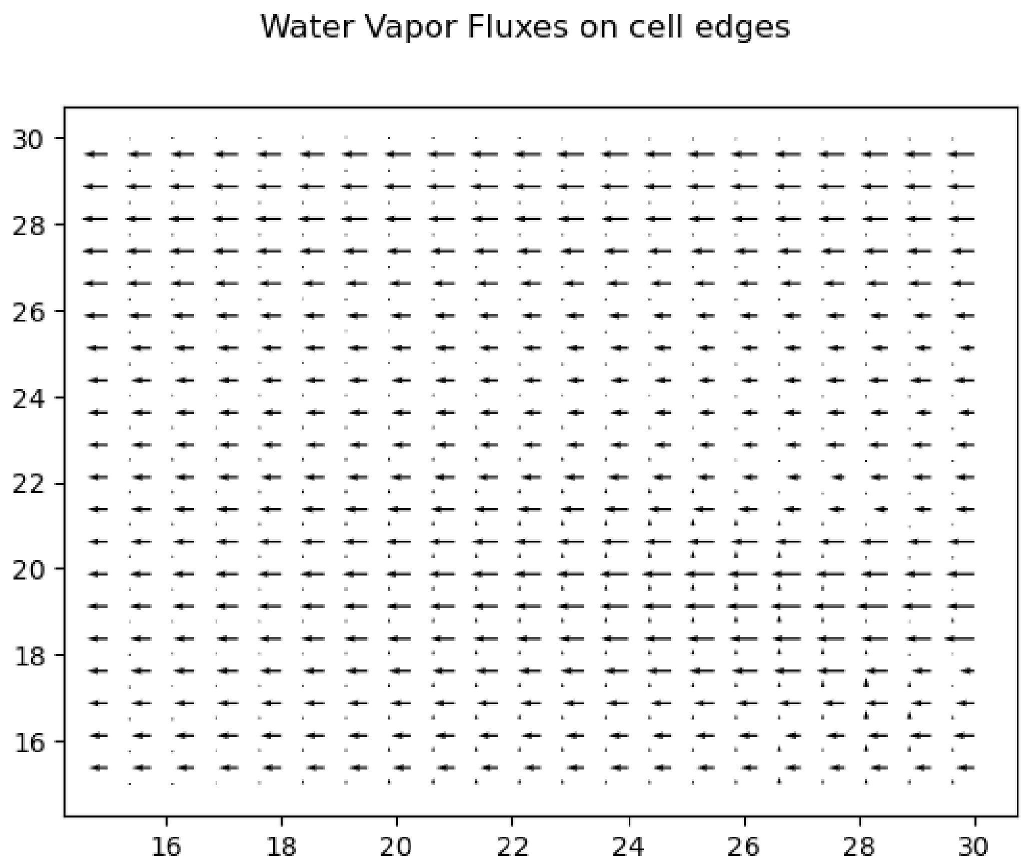
0.4
0.2




```
INFO:bulk_recycling_model.main:Converged in 148 iterations and 0:00:01.203281
```

```
3 1995-04-01T00:00:00.000000000
148
```


Water Vapor Fluxes on cell edges
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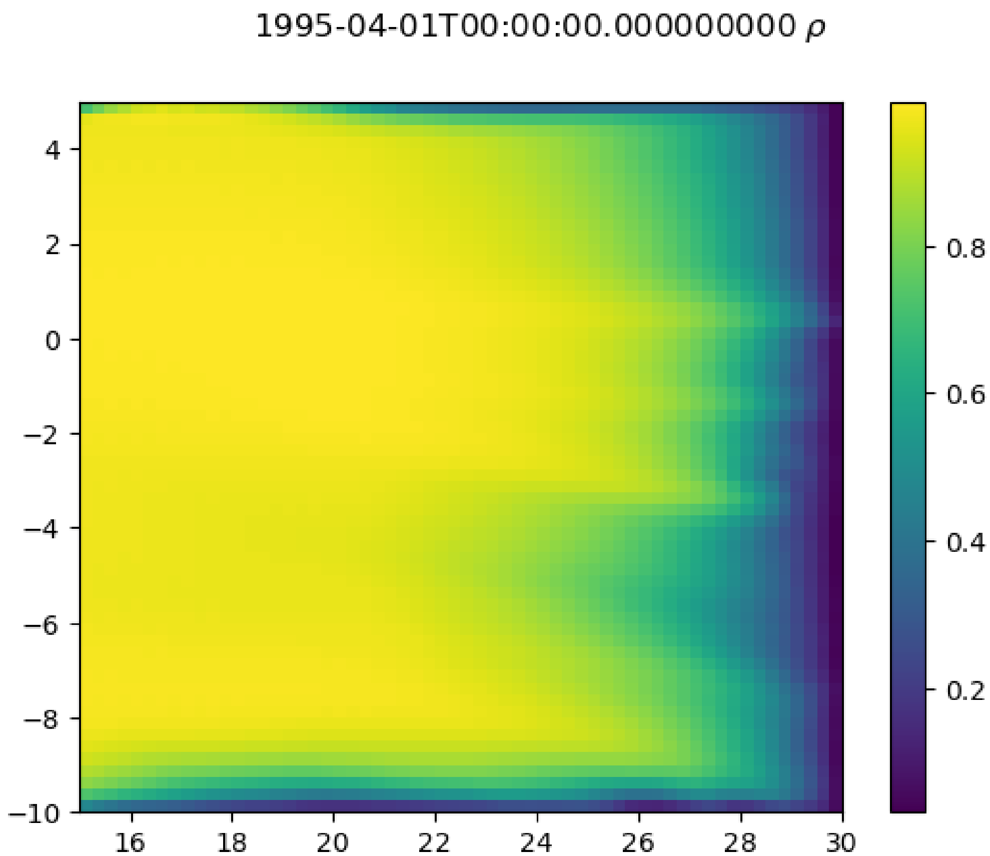
1995-04-01T00:00:00.000000000 ρ
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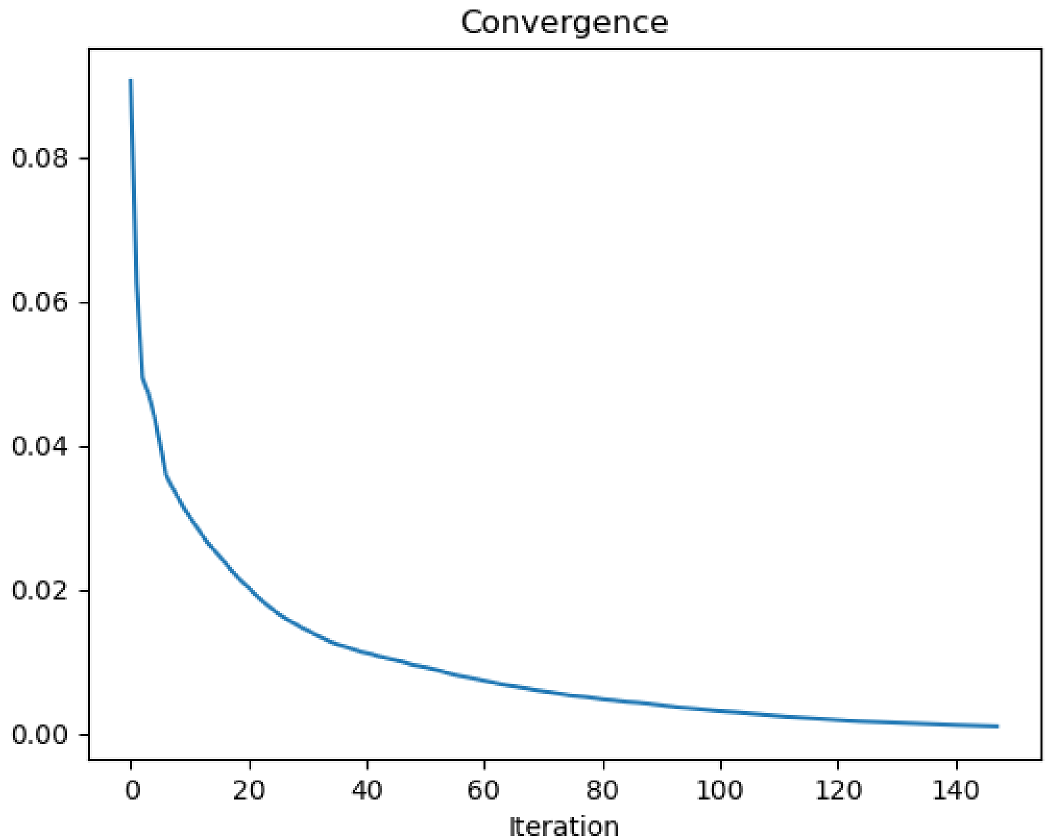
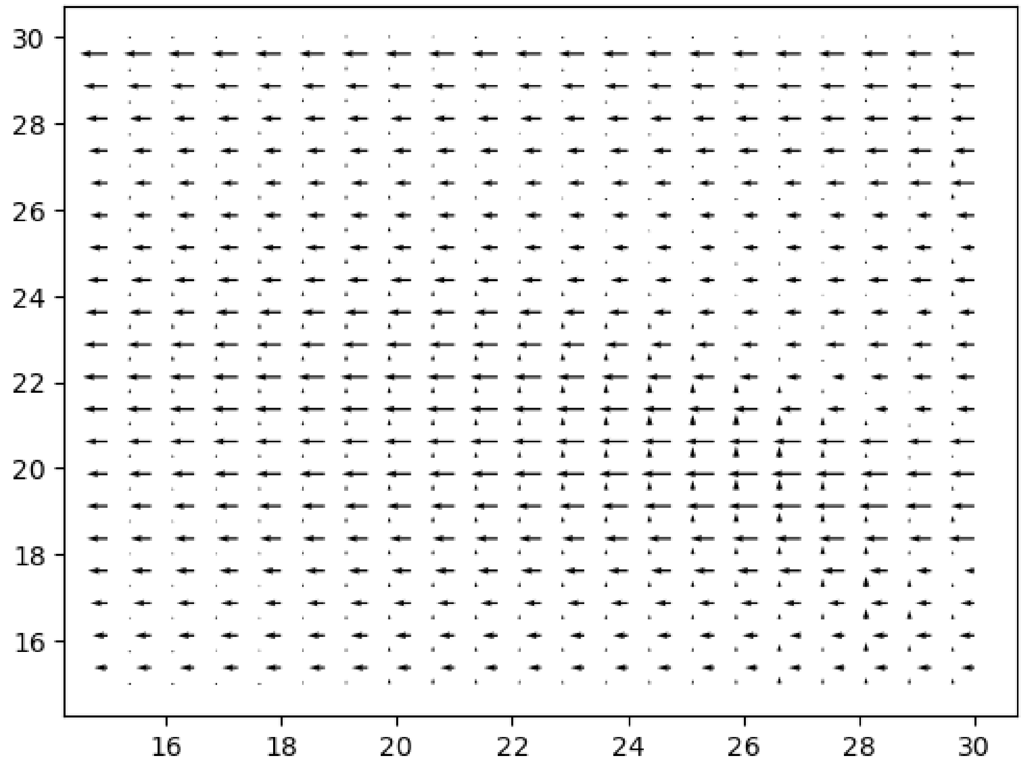
0.2

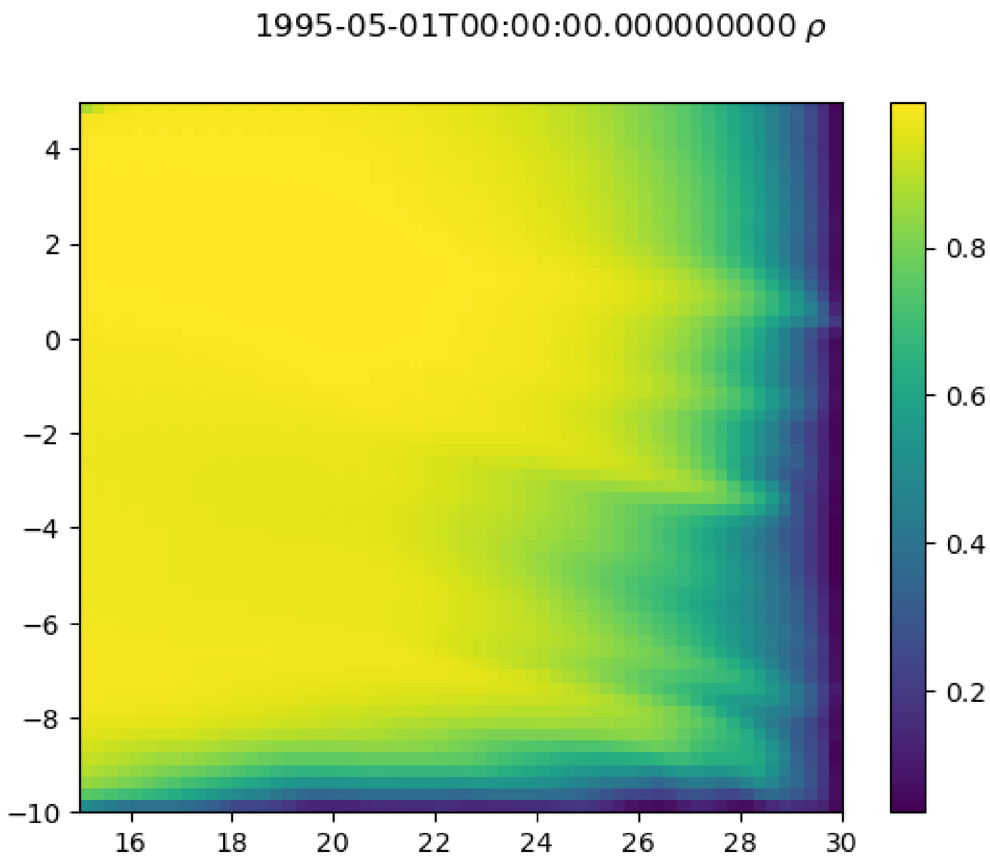



```
INFO:bulk_recycling_model.main:Converged in 152 iterations and 0:00:01.270163
```

```
4 1995-05-01T00:00:00.000000000
152
```

Water Vapor Fluxes on cell edges




1995-05-01T00:00:00.000000000 ρ
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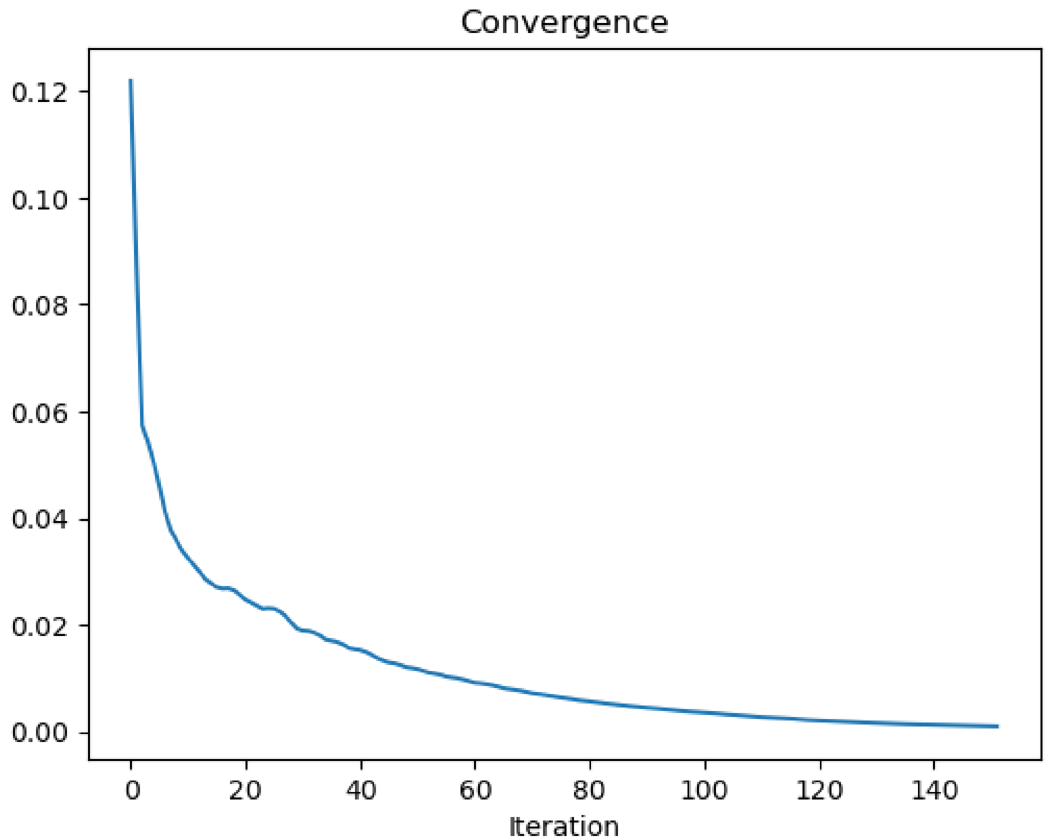


```
INFO:bulk_recycling_model.main:Converged in 135 iterations and 0:00:01.101397
```

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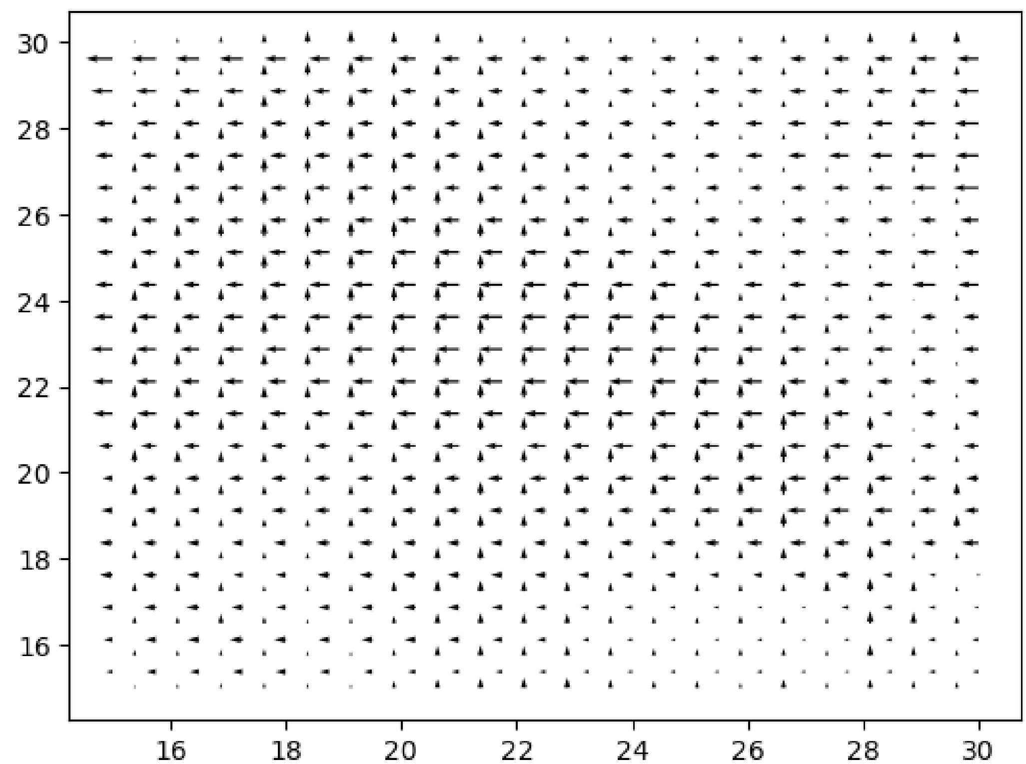
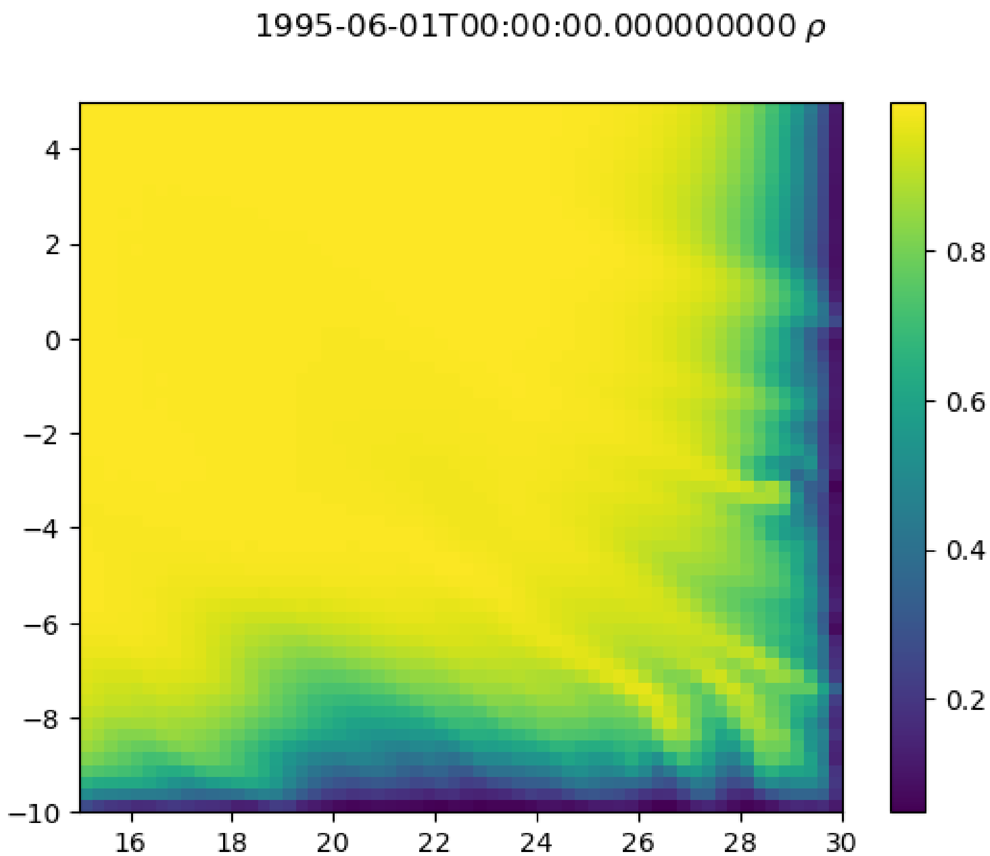
5 1995-06-01T00:00:00.000000000
135
```

Water Vapor Fluxes on cell edges




1995-06-01T00:00:00.000000000 ρ
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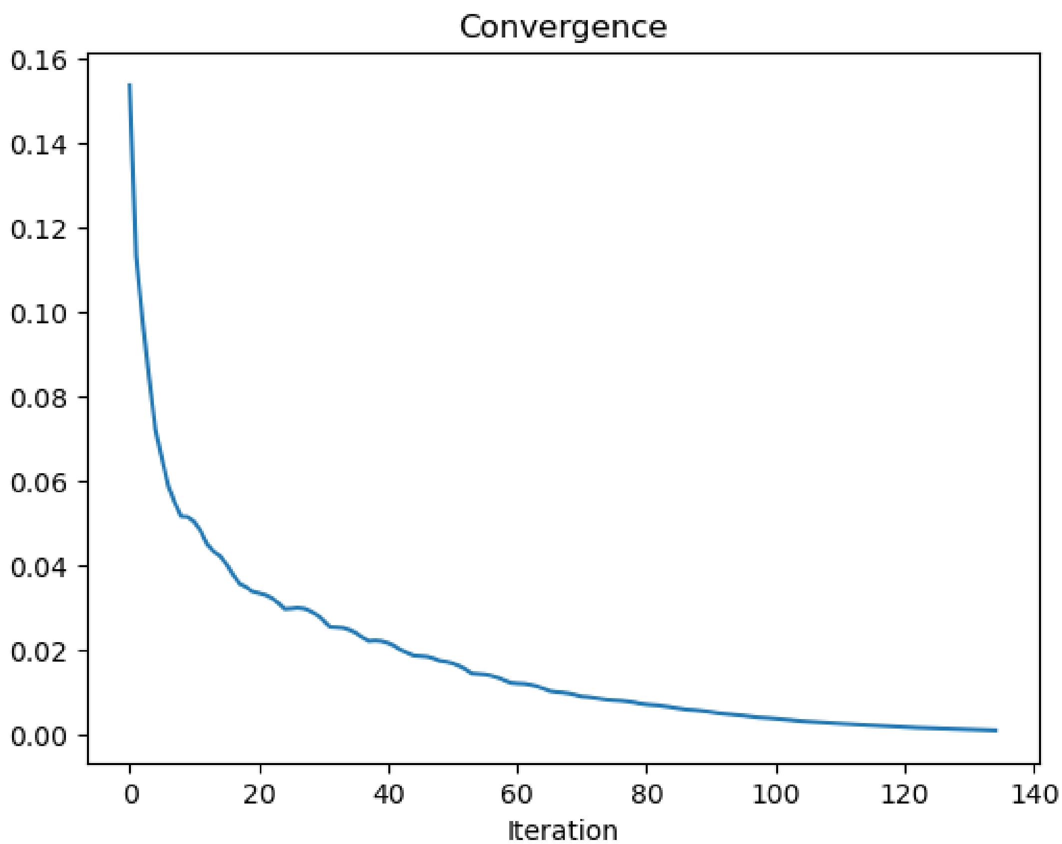
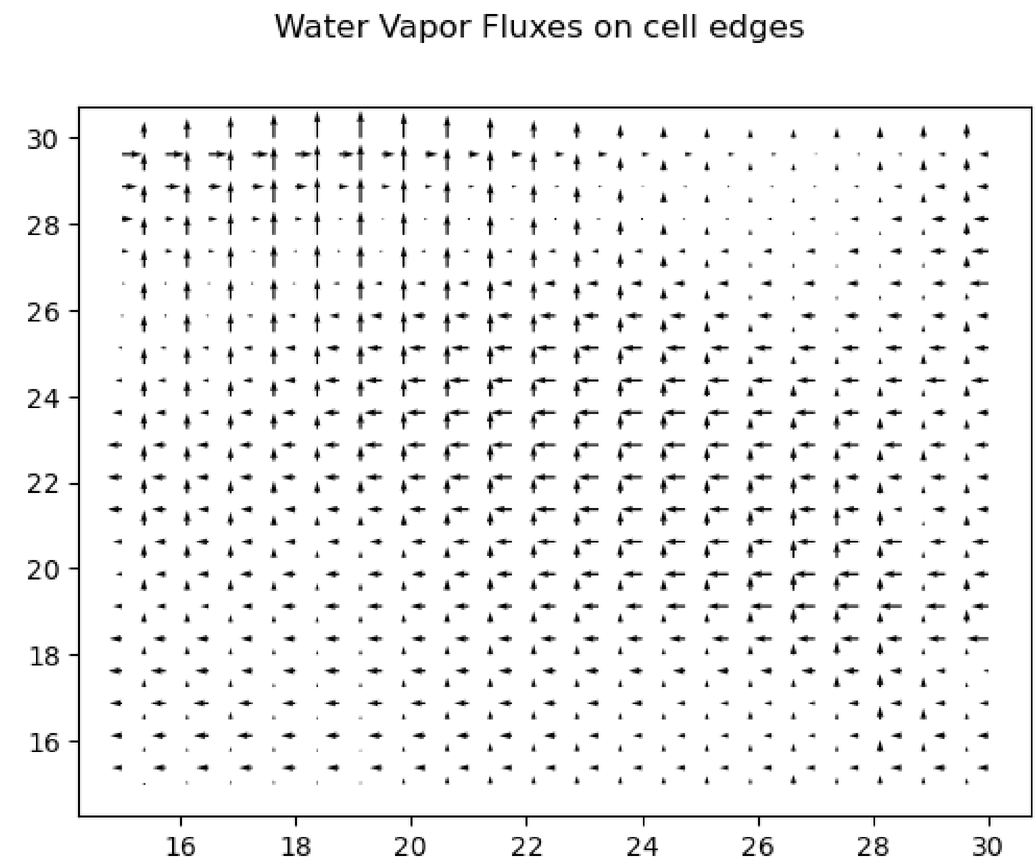



```
INFO:bulk_recycling_model.main:Converged in 149 iterations and 0:00:01.232036
```

```
6 1995-07-01T00:00:00.000000000
149
```


Water Vapor Fluxes on cell edges
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24
22
20
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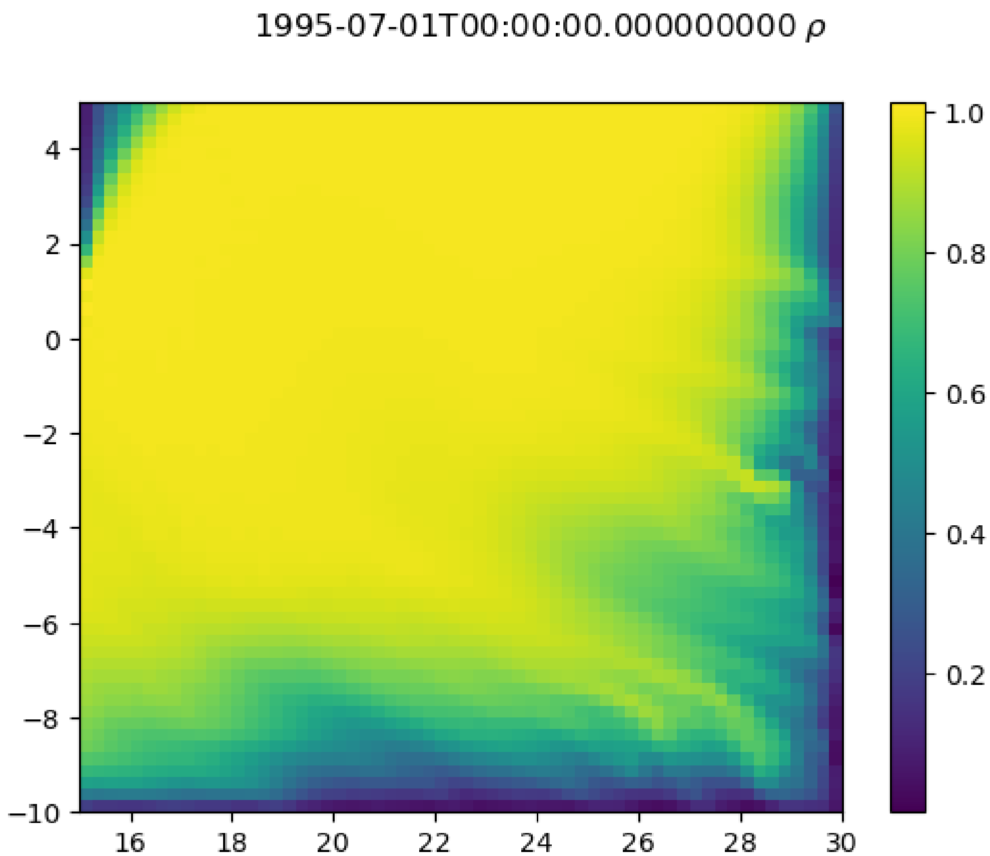
30


1995-07-01T00:00:00.000000000 ρ
4
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28
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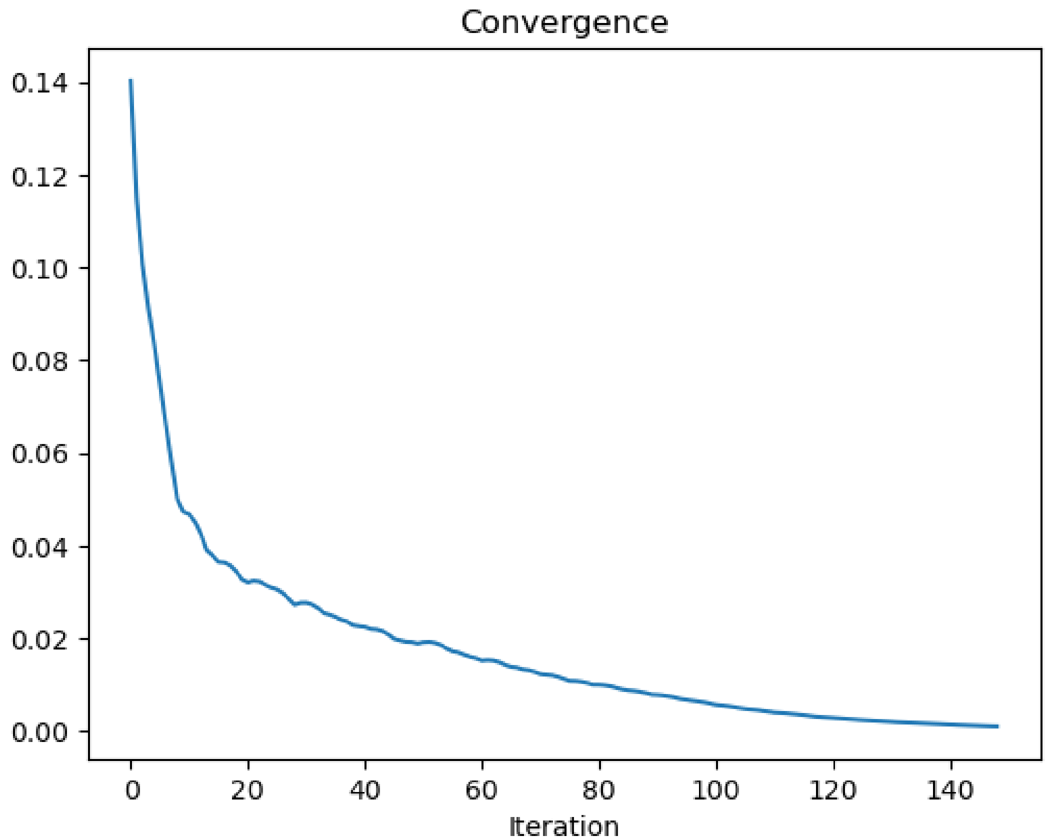
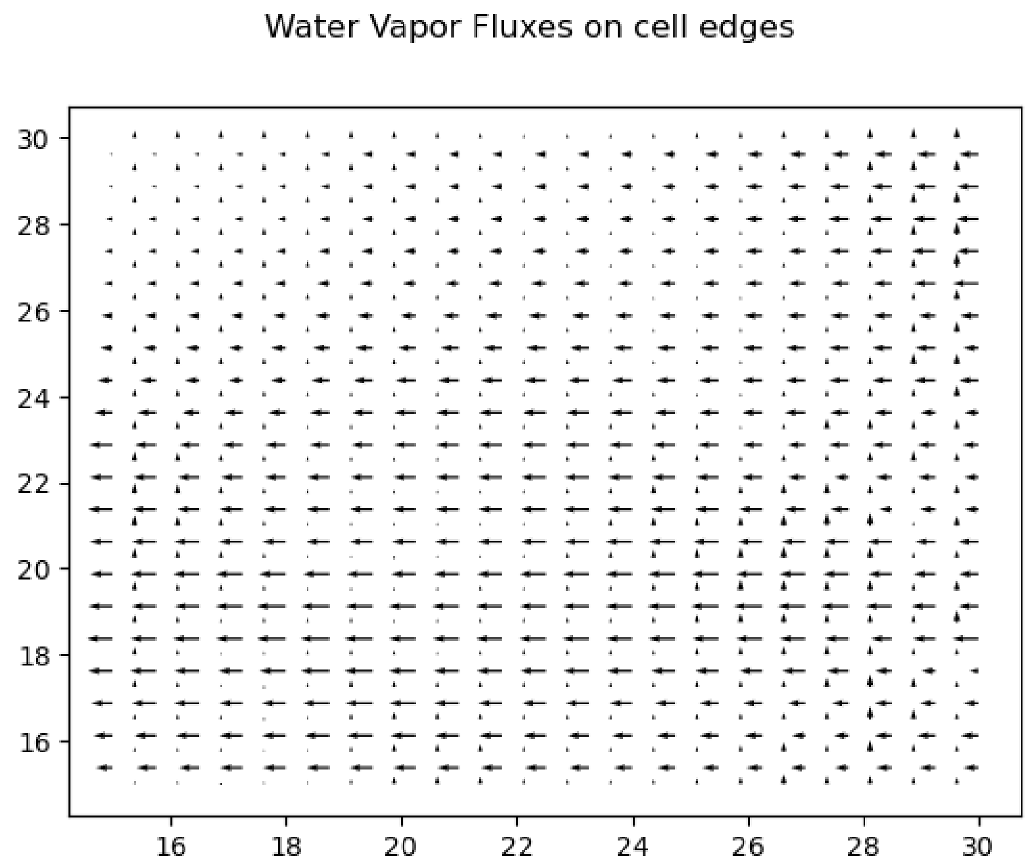
1.0
0.8
0.6
0.4
0.2




```
INFO:bulk_recycling_model.main:Converged in 179 iterations and 0:00:01.458896
```

```
7 1995-08-01T00:00:00.000000000
179
```


Water Vapor Fluxes on cell edges
30
28
26
24
22
20
18
16
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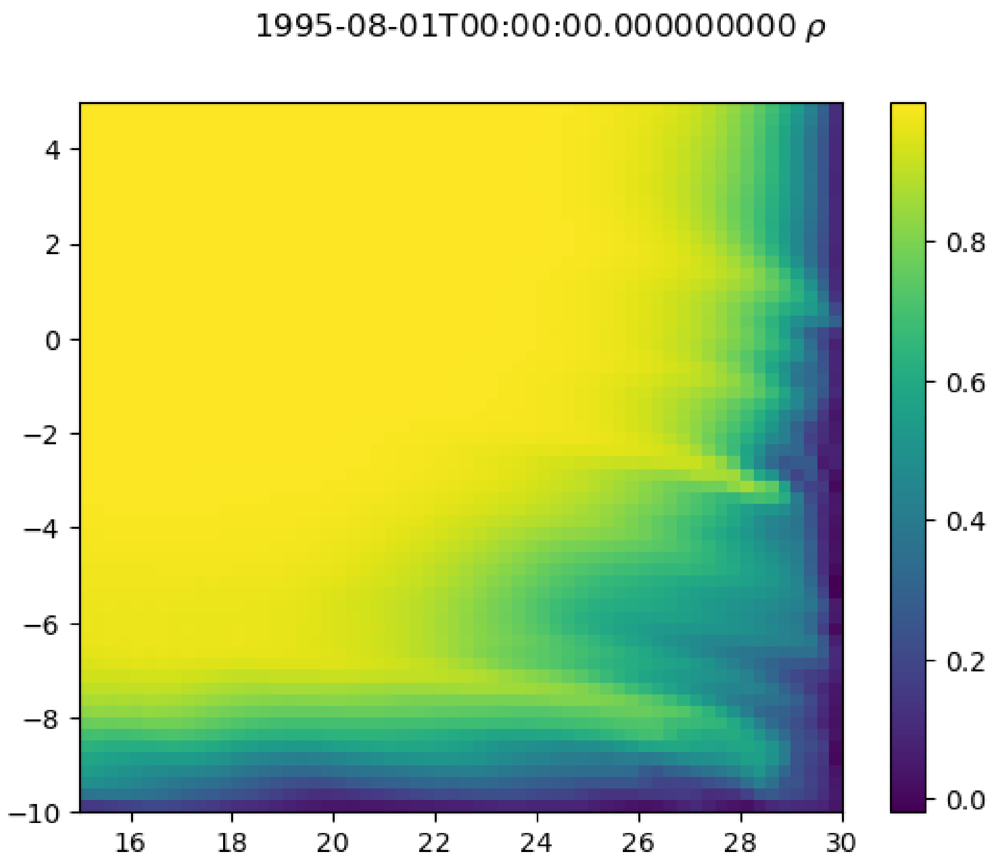
24
26
28
30


1995-08-01T00:00:00.000000000 ρ
4
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0
−2
−4
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−8
−10
16
18
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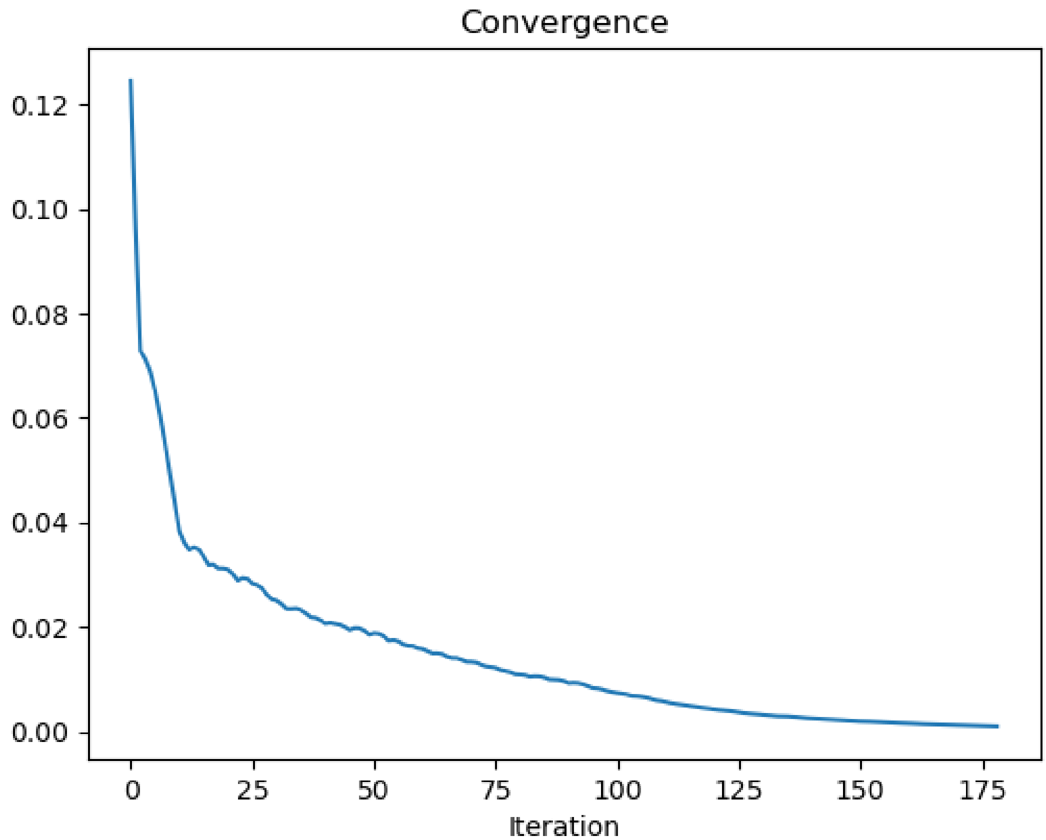
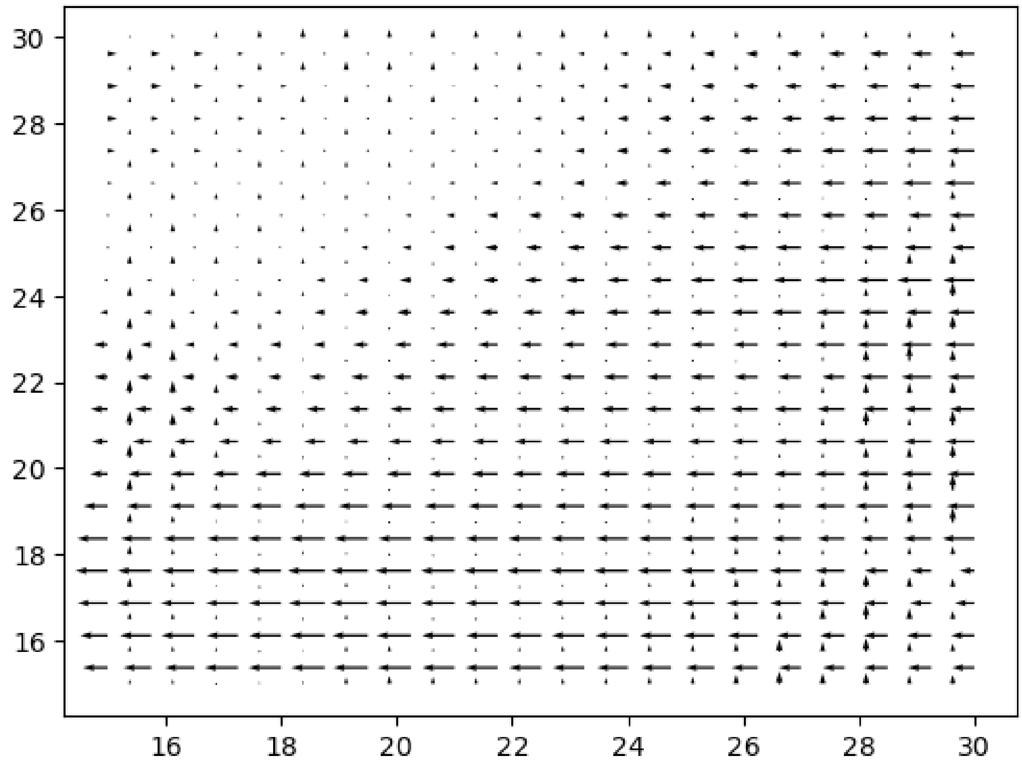
26
28
30
0.8
0.6
0.4
0.2
0.0

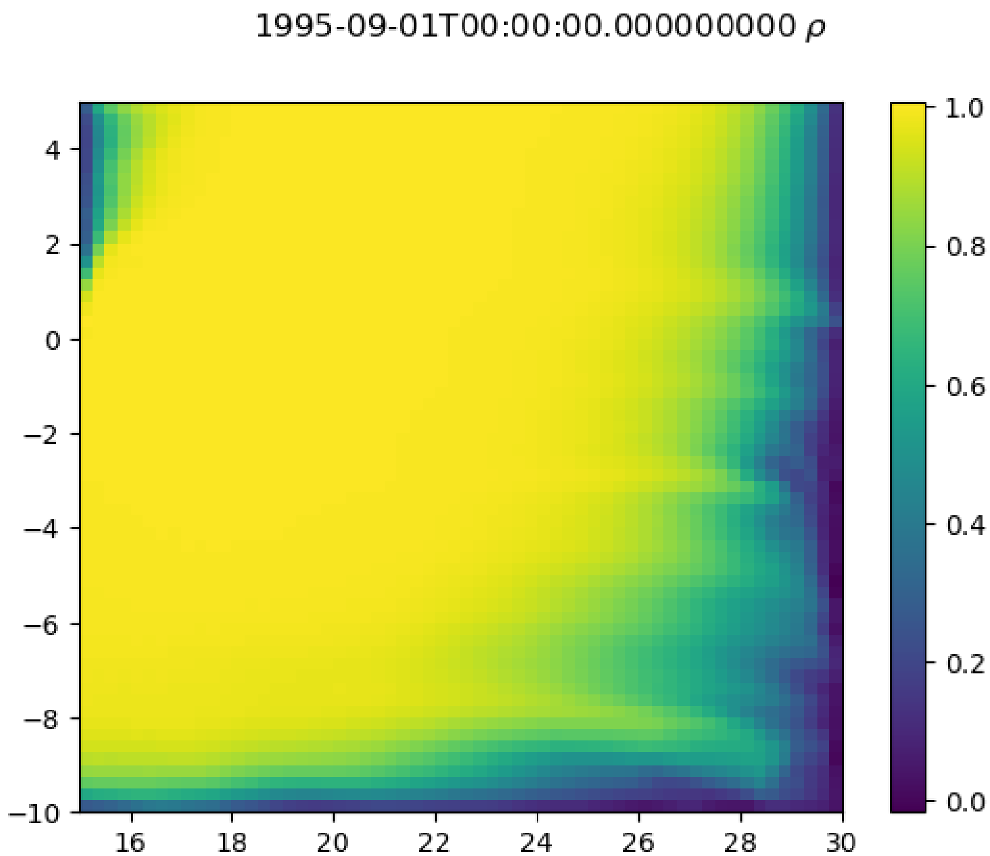


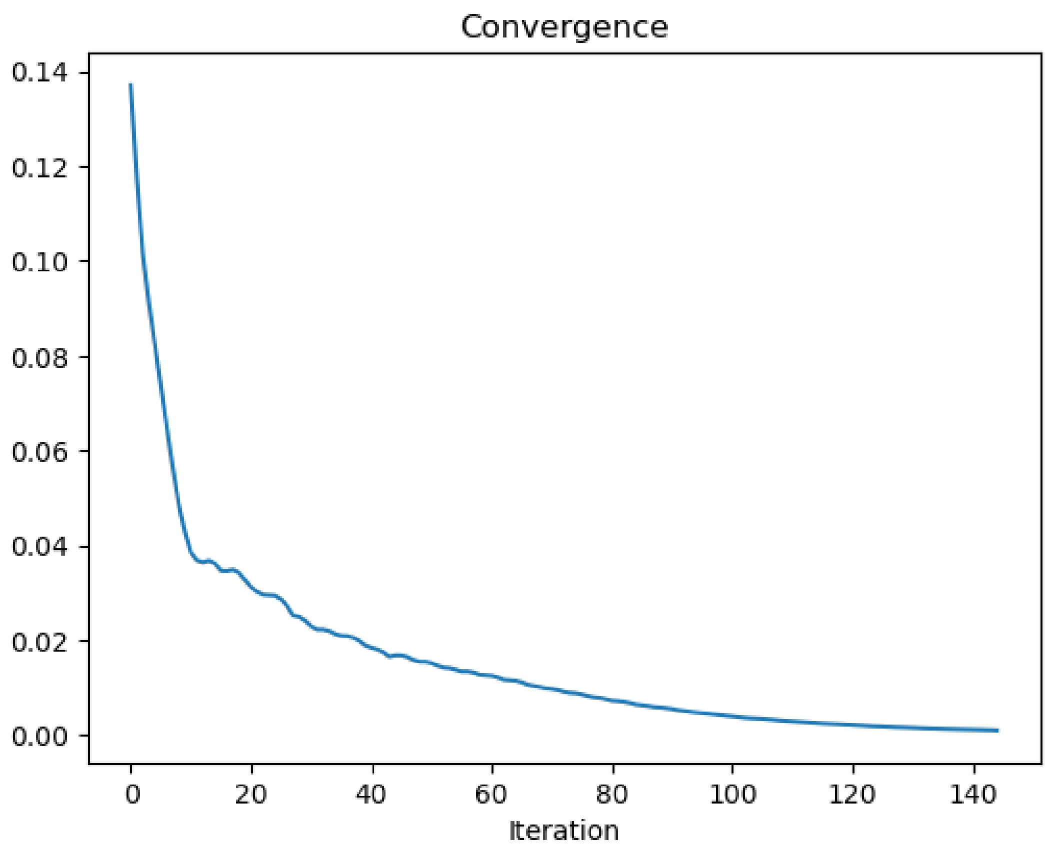

```
INFO:bulk_recycling_model.main:Converged in 145 iterations and 0:00:01.254586
```

```
8 1995-09-01T00:00:00.000000000
145
```

Water Vapor Fluxes on cell edges

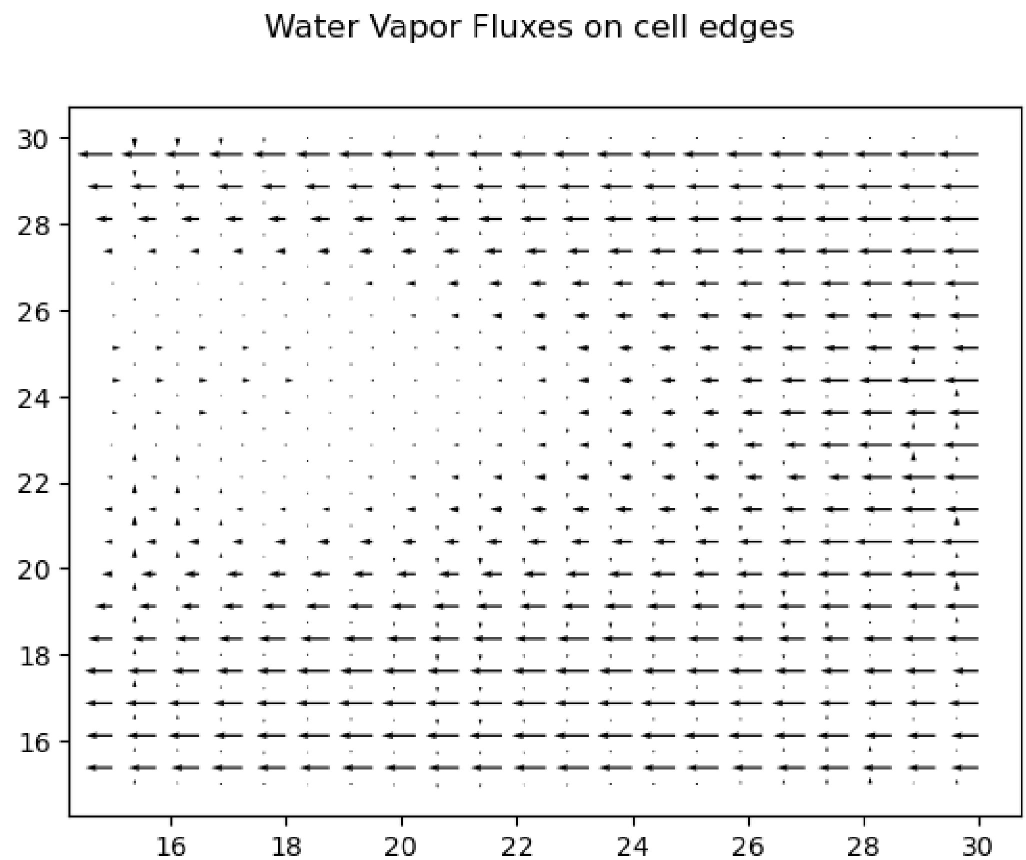


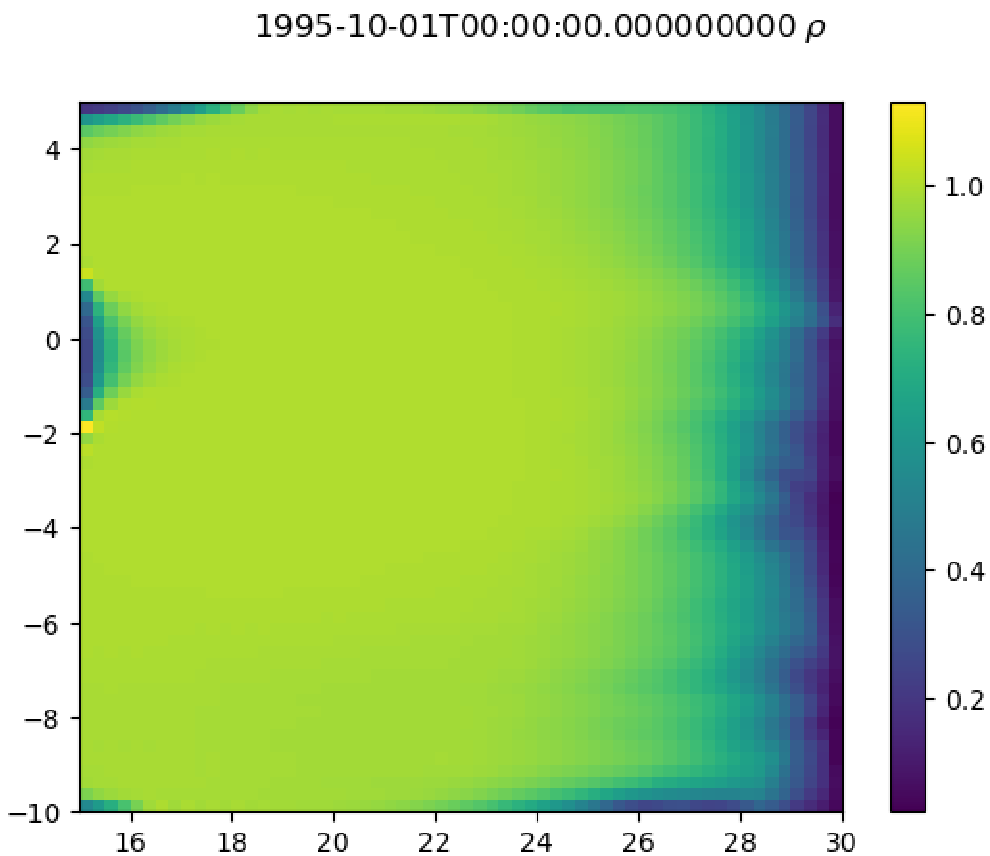

1995-09-01T00:00:00.000000000 ρ
4
2
0
−2
−4
−6
−8
−10
16
18
20
22
24
26
28
30
1.0
0.8
0.6
0.4
0.2
0.0

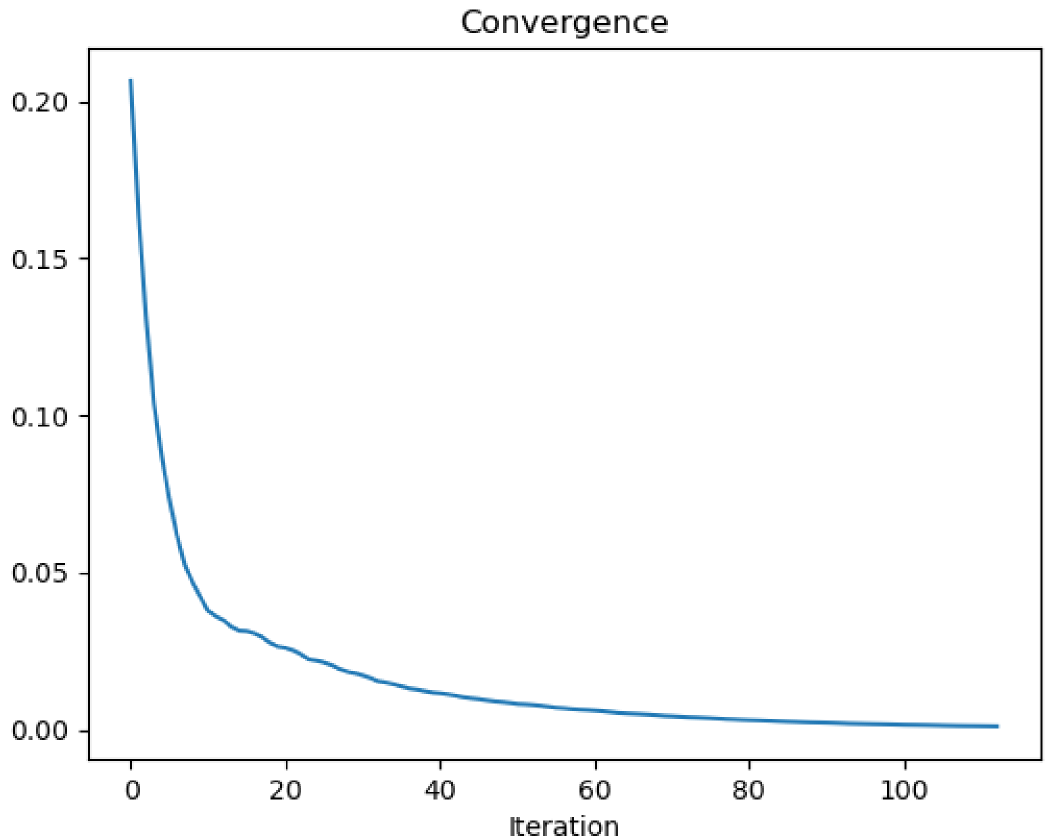



```
INFO:bulk_recycling_model.main:Converged in 113 iterations and 0:00:00.920279
```

```
9 1995-10-01T00:00:00.000000000
113
```


Water Vapor Fluxes on cell edges
30
28
26
24
22
20
18
16
16
18
20
22
24
26
28
30

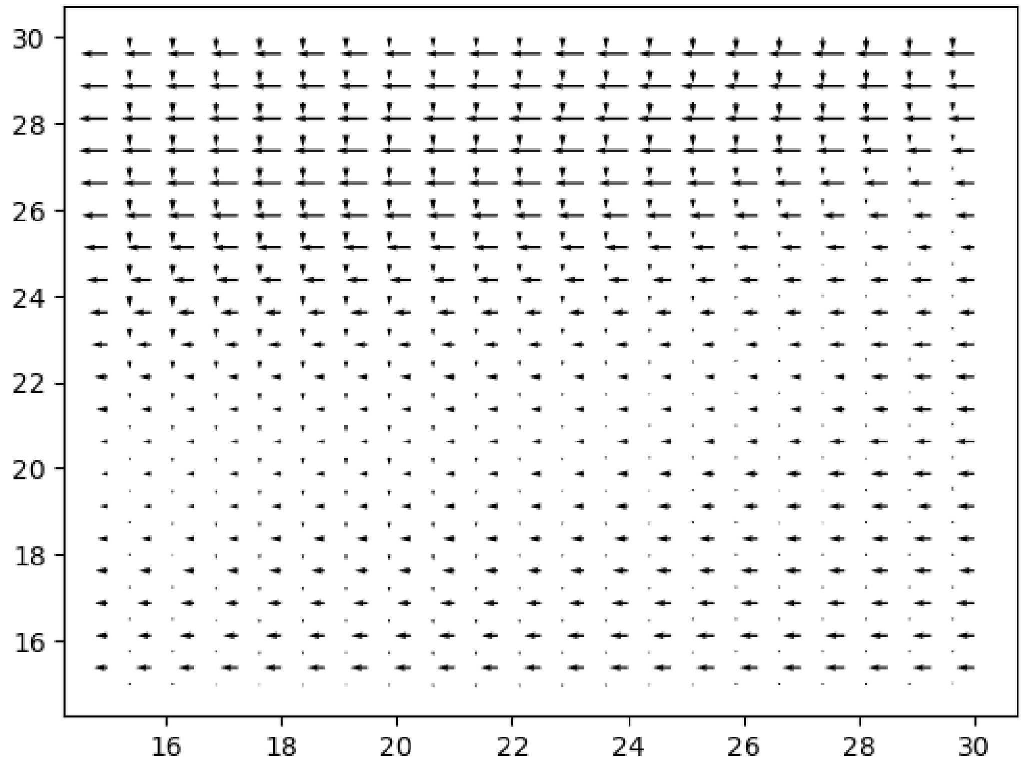

1995-10-01T00:00:00.000000000 ρ
4
2
0
−2
−4
−6
−8
−10
16
18
20
22
24
26
28
30
1.0
0.8
0.6
0.4
0.2

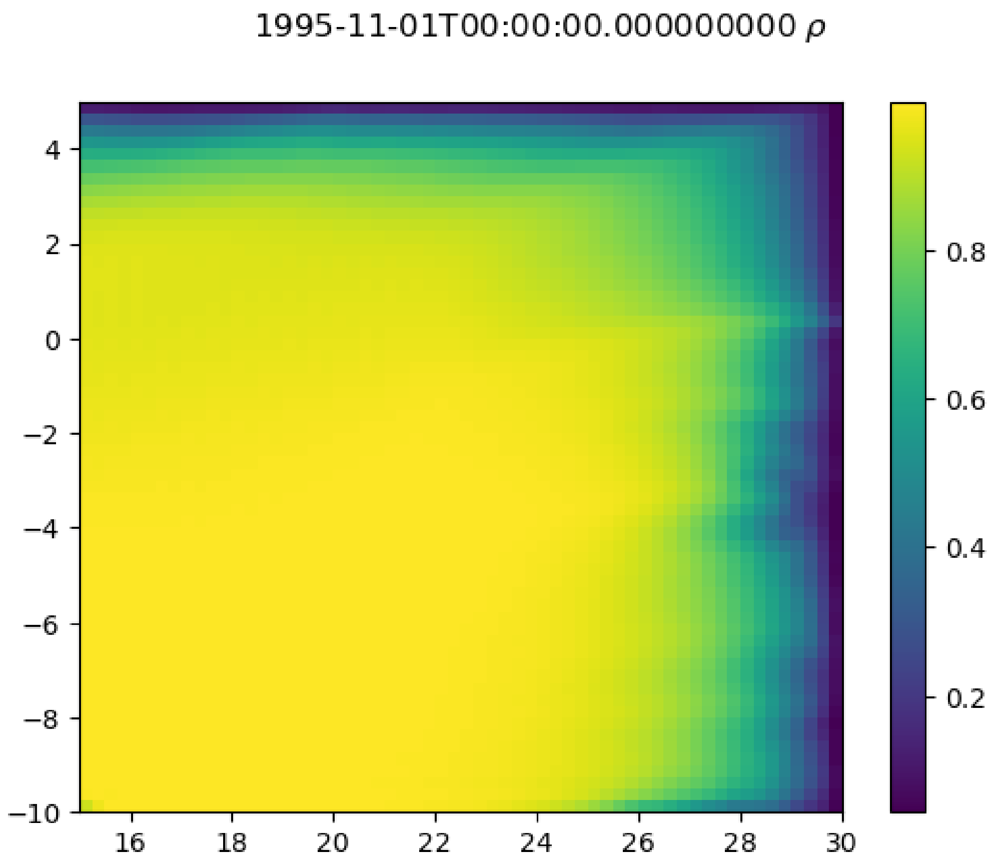



```
INFO:bulk_recycling_model.main:Converged in 150 iterations and 0:00:01.215269
```

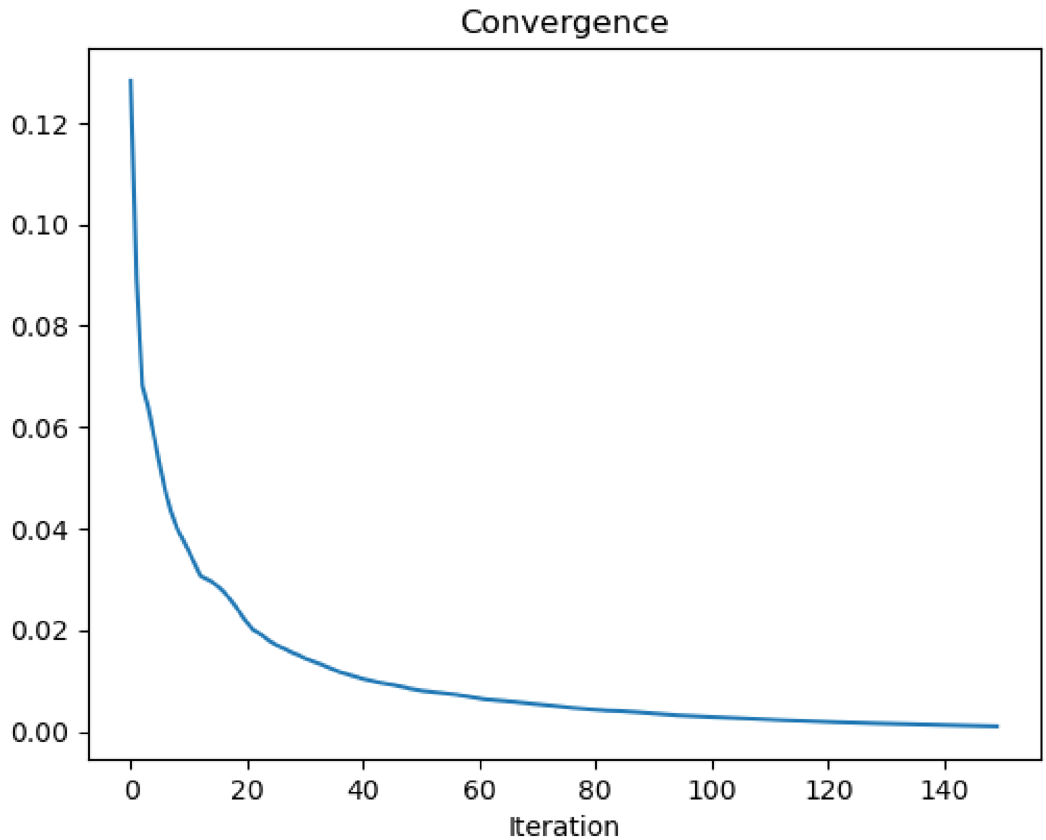
```
10 1995-11-01T00:00:00.000000000
150
```

Water Vapor Fluxes on cell edges





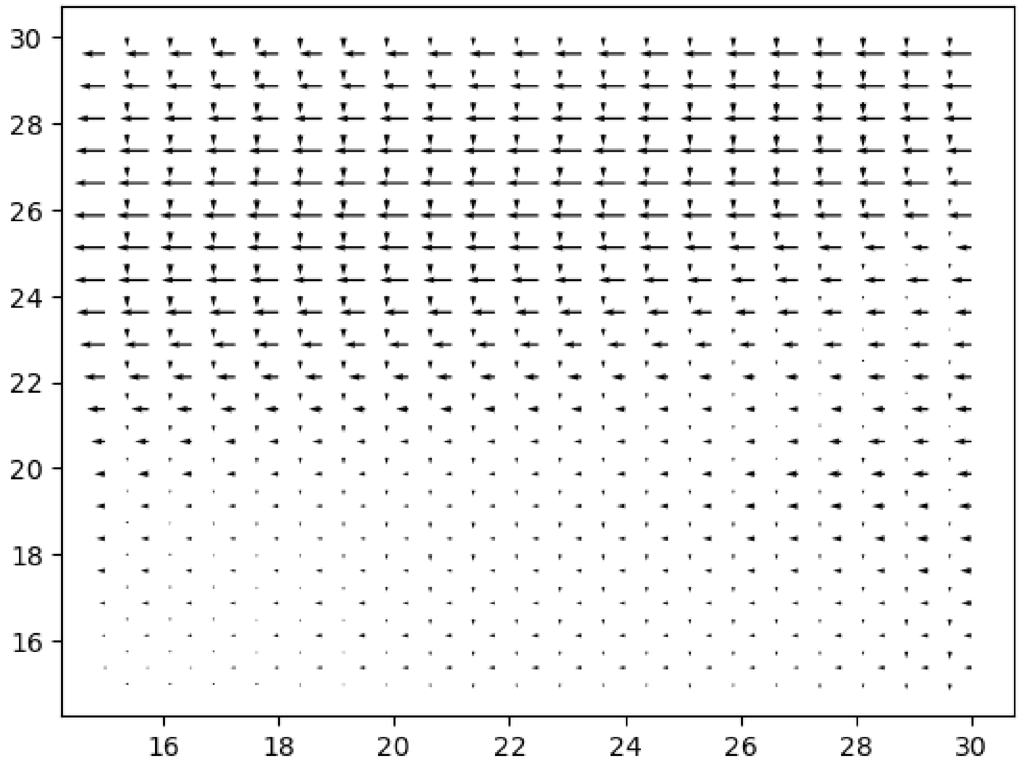
1995-11-01T00:00:00.000000000 ρ
4
2
0
−2
−4
−6
−8
−10
16
18
20
22
24
26
28
30
0.8
0.6
0.4
0.2

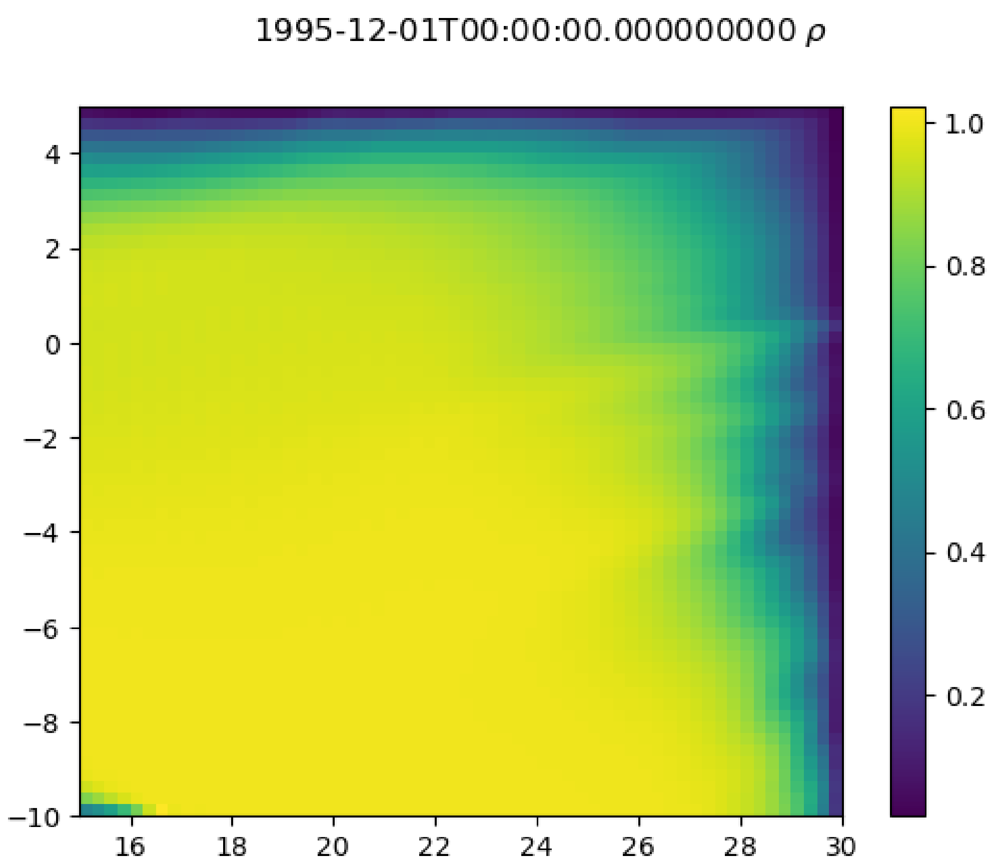


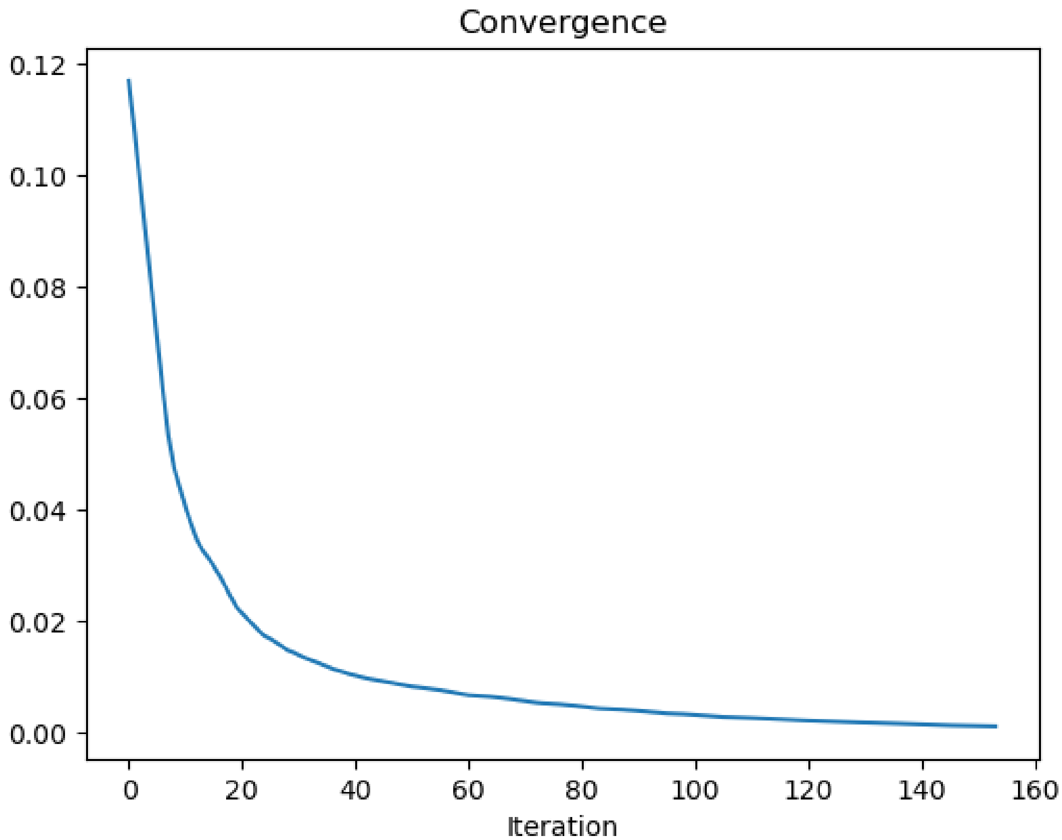

```
INFO:bulk_recycling_model.main:Converged in 154 iterations and 0:00:01.250855
```

```
11 1995-12-01T00:00:00.000000000
154
```

Water Vapor Fluxes on cell edges




1995-12-01T00:00:00.000000000 ρ
4
2
0
−2
−4
−6
−8
−10
16
18
20
22
24
26
28
30
1.0
0.8
0.6
0.4
0.2



- Create an xarray to store all of the calculated recycling ratios that is organised in an easy to plot/interpret format
- Count number of values in array over 1 - replace all of these with 1
- Save to file

[10]:
```
lon_ar = np.linspace(start=ds.coords["lon"].min().values+lon_axis.step/2,
                     stop=ds.coords["lon"].max().values-lon_axis.step/2,
                     num=lon_axis.n_points-1)
lat_ar = np.linspace(start=ds.coords["lat"].min().values+lat_axis.step/2,
                     stop=ds.coords["lat"].max().values-lat_axis.step/2,
                     num=lat_axis.n_points-1)
rho_xarr = xr.DataArray(
    data=rho_ar,
    dims=["lon", "lat", "time"],
    coords=dict(
        lon=(["lon"], lon_ar),
        lat=(["lat"], lat_ar),
        time=(["time"],ds.time.data)
    ),
    attrs=dict(
```

```
        description="Recycling ratio",
        units="%",
    ),
)
rho_xarr = rho_xarr.transpose("time","lat","lon")
print('Number of rhos over 1: ', rho_xarr.where(rho_xarr.values>1.0).count().
 ↪values)
rho_xarr = rho_xarr.where(rho_xarr.values<=1.0,1.0)
print('Number of rhos over 1: ', rho_xarr.where(rho_xarr.values>1.0).count().
 ↪values)
rho_xarr.to_netcdf(datao+"rho_era5_"+str(Y1)+".nc")

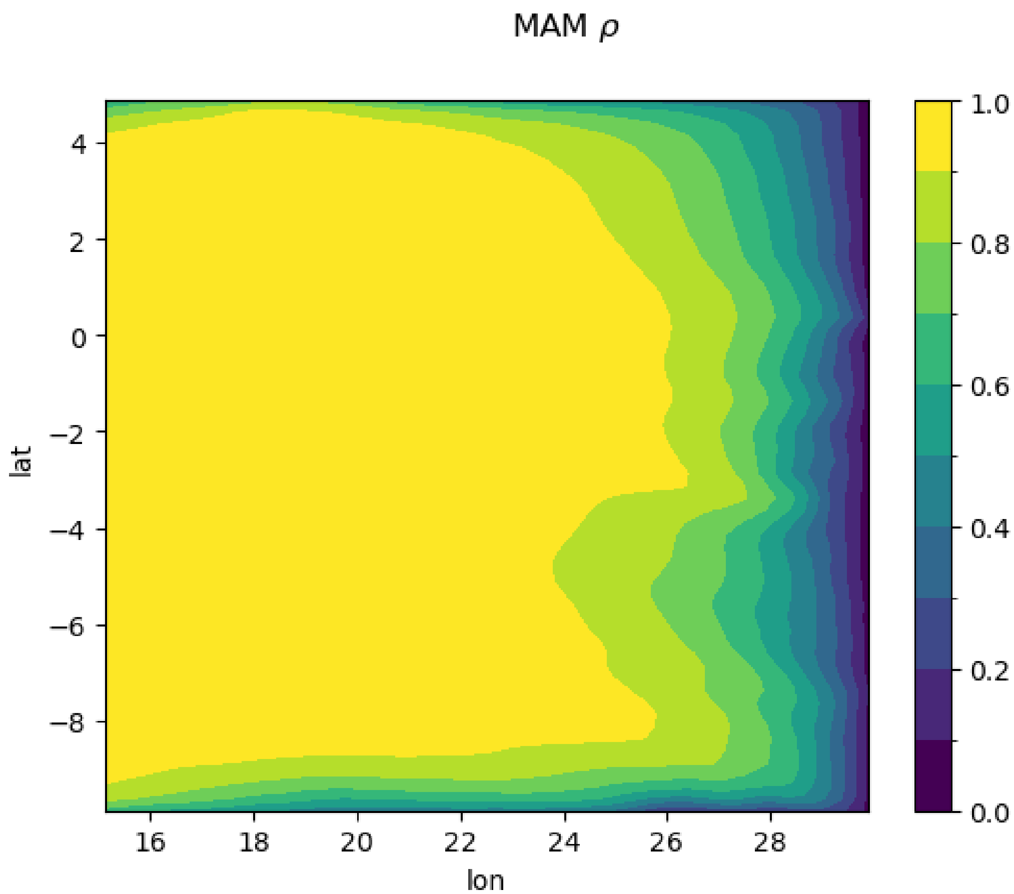
end_all = timer.time()
length = end_all - start_all
print("Running the whole prep and recycling code took ", length, "seconds")
```

```
Number of rhos over 1:  254
Number of rhos over 1:  0
Running the whole prep and recycling code took  834.5618209838867 seconds
```

Create seasonal arrays and plot these

[11]:
```
mam_rho = rho_xarr.sel(time=rho_xarr.time.dt.month.isin([3,4,5]))
fig, ax = plt.subplots()
#collection = mam_rho.mean("time").plot.contourf(vmin=0.0,vmax=0.
 ↪75,levels=12,ax=ax)
collection = mam_rho.mean("time").plot.contourf(levels=12,ax=ax)
fig.suptitle("MAM $\\rho$")
plt.savefig(datao+"rho_MAM_"+str(Y1)+".png")
plt.show()

#son_rho = rho_xarr.sel(time=rho_xarr.time.dt.month.isin([9,10,11]))
#print(son_rho)
#fig, ax = plt.subplots()
#collection = son_rho.mean("time").plot.contourf(vmin=0.0,vmax=0.
 ↪75,levels=12,ax=ax)
#fig.suptitle("SON $\\rho$")
##plt.savefig(datap+"rho_SON"+str(year1)+"_"+str(year2)+".png")
#plt.show()
#
#jja_rho = rho_xarr.sel(time=rho_xarr.time.dt.month.isin([6,7,8]))
#print(jja_rho)
#fig, ax = plt.subplots()
#collection = jja_rho.mean("time").plot.contourf(vmin=0.0,vmax=0.
 ↪75,levels=12,ax=ax)
#fig.suptitle("JJA $\\rho$")
##plt.savefig(datap+"rho_JJA"+str(year1)+"_"+str(year2)+".png")
#plt.show()
```


MAM ρ
lat
lon
4
2
0
−2
−4
−6
−8
16
18
20
22
24
26
28
1.0
0.8
0.6
0.4
0.2
0.0