SenSE Documentation

Release 0.1

Thomas Weiß

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CHAPTER

ONE

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1.1 Introduction

1.1.1 Statement of need

1.1.2 Getting Started

Please find instructions on how to download and install SenSE in the *Installation for Linux (tested with Ubuntu 20.04)* section.

1.1.3 Support, contributing and testing

Please contribute using Github Flow. Create a branch, add commits, and open a pull request.

Reporting bugs

If you find a bug in SenSE, please open an new issue and tag it "bug".

Suggesting enhancements

If you want to suggest a new feature or an improvement of a current feature, you can submit this on the issue tracker and tag it "enhancement".

Testing

The package is currently tested for Python >= 3.6 on Unix-like systems. To run unit tests, execute the following line from the root of the repository:

```
pytest
```

1.2 Installation for Linux (tested with Ubuntu 20.04)

Note: The SenSE has been developed against Python 3.6. It cannot be guaranteed to work with previous Python versions.

The first step is to clone the latest code and step into the check out directory:

```
git clone https://github.com/McWhity/sense.git
cd sense
```

1.2.1 Installation with Conda

Download and install Anaconda or Miniconda. Anaconda/Miniconda installation instructions can be found here

To install all required modules, use:

```
conda env create --prefix ./env --file environment.yml
conda activate ./env # activate the environment
```

To install SenSE into an existing Python environment, use:

```
python setup.py install
```

To install for development, use:

```
python setup.py develop
```

1.2.2 Installation with virtualenv and python

Install system requirements:

```
sudo apt install python3-pip python3-tk python3-virtualenv python3-venv virtualenv
```

Create a virtual environment:

```
virtualenv -p /usr/bin/python3 env
source env/bin/activate # activate the environment
pip install --upgrade pip setuptools # update pip and setuptools
```

To install SenSE into an existing Python environment, use:

```
python setup.py install
```

To install for development, use:

```
python setup.py develop
```

1.2.3 Further information

Please see the environment file for a list of all installed dependencies during the installation process.

1.3 Usage

1.3.1 Example 1: Use of Oh04

1. Requirements

- Installation of SenSE

2. Oh04 for different incidence angles

[2]:
```
import numpy as np
import matplotlib.pyplot as plt
from sense.surface import Oh92, Oh04
from sense.util import f2lam
```

[3]:
```
def db(x):
    return 10.*np.log10(x)

f  = 5.3 # GHz
lam = f2lam(f)  # m
k = 2.*np.pi/lam
mv = np.linspace(0.01,0.4)
theta = np.deg2rad(40)

f = plt.figure()
ax1 = f.add_subplot(121)
ax2 = f.add_subplot(122)

s = 0.3/100.
ks = k * s
Oh = Oh04(mv, ks, theta)
ax1.plot(db(Oh.hv), mv, label=['s=0.3 cm'])
ax2.plot(db(Oh.p), mv, label=['s=0.3 cm'])
s = 1.2/100.
ks = k * s
Oh = Oh04(mv, ks, theta)
ax1.plot(db(Oh.hv), mv, label=['s=1.2 cm'])
ax2.plot(db(Oh.p), mv, label=['s=1.2 cm'])
s = 4.8/100.
ks = k * s
Oh = Oh04(mv, ks, theta)
ax1.plot(db(Oh.hv), mv, label=['s=4.8 cm'])
ax2.plot(db(Oh.p), mv, label=['s=4.8 cm'])

ax1.grid()
ax1.set_xlim(-34.,-14.)
```

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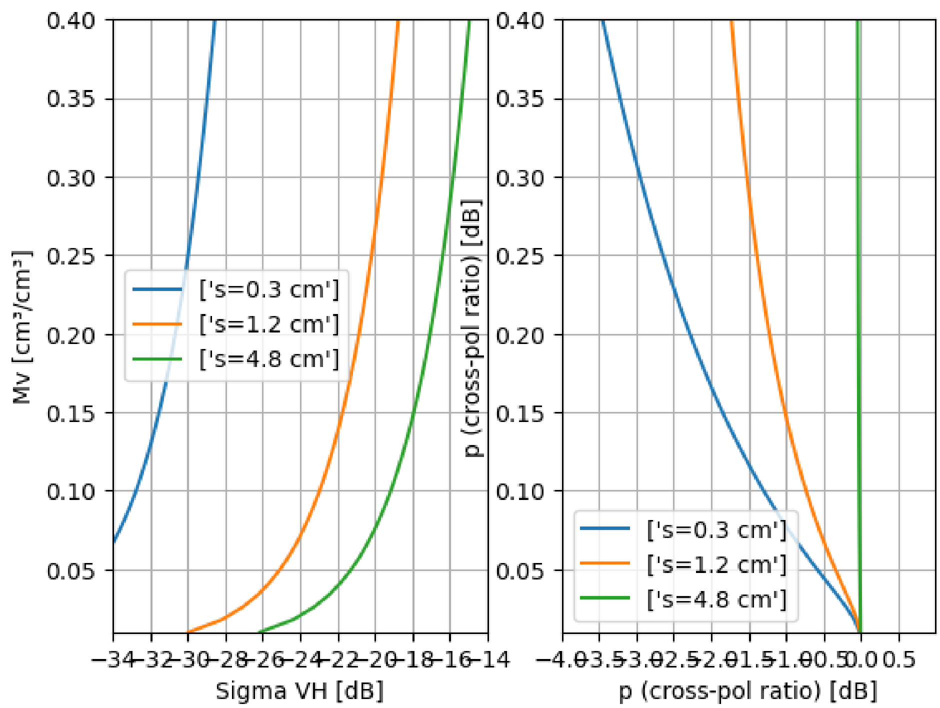
```
ax1.set_ylim(0.01,0.4)
ax1.set_xticks(np.arange(-34, -12, 2))
ax2.grid()
ax2.set_xlim(-4.,1.)
ax2.set_ylim(0.01,0.4)
ax2.set_xticks(np.arange(-4, 1, 0.5))

ax1.set_xlabel('Sigma VH [dB]')
ax2.set_xlabel('p (cross-pol ratio) [dB]')

ax1.set_ylabel('Mv [cm^3/cm^3]')
ax2.set_ylabel('p (cross-pol ratio) [dB]')
ax1.legend()
ax2.legend()
plt.show()
```



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[4]:
```
print(theta)
```

```
0.6981317007977318
```

[6]:
```
type(mv)
```

[6]:
```
numpy.ndarray
```

[ ]:

1.3.2 Example 1: Use of I2EM

1. Requirements

- Installation of SenSE

2. I2EM for different incidence angles

[2]:
```
import sense
import sys
import os
import numpy as np
from sense.surface import I2EM
import matplotlib.pyplot as plt
import time
```

[3]:
```

def db(x):
    return 10.*np.log10(x)

theta_deg = np.linspace(0.,70., 71)
theta = np.deg2rad(theta_deg)

eps = 11.3-1.5j
f = 3.

s = 1./100.
l = 10./100.

hh1=[]
hh2=[]
vv1=[]
vv2=[]
hv1=[]
hv2=[]
xpol = True
auto=False
for t in theta:
    print(t)
    I1 = I2EM(f, eps, s, l, t, acf_type='gauss', xpol=xpol, auto=auto)
    I2 = I2EM(f, eps, s, l, t, acf_type='exp15', xpol=xpol, auto=auto)
    print(I1.ks, I1.kl)
    hh1.append(I1.hh)
    hh2.append(I2.hh)
    vv1.append(I1.vv)
    vv2.append(I2.vv)
    if xpol:
        hv1.append(I1.hv)
        hv2.append(I2.hv)

hh1 = np.array(hh1)
hh2 = np.array(hh2)
```

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```
vv1 = np.array(vv1)
vv2 = np.array(vv2)
hv1 = np.array(hv1)
hv2 = np.array(hv2)
```

```
0.0
```

```
/media/wodan/data/Git/Github/mcwhity/sense/env/lib/python3.10/site-packages/sense-0.1-
↪py3.10.egg/sense/surface/i2em.py:377: RuntimeWarning: divide by zero encountered in␣
↪double_scalars
  ct = np.cos(self.theta)/np.sin(self.theta)
/media/wodan/data/Git/Github/mcwhity/sense/env/lib/python3.10/site-packages/sense-0.1-
↪py3.10.egg/sense/surface/i2em.py:378: RuntimeWarning: divide by zero encountered in␣
↪double_scalars
  cts = np.cos(self.thetas)/np.sin(self.thetas)
/media/wodan/data/Git/Github/mcwhity/sense/env/lib/python3.10/site-packages/sense-0.1-
↪py3.10.egg/sense/surface/i2em.py:368: RuntimeWarning: divide by zero encountered in␣
↪double_scalars
/media/wodan/data/Git/Github/mcwhity/sense/env/lib/python3.10/site-packages/sense-0.1-
↪py3.10.egg/sense/surface/i2em.py:282: NumbaWarning:
  ct = np.cos(self.theta)/np.sin(self.theta)
Compilation is falling back to object mode WITH looplifting enabled because Function "_
↪xpol_integralfunc" failed type inference due to: non-precise type pyobject
During: typing of argument at /media/wodan/data/Git/Github/mcwhity/sense/env/lib/python3.

↪10/site-packages/sense-0.1-py3.10.egg/sense/surface/i2em.py (291)
File "../../env/lib/python3.10/site-packages/sense-0.1-py3.10.egg/sense/surface/i2em.py",
    def _xpol_integralfunc(self, r, phi, *args):
        <source elided>
        rvh = args[0][0]
↪ line 291:
        ^

/media/wodan/data/Git/Github/mcwhity/sense/env/lib/python3.10/site-packages/sense-0.1-
↪py3.10.egg/sense/surface/i2em.py:282: NumbaWarning:
  @jit(cache=True)
Compilation is falling back to object mode WITHOUT looplifting enabled because Function
↪"_xpol_integralfunc" failed type inference due to: Cannot determine Numba type of

↪<class 'numba.core.dispatcher.LiftedLoop'>
File "../../env/lib/python3.10/site-packages/sense-0.1-py3.10.egg/sense/surface/i2em.py",
    def _xpol_integralfunc(self, r, phi, *args):
        <source elided>
        vhmnsum = 0.
        for i in xrange(nspec):
↪ line 335:
        ^

/media/wodan/data/Git/Github/mcwhity/sense/env/lib/python3.10/site-packages/numba/core/
↪object_mode_passes.py:151: NumbaWarning: Function "_xpol_integralfunc" was compiled in␣
↪object mode without forceobj=True, but has lifted loops.

  @jit(cache=True)
```

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```
File "../../env/lib/python3.10/site-packages/sense-0.1-py3.10.egg/sense/surface/i2em.py",
    def _xpol_integralfunc(self, r, phi, *args):
        <source elided>
        rvh = args[0][0]
↪ line 291:
        ^

/media/wodan/data/Git/Github/mcwhity/sense/env/lib/python3.10/site-packages/numba/core/
↪object_mode_passes.py:161: NumbaDeprecationWarning:
Fall-back from the nopython compilation path to the object mode compilation path has␣
↪been detected, this is deprecated behaviour.
For more information visit https://numba.readthedocs.io/en/stable/reference/deprecation.
↪html#deprecation-of-object-mode-fall-back-behaviour-when-using-jit

  warnings.warn(errors.NumbaWarning(warn_msg,
File "../../env/lib/python3.10/site-packages/sense-0.1-py3.10.egg/sense/surface/i2em.py",
    def _xpol_integralfunc(self, r, phi, *args):
        <source elided>
        rvh = args[0][0]
↪ line 291:
        ^

  warnings.warn(errors.NumbaDeprecationWarning(msg,
/media/wodan/data/Git/Github/mcwhity/sense/env/lib/python3.10/site-packages/sense-0.1-
↪py3.10.egg/sense/surface/i2em.py:282: NumbaWarning: Cannot cache compiled function "_
↪xpol_integralfunc" as it uses lifted code
/media/wodan/data/Git/Github/mcwhity/sense/env/lib/python3.10/site-packages/numba/core/
↪ir_utils.py:2147: NumbaPendingDeprecationWarning:
Encountered the use of a type that is scheduled for deprecation: type 'reflected list'␣
↪found for argument 'fac' of function 'I2EM._xpol_integralfunc'.
For more information visit https://numba.readthedocs.io/en/stable/reference/deprecation.
↪html#deprecation-of-reflection-for-list-and-set-types

  @jit(cache=True)
File "../../env/lib/python3.10/site-packages/sense-0.1-py3.10.egg/sense/surface/i2em.py",
    def _xpol_integralfunc(self, r, phi, *args):
        <source elided>
        vhmnsum = 0.
        for i in xrange(nspec):
↪ line 335:
        ^

  warnings.warn(NumbaPendingDeprecationWarning(msg, loc=loc))
```

```
0.0007870779703274
```

```
/media/wodan/data/Git/Github/mcwhity/sense/env/lib/python3.10/site-packages/sense-0.1-
↪py3.10.egg/sense/surface/i2em.py:377: RuntimeWarning: divide by zero encountered in␣
↪double_scalars
  ct = np.cos(self.theta)/np.sin(self.theta)
/media/wodan/data/Git/Github/mcwhity/sense/env/lib/python3.10/site-packages/sense-0.1-
↪py3.10.egg/sense/surface/i2em.py:378: RuntimeWarning: divide by zero encountered in␣
↪double_scalars
  cts = np.cos(self.thetas)/np.sin(self.thetas)
```

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```
/media/wodan/data/Git/Github/mcwhity/sense/env/lib/python3.10/site-packages/sense-0.1-
↪py3.10.egg/sense/surface/i2em.py:368: RuntimeWarning: divide by zero encountered in␣
↪double_scalars
  ct = np.cos(self.theta)/np.sin(self.theta)
```

```
0.001217568974107298
0.6287535065855046 6.287535065855046
0.017453292519943295
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0.0007724472676413573
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0.0007545881118301572
0.001214529526372035
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0.0012050703982415306
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0.0011736587386531575
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0.20943951023931956
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```
0.0004115276939570183
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```
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```
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1.2042771838760873
6.091010720889855e-10
6.937504617069839e-05
0.6287535065855046 6.287535065855046
1.2217304763960306
4.1413548225238386e-10
5.910102462802539e-05
0.6287535065855046 6.287535065855046
```

[4]:

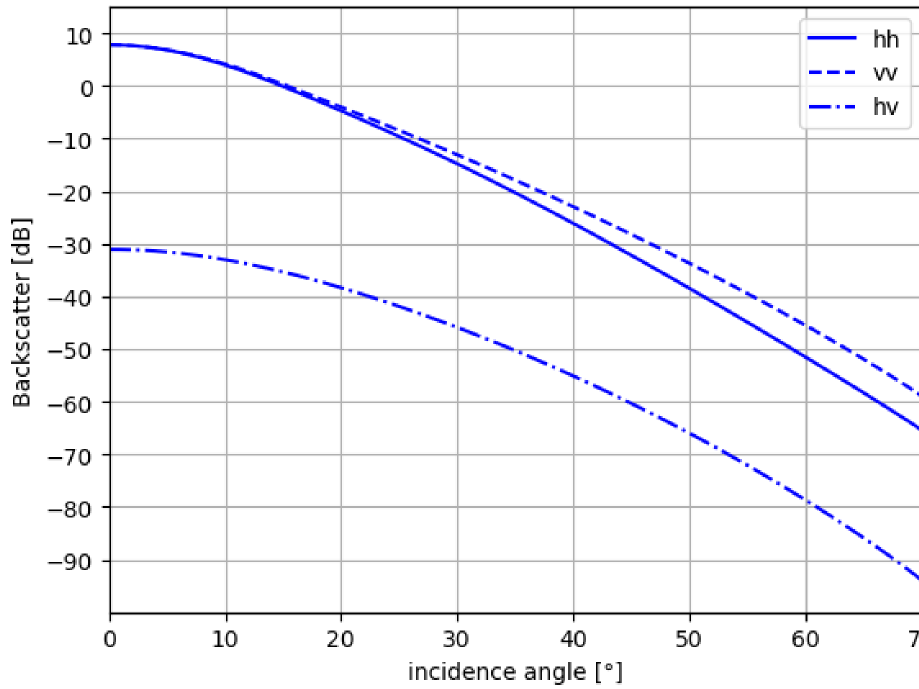
```
f = plt.figure()
ax = f.add_subplot(111)

# ax.plot(theta_deg, db(hh2), color='red', label='hh')
ax.plot(theta_deg, db(hh1), color='blue', label='hh')

# ax.plot(theta_deg, db(vv2), color='red', label='vv', linestyle='--')
ax.plot(theta_deg, db(vv1), color='blue', label='vv', linestyle='--')

# ax.plot(theta_deg, db(hv2), color='red', label='hv', linestyle='-.')
ax.plot(theta_deg, db(hv1), color='blue', label='hv', linestyle='-.')

ax.grid()
ax.set_xlim(0.,70.)
ax.set_ylim(-100.,15.)
ax.set_yticks(np.arange(-90, 20, 10))
plt.ylabel('Backscatter [dB]')
plt.xlabel('incidence angle [°]')
plt.legend()
plt.show()
```



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```
[ ]:
```

1.3.3 Example 1: Use of surface model Dubois95 and canopy model SSRT

1. Requirements

- Installation of SenSE

2. Dubois95+SSRT for different incidence angles

```
[41]: import numpy as np
#from sense.surface import Dubois95, Oh92
from sense.util import f2lam
from sense.model import RTModel
from sense.soil import Soil
from sense.canopy import OneLayer
import matplotlib.pyplot as plt
```

```
[42]: theta_deg = np.arange(0.,70.)
theta = np.deg2rad(theta_deg)

# soil model paraters
f  = 13.  # GHz
lam = f2lam(f)  # m
s = 0.0015  # m
eps = 15. - 4.0j
```

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```
models = {'surface' : 'Dubois95', 'canopy' : 'turbid_rayleigh'}

pol='vv'
```

[43]:
```
# short alfalfa
omega = 0.1
d = 0.17
tau = 2.5
ke = tau/d
omega = 0.27
ks=omega*ke
# Soil model initialization
S = Soil(f=f, s=s, eps=eps)
# Canopy model initialization
C = OneLayer(ke_h=ke, ke_v=ke, d=d, ks_v=ks, ks_h=ks, canopy=models['canopy'])
# Combined Model initialization
RT = RTModel(theta=theta, models=models, surface=S, canopy=C, freq=f)
# Run RT model
RT.sigma0()
back_short = RT.stot[pol]
```

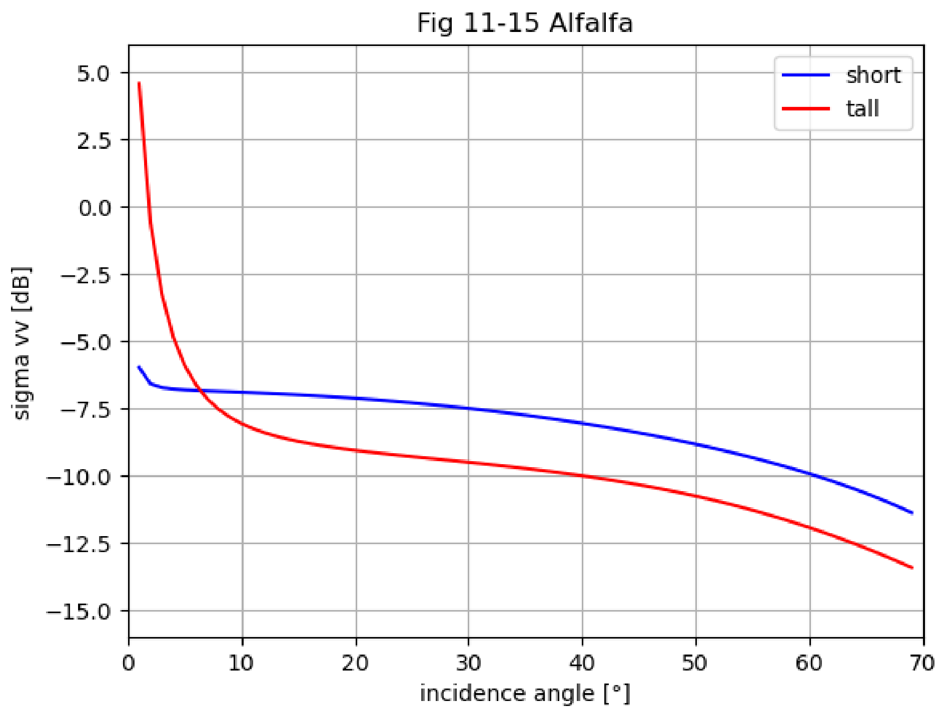
[44]:
```
# tall alfalfa
d = 0.55
tau = 0.45
ke = tau/d
omega = 0.175
ks=omega*ke
S = Soil(f=f, s=s, eps=eps)
C = OneLayer(ke_h=ke, ke_v=ke, d=d, ks_v=ks, ks_h=ks, canopy=models['canopy'])
RT = RTModel(theta=theta, models=models, surface=S, canopy=C, freq=f)
RT.sigma0()
```

[45]:
```
# plot first part
fig = plt.figure()
ax = fig.add_subplot(111)
ax.plot(theta_deg, 10.*np.log10(back_short), label='short', color='b')
ax.plot(theta_deg, 10.*np.log10(RT.stot[pol]), label='tall', color='r')

ax.legend()
ax.set_title('Fig 11-15 Alfalfa')


ax.grid()
ax.set_xlabel('incidence angle [°]')
ax.set_ylabel('sigma vv [dB]')
ax.set_xlim(0.,70.)
ax.set_ylim(-16.,6.)

plt.show()
```



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[ ]:

```

```

1.3.4 Example 1: Use of surface model Oh92 and canopy model SSRT

1. Requirements

- Installation of SenSE

2. Oh92+SSRT retrieval of soil moisture

[1]:

```
import numpy as np
#from sense.surface import Dubois95, Oh92
from sense.util import f2lam
from sense.model import RTModel
from sense.soil import Soil
from sense.canopy import OneLayer
import matplotlib.pyplot as plt
import random
from sense.surface import Oh92, Oh04
from scipy.optimize import minimize
import pdb
```

[2]:

```
#### Choose models
#-----------------
canopy = 'turbid_isotropic'
surface = 'Oh92'
```

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```
models = {'surface' : surface, 'canopy' : canopy}
pol='vv'
```

[3]:
```
# model parameter Oh92
#-----------------
freq = 5.405
clay = 0.0738
sand = 0.2408
bulk = 1.45
theta = np.deg2rad(35)
s = 0.013
sm = np.random.uniform(low=0.05, high=0.35, size=(50,))
```

[4]:
```
# model parameter SSRT
#-----------------
d = 0.55
tau = 0.45
ke = tau/d
omega = 0.175
ks=omega*ke
```

[5]:
```
# run model to produce backscatter
#-----------------
S = Soil(f=freq, s=s, mv=sm, sand=sand, clay=clay, bulk=bulk)
C = OneLayer(ke_h=ke, ke_v=ke, d=d, ks_v=ks, ks_h=ks, canopy=models['canopy'])
RT = RTModel(theta=theta, models=models, surface=S, canopy=C, freq=freq)
RT.sigma0()
back_vv = RT.stot['vv']
back_hv = RT.stot['hv']
```

[6]:
```
# helper function retrieval
#-----------------
def run_model(dic, models):
    # surface
    soil = Soil(mv=dic['mv'], s=dic['s'], clay=dic['clay'], sand=dic['sand'], f=dic['f'],
↪ bulk=dic['bulk'])

    # canopy
    can = OneLayer(canopy=dic['canopy'], ke_h=dic['ke'], ke_v=dic['ke'], d=dic['d'], ks_
↪h = dic['omega']*dic['ke'],
                   ks_v = dic['omega']*dic['ke'])

    S = RTModel(surface=soil, canopy=can, models=models, theta=dic['theta'], freq=dic['f
↪'])
    S.sigma0()
    return S.__dict__['stot']['vv'[::-1]], S.__dict__['stot']['vh'[::-1]]

def solve_fun(VALS, var_opt, dic, models):

    for i in range(len(var_opt)):
```

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```
        dic[var_opt[i]] = VALS[i]

    vv, vh = run_model(dic, models)

    return vv, vh

def fun_opt(VALS, var_opt, dic, models, pol):
    if pol == 'vv':
        return(np.nansum(np.square(solve_fun(VALS, var_opt, dic, models)[0]-dic['vv'])))
    elif pol == 'vh':
        return(np.nansum(np.square(solve_fun(VALS, var_opt, dic, models)[1]-dic['vh'])))
    elif pol == 'vv_vh':
        return(np.nansum(np.square((solve_fun(VALS, var_opt, dic, models)[0]-dic['vv'])/
↪2+(solve_fun(VALS, var_opt, dic, models)[1]-dic['vh'])/2)))
```

[7]:
```
# run soil moisture retrieval
#------------------

dic = {"mv":0.2, "s":s, "clay":clay, "sand":sand, "f":freq, "bulk":bulk, "canopy":canopy,
↪ "d":d,
       "ke":ke, "vv":back_vv, "vh":back_hv, "theta":theta, "omega": omega}

var_opt = ['mv']
guess = [0.2]
bounds = [(0.05,0.35)]

method = 'L-BFGS-B'

sm_retrieved = []

for i,ii in enumerate(back_vv):

    dic = {"mv":0.2, "s":s, "clay":clay, "sand":sand, "f":freq, "bulk":bulk, "canopy":
↪canopy, "d":d,
       "ke":ke, "vv":back_vv[i], "vh":back_hv[i], "theta":theta, "omega": omega}

    res = minimize(fun_opt,guess,args=(var_opt, dic, models, pol),bounds=bounds,␣
↪method=method)

    fun_opt(res.x, var_opt, dic, models, 'vv')
    sm_retrieved.append(res.x[0])
```

[8]:
```
diff = sm - sm_retrieved
diff_average = np.sum(abs(diff))/len(diff)
print(diff)
print(diff_average)
```

```
[ 6.59330364e-06  3.07387396e-05 -1.64056693e-05  1.26983242e-06
  1.59499940e-05  6.26880566e-06  1.51476691e-04  1.82387528e-05
  1.19301459e-06  3.88467200e-05  4.58888086e-06  8.67545295e-06
  2.53841100e-05  1.62021203e-05  4.35594912e-06  1.95046970e-05
```

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```
  1.85616690e-05  1.74444353e-04  4.85911293e-05 -5.68510333e-06
 -9.97495284e-06  4.40446923e-05  2.19569464e-05 -6.49517331e-06
  3.60644372e-05  2.20953377e-06 -8.19768433e-06 -1.48786469e-06
  1.16335317e-04  1.52661750e-05 -6.06365025e-06 -6.37658096e-06
 -9.41156403e-06  1.37811644e-05  1.08180119e-04  1.25106158e-06
 -1.26556797e-05 -1.28062762e-05  2.77727528e-05 -8.58538885e-06
 -8.22013037e-06  1.86317181e-05 -3.80880104e-06  1.86729943e-06
 -1.27028686e-05  5.38805515e-05  6.44892535e-06  2.94535935e-05
  4.78866799e-06 -1.66380938e-06]
2.446716736412141e-05
```

[ ]:

```

```

1.4 Theory of RT-models

to be continued

1.5 Technical documentation

to be continued

1.6 Developers

- Alexander Löw
- Thomas Weiß <"weiss.thomas@lmu.de">

1.7 Change Log SenSE

1.7.1 [0.1] - 2023-02-13

initial version

1.8 Licence

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Version 3, 29 June 2007

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CHAPTER

TWO

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