Signatures_Paper.ipynb

This notebook shows how to create the figures in

Understanding the effects of spacecraft trajectories through solar coronal mass ejection flux ropes using 3DCOREweb

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1. Import packages

The necessary packages are imported.

In [ ]:
```
import coreweb
from coreweb.methods.offwebutils import get_modelkwargs_ranges, offwebfit
from coreweb.dashcore.utils.plotting import check_animation, check_fittin
from coreweb.dashcore.utils.utils import load_fit, cart2sphere, sphere2ca
from coreweb.dashcore.assets.config_sliders import modelslidervars, magsl
from coreweb.dashcore.app import update_launch_label, generate_graphstore
from coreweb.dashcore.pages.Start import update_alert_for_init

import coreweb.dashcore.utils.heliocats as hc

from plotly.subplots import make_subplots
import plotly.graph_objects as go
import plotly_express as px
import plotly.figure_factory as ff
from plotly.validators.scatter.marker import SymbolValidator
import plotly.io as pio

pio.renderers.default = "png"

import pandas as pd
from IPython.display import display, HTML
```

```
import os

import datetime
import numpy as np

import warnings
warnings.filterwarnings('ignore')
```

2. Import and process data

The data for the synthetic spacecraft is generated and preprocessed.

In [ ]:
```
reference_frame = "RTN"
idd = 'ICME_SYN_CUSTOM'


eventinfo = get_eventinfo(idd, purelysyn=True)
graphstore, posstore, _ = generate_graphstore(eventinfo, reference_frame,

spacecraftoptions = None
bodyoptions = ["Sun"]

firstfield = 50.
secondfield = 5.
nameadd = ''

view_legend_insitu = True
insitu = False
positions = True
plottheme = 'light-simple'
currenttimeslider = 55
launchlabel = None
rinput = 0.8
lonput = 0
latput = 0

deltatime = 100
longmove =  0

longmove_array = get_longmove_array(longmove, rinput,lonput,latput, graph
```

```
Data loaded from /Users/hannahruedisser/3DCOREweb/src/coreweb/dashcore/dat
a/ICME_SYN_CUSTOM.pkl
```

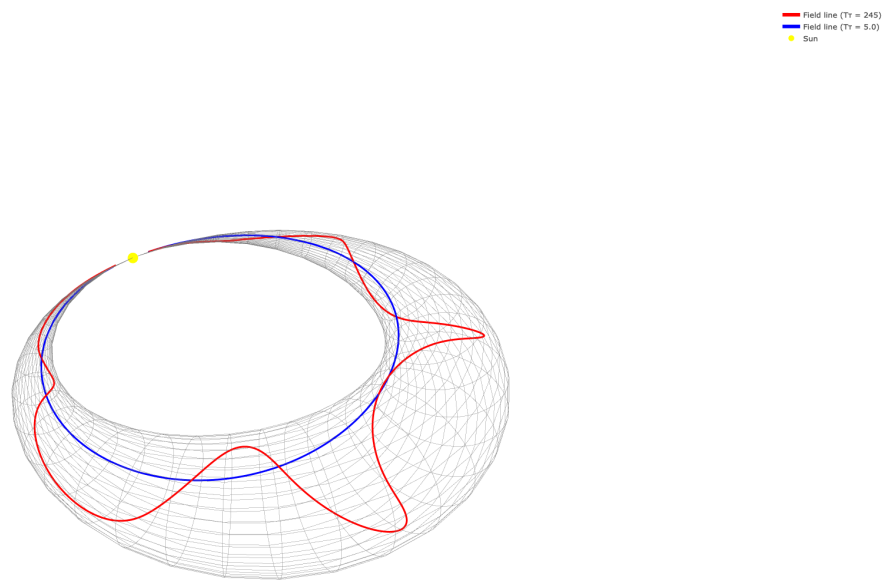
3. Create 3D plots (shape with fieldlines)

3D plots showing the shape of the CME are generated according to the model parameters defined. The fieldlines for two different twist factors are shown inside of the CME.

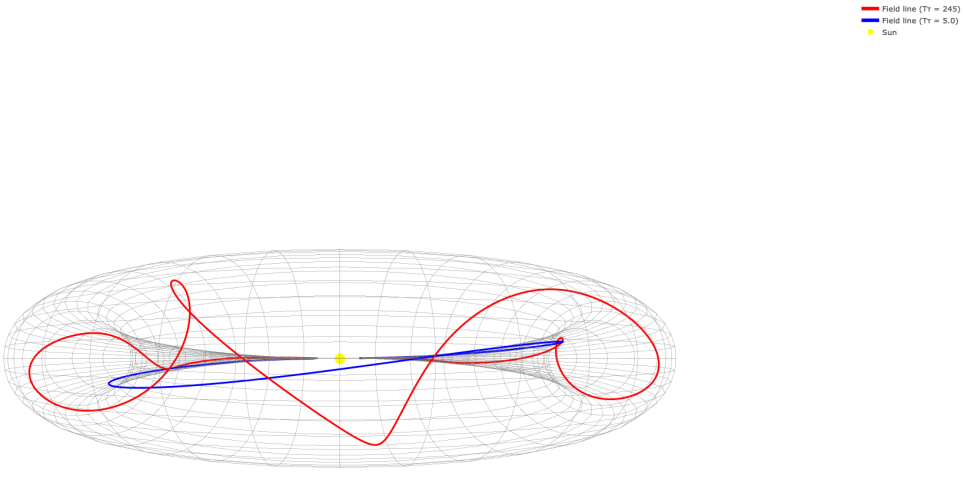
In [ ]:
```
# quarter top
camera = [1,-0.78,1.1]
plot_options = ["Synthetic Event","dotted"]
```

```
modelstatevars1 = [0., # Longitude
                   0., # Latitude
                   0., # Inclination # high inclination: 90.
                   0.3, # Diameter 1 AU
                   2., # Aspect Ratio
                   20., # Launch Radius
                   600., # Launch Velocity
                   1.14, # Expansion Rate
                   1.00, # Background Drag
                   500., # Background Velocity
                   firstfield, # T_Factor
                   1.64, # Magnetic Decay Rate
                   25., # Magnetic Field Strength 1 AU
                   ]

tracingfield1 = check_animation(None,
                                None,
                                plottheme,
                                graphstore,
                                reference_frame,
                                rinput, lonput, latput,
                                currenttimeslider,
                                eventinfo, launchlabel, plot_options, spacecr

tracingfield1.write_image("quartertopdownfield.png", width = 1920 , heigh
tracingfield1.show()

# front
camera = [1.3,0,0]
tracingfield1 = check_animation(None,
                                None,
                                plottheme,
                                graphstore,
                                reference_frame,
                                rinput, lonput, latput,
                                currenttimeslider,
                                eventinfo, launchlabel, plot_options, spacecr

tracingfield1.write_image("frontfield.png", width = 1920 , height = 1920
tracingfield1.show()

# top
camera = [0,0,1.2]

tracingfield1 = check_animation(None,
                                None,
                                plottheme,
                                graphstore,
                                reference_frame,
                                rinput, lonput, latput,
                                currenttimeslider,
                                eventinfo, launchlabel, plot_options, spacecr


tracingfield1.write_image("topdownfield.png", width = 1920 , height = 192
tracingfield1.show()
```

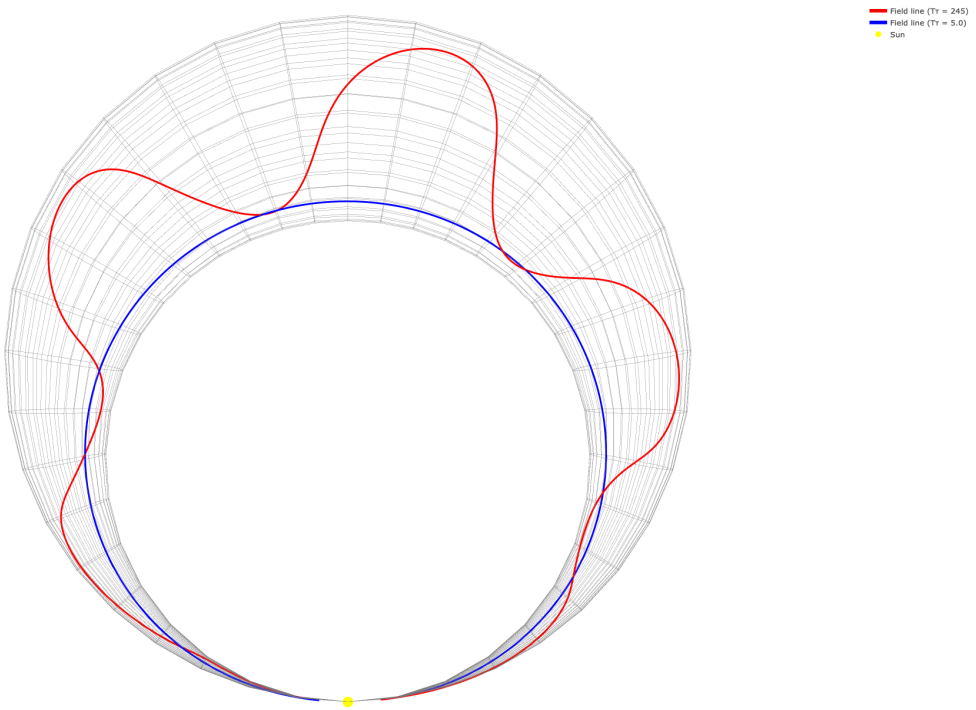
```
Tracing Fieldlines
Residuals are not finite in the initial point.
Residuals are not finite in the initial point.
total turns estimates:  5.079705183439121 0.5602941538854768
```




```
Tracing Fieldlines
Residuals are not finite in the initial point.
Residuals are not finite in the initial point.
total turns estimates:  5.079705183439121 0.5602941538854768
```

```
Tracing Fieldlines
Residuals are not finite in the initial point.
Residuals are not finite in the initial point.
total turns estimates:  5.079705183439121 0.5602941538854768
```

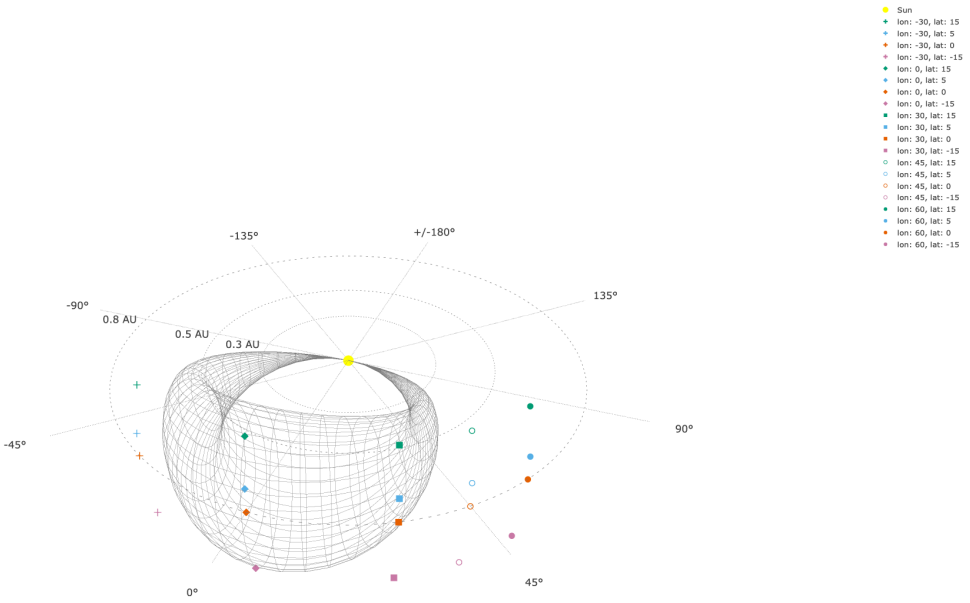


4. Create 3D plots (spacecraft setup)

A 3D plot of the spacecraft setup around the CME in the inner heliosphere.

In [ ]:
```
# Low Inc

plot_options = [
    "Longitudinal Grid",
    "AU axis",
    "Synthetic Event",
    "dotted", # if you want the grid to be dotted, use dashed or remove i
    "AU lines"
    ]

syncolors = [
    '#009e74',
    '#56b3e9',
    '#e66000',
    '#cc79a7',
]

synshapes = [
    'cross',
    'diamond',
    'square',
    'circle-open',
    'circle'
]
```

```
# quarter top
camera = [1,0.37,0.7]

checkanim = check_animation(None,
                            None,
                            plottheme,
                            graphstore,
                            reference_frame,
                            rinput, lonput, latput,
                            currenttimeslider,
                            eventinfo, launchlabel, plot_options, spacecr

lons = [-30, 0 , 30, 45, 60] # high inclination: [-15, 0 , 5, 15]

lats = [15, 5, 0, -15] # high inclination: [45, 30, 0, -30]

namecount = 0

for j, lon in enumerate(lons):
    for k,lat in enumerate(lats):
        x,y,z = sphere2cart(float(rinput), np.deg2rad(-float(lat)+90), np

        checkanim.add_trace(
            go.Scatter3d(
                x=[x], y=[y], z=[z],
                mode='markers',
                marker=dict(size=6,
                            symbol=synshapes[j],
                            color=syncolors[k]),
                name="lon: "+str(lon)+', lat: ' + str(lat),
                legendgroup = '1',
                showlegend=True,
            ), row=1, col=1)

        namecount += 1

checkanim.show()
checkanim.write_image("Figure3_quartertop.png", width = 1920 , height = 1
#checkanim.write_image("Figure3_quartertop.svg", width = 1920 , height =
```



5. Create in situ plots

The synthetic in situ signatures are plotted for all spacecraft. This is repeated for all fluxrope types and two different twist factors.

In [ ]:

```
iparams = get_iparams_live(*modelstatevars1)
iparamslist, inccheck = ropechecker(iparams)

fluxtypeslow = ['SWN_low','NES_low', 'NWS_low','SEN_low']

fluxtypeshigh = ['WNE_high','ESW_high', 'ENW_high','WSE_high']

for i, namedir in enumerate(fluxtypeslow):


    iparams = iparamslist[i]

    print(iparams)
    print(namedir)

    t_launch = datetime.datetime(2012,12,21,6)
    model_obj = coreweb.ToroidalModel(t_launch, **iparams) # model gets i
    model_obj.generator()
    checkanimany = check_animation(None,
                                   None,
                                   plottheme,
                                   graphstore,
                                   reference_frame,
                                   rinput, lonput, latput,
                                   currenttimeslider,
                                   eventinfo, launchlabel, plot_options, spa

    signaturecheckfull(lats, lons, model_obj, rinput, 'low_inc_low_twist_
```

```
############## HIGH INC LOW TWIST

##### model parameters

modelstatevars1 = [0., # Longitude
                   0., # Latitude
                   90., # Inclination
                   0.3, # Diameter 1 AU
                   2., # Aspect Ratio
                   20., # Launch Radius
                   600., # Launch Velocity
                   1.14, # Expansion Rate
                   1.00, # Background Drag
                   500., # Background Velocity
                   secondfield, # T_Factor
                   1.64, # Magnetic Decay Rate
                   25., # Magnetic Field Strength 1 AU
                   ]

iparams = get_iparams_live(*modelstatevars1)
iparamslist, inccheck = ropechecker(iparams)


checkanim = check_animation(None,
                            None,
                            plottheme,
                            graphstore,
                            reference_frame,
                            rinput, lonput, latput,
                            currenttimeslider,
                            eventinfo, launchlabel, plot_options, spacecr



lons = [-15, 0, 5, 15]

lats = [45, 30 , 0, -30]

namecount = 0

for j, lon in enumerate(lons):
    for k,lat in enumerate(lats):
        x,y,z = sphere2cart(float(rinput), np.deg2rad(-float(lat)+90), np

        checkanim.add_trace(
            go.Scatter3d(
                x=[x], y=[y], z=[z],
                mode='markers',
                marker=dict(size=4,
                            symbol=synshapes[j],
                            color=syncolors[k]),
                name="SYN_"+str(namecount),
                legendgroup = '1',
                showlegend=True,
            ), row=1, col=1)

        namecount += 1
```

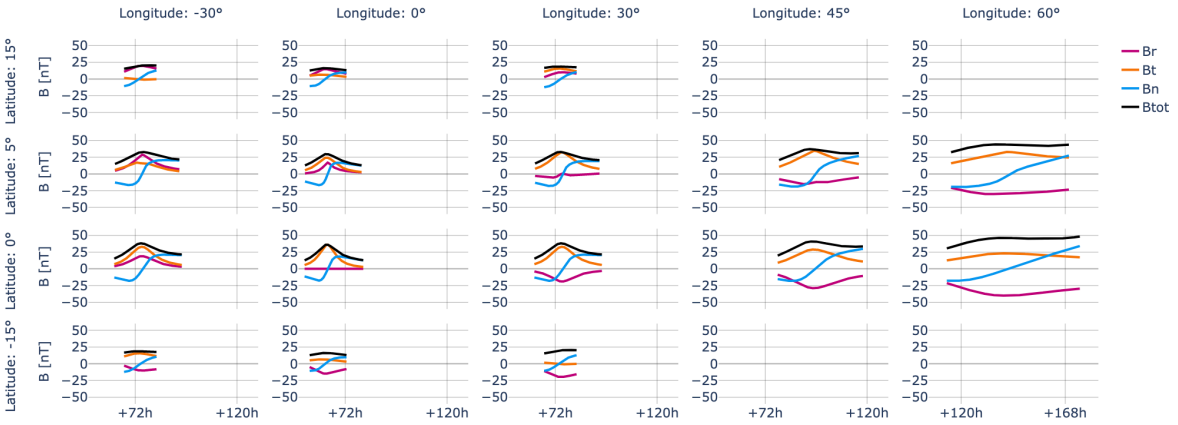
```
for i, namedir in enumerate(fluxtypeshigh):


    iparams = iparamslist[i]

    print(iparams)
    print(namedir)

    t_launch = datetime.datetime(2012,12,21,6)
    model_obj = coreweb.ToroidalModel(t_launch, **iparams) # model gets i
    model_obj.generator()
    checkanimany = check_animation(None,
                                   None,
                                   plottheme,
                                   graphstore,
                                   reference_frame,
                                   rinput, lonput, latput,
                                   currenttimeslider,
                                   eventinfo, launchlabel, plot_options, spa

    signaturecheckfull(lats, lons, model_obj, rinput, 'high_inc_low_twist




#########   LOW INC HIGH TWIST

##### model parameters

modelstatevars1 = [0., # Longitude
                   0., # Latitude
                   0., # Inclination
                   0.3, # Diameter 1 AU
                   2., # Aspect Ratio
                   20., # Launch Radius
                   600., # Launch Velocity
                   1.14, # Expansion Rate
                   1.00, # Background Drag
                   500., # Background Velocity
                   firstfield, # T_Factor
                   1.64, # Magnetic Decay Rate
                   25., # Magnetic Field Strength 1 AU
                   ]

iparams = get_iparams_live(*modelstatevars1)
iparamslist, inccheck = ropechecker(iparams)

fluxtypeslow = ['SWN_low','NES_low', 'NWS_low','SEN_low']

fluxtypeshigh = ['WNE_high','ESW_high', 'ENW_high','WSE_high']

checkanim = check_animation(None,
                            None,
                            plottheme,
                            graphstore,
                            reference_frame,
                            rinput, lonput, latput,
                            currenttimeslider,
                            eventinfo, launchlabel, plot_options, spacecr
```

```
lons = [-30, 0 , 30, 45, 60]

lats = [15, 5, 0, -15]

namecount = 0

for j, lon in enumerate(lons):
    for k,lat in enumerate(lats):
        x,y,z = sphere2cart(float(rinput), np.deg2rad(-float(lat)+90), np

        checkanim.add_trace(
            go.Scatter3d(
                x=[x], y=[y], z=[z],
                mode='markers',
                marker=dict(size=4,
                            symbol=synshapes[j],
                            color=syncolors[k]),
                name="SYN_"+str(namecount),
                legendgroup = '1',
                showlegend=True,
            ), row=1, col=1)

        namecount += 1

for i, namedir in enumerate(fluxtypeslow):


    iparams = iparamslist[i]

    print(iparams)
    print(namedir)

    t_launch = datetime.datetime(2012,12,21,6)
    model_obj = coreweb.ToroidalModel(t_launch, **iparams) # model gets i
    model_obj.generator()
    checkanimany = check_animation(None,
                                   None,
                                   plottheme,
                                   graphstore,
                                   reference_frame,
                                   rinput, lonput, latput,
                                   currenttimeslider,
                                   eventinfo, launchlabel, plot_options, spa

    signaturecheckfull(lats, lons, model_obj, rinput, 'low_inc_high_twist



############## HIGH INC HIGH TWIST

##### model parameters

modelstatevars1 = [0., # Longitude
                   0., # Latitude
                   90., # Inclination
                   0.3, # Diameter 1 AU
                   2., # Aspect Ratio
                   20., # Launch Radius
```

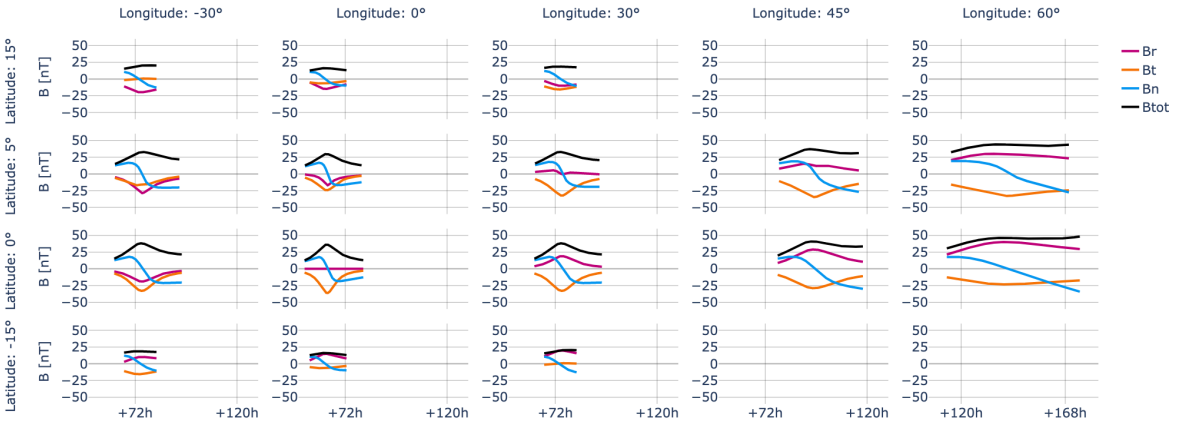
```
                    600., # Launch Velocity
                    1.14, # Expansion Rate
                    1.00, # Background Drag
                    500., # Background Velocity
                    firstfield, # T_Factor
                    1.64, # Magnetic Decay Rate
                    25., # Magnetic Field Strength 1 AU
                    ]

iparams = get_iparams_live(*modelstatevars1)
iparamslist, inccheck = ropechecker(iparams)


checkanim = check_animation(None,
                            None,
                            plottheme,
                            graphstore,
                            reference_frame,
                            rinput, lonput, latput,
                            currenttimeslider,
                            eventinfo, launchlabel, plot_options, spacecr



lons = [-5, 0, 5, 15]

lats = [45, 30 , 0, -30]

namecount = 0

for j, lon in enumerate(lons):
    for k,lat in enumerate(lats):
        x,y,z = sphere2cart(float(rinput), np.deg2rad(-float(lat)+90), np

        checkanim.add_trace(
            go.Scatter3d(
                x=[x], y=[y], z=[z],
                mode='markers',
                marker=dict(size=4,
                            symbol=synshapes[j],
                            color=syncolors[k]),
                name="SYN_"+str(namecount),
                legendgroup = '1',
                showlegend=True,
            ), row=1, col=1)

        namecount += 1

for i, namedir in enumerate(fluxtypeshigh):


    iparams = iparamslist[i]

    print(iparams)
    print(namedir)

    t_launch = datetime.datetime(2012,12,21,6)
    model_obj = coreweb.ToroidalModel(t_launch, **iparams) # model gets i
    model_obj.generator()
    checkanimany = check_animation(None,
```

```
                                None,
                                plottheme,
                                graphstore,
                                reference_frame,
                                rinput, lonput, latput,
                                currenttimeslider,
                                eventinfo, launchlabel, plot_options, spa

    signaturecheckfull(lats, lons, model_obj, rinput, 'high_inc_high_twis
```

```
righthanded: NES
{'ensemble_size': 1, 'iparams': {'cme_longitude': {'distribution': 'fixe
d', 'default_value': 0.0}, 'cme_latitude': {'distribution': 'fixed', 'defa
ult_value': 0.0}, 'cme_inclination': {'distribution': 'fixed', 'default_va
lue': 180.0}, 'cme_diameter_1au': {'distribution': 'fixed', 'default_valu
e': 0.3}, 'cme_aspect_ratio': {'distribution': 'fixed', 'default_value':
2.0}, 'cme_launch_radius': {'distribution': 'fixed', 'default_value': 20.
0}, 'cme_launch_velocity': {'distribution': 'fixed', 'default_value': 600.
0}, 't_factor': {'distribution': 'fixed', 'default_value': 50.0}, 'cme_exp
ansion_rate': {'distribution': 'fixed', 'default_value': 1.14}, 'magnetic_
decay_rate': {'distribution': 'fixed', 'default_value': 1.64}, 'magnetic_f
ield_strength_1au': {'distribution': 'fixed', 'default_value': 25.0}, 'bac
kground_drag': {'distribution': 'fixed', 'default_value': 1.0}, 'backgroun
d_velocity': {'distribution': 'fixed', 'default_value': 500.0}}}
SWN_low
```

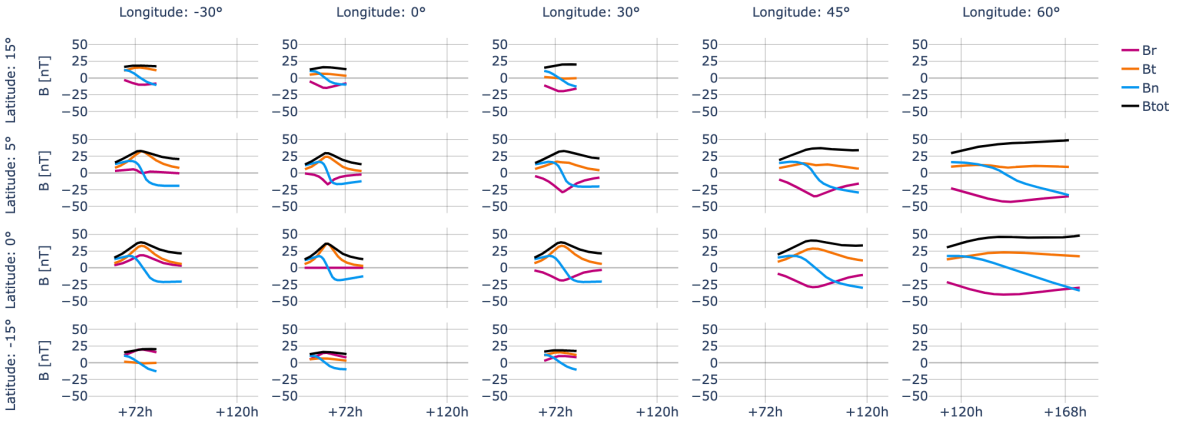



```
{'ensemble_size': 1, 'iparams': {'cme_longitude': {'distribution': 'fixe
d', 'default_value': 0.0}, 'cme_latitude': {'distribution': 'fixed', 'defa
ult_value': 0.0}, 'cme_inclination': {'distribution': 'fixed', 'default_va
lue': 0.0}, 'cme_diameter_1au': {'distribution': 'fixed', 'default_value':
0.3}, 'cme_aspect_ratio': {'distribution': 'fixed', 'default_value': 2.0},
'cme_launch_radius': {'distribution': 'fixed', 'default_value': 20.0}, 'cm
e_launch_velocity': {'distribution': 'fixed', 'default_value': 600.0}, 't_
factor': {'distribution': 'fixed', 'default_value': 50.0}, 'cme_expansion_
rate': {'distribution': 'fixed', 'default_value': 1.14}, 'magnetic_decay_r
ate': {'distribution': 'fixed', 'default_value': 1.64}, 'magnetic_field_st
rength_1au': {'distribution': 'fixed', 'default_value': 25.0}, 'background
_drag': {'distribution': 'fixed', 'default_value': 1.0}, 'background_veloc
ity': {'distribution': 'fixed', 'default_value': 500.0}}}
NES_low
```



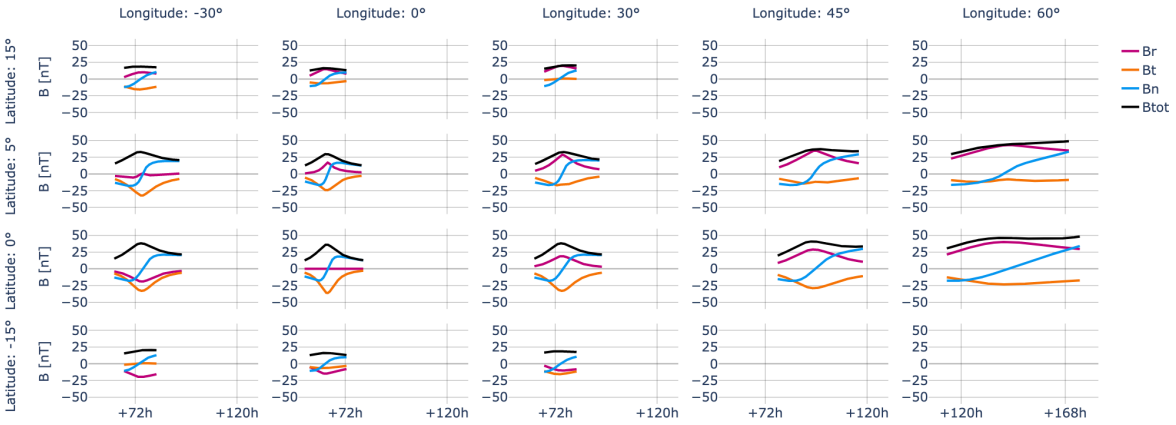
{'ensemble_size': 1, 'iparams': {'cme_longitude': {'distribution': 'fixed', 'default_value': 0.0}, 'cme_latitude': {'distribution': 'fixed', 'default_value': 0.0}, 'cme_inclination': {'distribution': 'fixed', 'default_value': 180.0}, 'cme_diameter_1au': {'distribution': 'fixed', 'default_value': 0.3}, 'cme_aspect_ratio': {'distribution': 'fixed', 'default_value': 2.0}, 'cme_launch_radius': {'distribution': 'fixed', 'default_value': 20.0}, 'cme_launch_velocity': {'distribution': 'fixed', 'default_value': 600.0}, 't_factor': {'distribution': 'fixed', 'default_value': -50.0}, 'cme_expansion_rate': {'distribution': 'fixed', 'default_value': 1.14}, 'magnetic_decay_rate': {'distribution': 'fixed', 'default_value': 1.64}, 'magnetic_field_strength_1au': {'distribution': 'fixed', 'default_value': 25.0}, 'background_drag': {'distribution': 'fixed', 'default_value': 1.0}, 'background_velocity': {'distribution': 'fixed', 'default_value': 500.0}}}

NWS_low

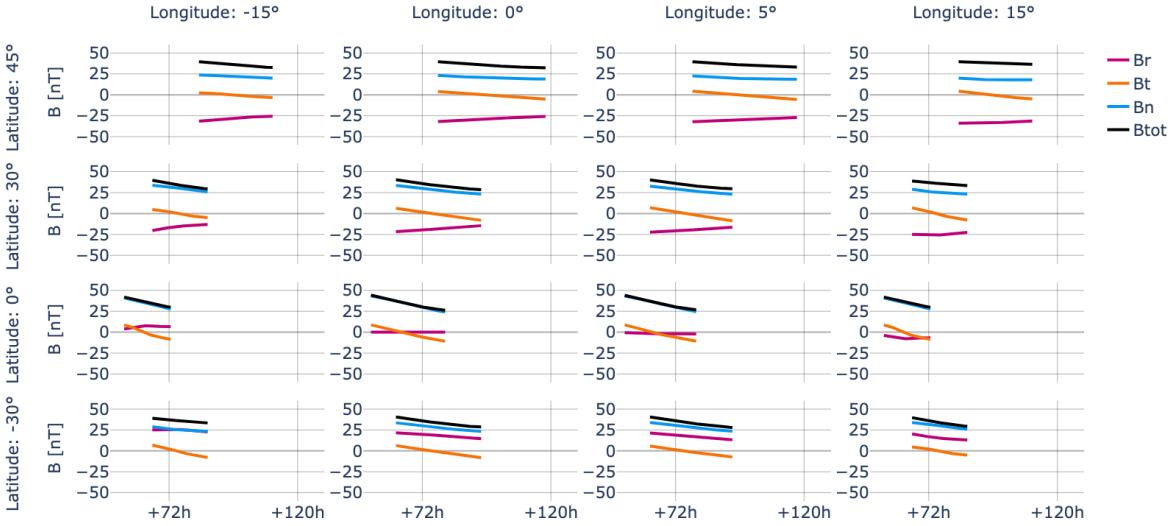


{'ensemble_size': 1, 'iparams': {'cme_longitude': {'distribution': 'fixed', 'default_value': 0.0}, 'cme_latitude': {'distribution': 'fixed', 'default_value': 0.0}, 'cme_inclination': {'distribution': 'fixed', 'default_value': 0.0}, 'cme_diameter_1au': {'distribution': 'fixed', 'default_value': 0.3}, 'cme_aspect_ratio': {'distribution': 'fixed', 'default_value': 2.0}, 'cme_launch_radius': {'distribution': 'fixed', 'default_value': 20.0}, 'cme_launch_velocity': {'distribution': 'fixed', 'default_value': 600.0}, 't_factor': {'distribution': 'fixed', 'default_value': -50.0}, 'cme_expansion_rate': {'distribution': 'fixed', 'default_value': 1.14}, 'magnetic_decay_rate': {'distribution': 'fixed', 'default_value': 1.64}, 'magnetic_field_strength_1au': {'distribution': 'fixed', 'default_value': 25.0}, 'background_drag': {'distribution': 'fixed', 'default_value': 1.0}, 'background_velocity': {'distribution': 'fixed', 'default_value': 500.0}}}

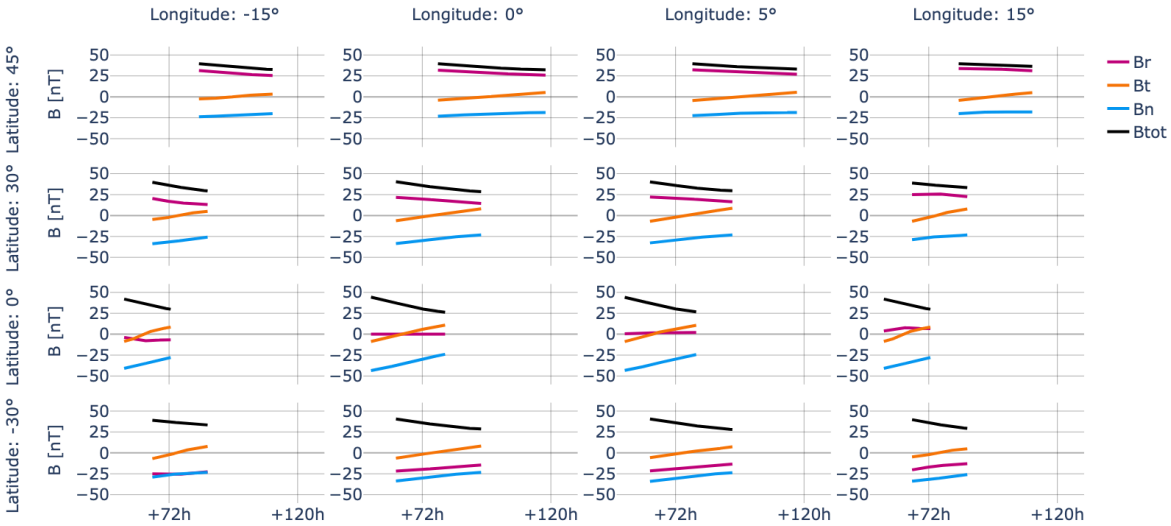
SEN_low



High Inclination!
righthanded: ENW
{'ensemble_size': 1, 'iparams': {'cme_longitude': {'distribution': 'fixed', 'default_value': 0.0}, 'cme_latitude': {'distribution': 'fixed', 'default_value': 0.0}, 'cme_inclination': {'distribution': 'fixed', 'default_value': 270.0}, 'cme_diameter_1au': {'distribution': 'fixed', 'default_value': 0.3}, 'cme_aspect_ratio': {'distribution': 'fixed', 'default_value': 2.0}, 'cme_launch_radius': {'distribution': 'fixed', 'default_value': 20.0}, 'cme_launch_velocity': {'distribution': 'fixed', 'default_value': 600.0}, 't_factor': {'distribution': 'fixed', 'default_value': 5.0}, 'cme_expansion_rate': {'distribution': 'fixed', 'default_value': 1.14}, 'magnetic_decay_rate': {'distribution': 'fixed', 'default_value': 1.64}, 'magnetic_field_strength_1au': {'distribution': 'fixed', 'default_value': 25.0}, 'background_drag': {'distribution': 'fixed', 'default_value': 1.0}, 'background_velocity': {'distribution': 'fixed', 'default_value': 500.0}}}
WNE_high



{'ensemble_size': 1, 'iparams': {'cme_longitude': {'distribution': 'fixe
d', 'default_value': 0.0}, 'cme_latitude': {'distribution': 'fixed', 'defa
ult_value': 0.0}, 'cme_inclination': {'distribution': 'fixed', 'default_va
lue': 90.0}, 'cme_diameter_1au': {'distribution': 'fixed', 'default_valu
e': 0.3}, 'cme_aspect_ratio': {'distribution': 'fixed', 'default_value':
2.0}, 'cme_launch_radius': {'distribution': 'fixed', 'default_value': 20.
0}, 'cme_launch_velocity': {'distribution': 'fixed', 'default_value': 600.
0}, 't_factor': {'distribution': 'fixed', 'default_value': 5.0}, 'cme_expa
nsion_rate': {'distribution': 'fixed', 'default_value': 1.14}, 'magnetic_d
ecay_rate': {'distribution': 'fixed', 'default_value': 1.64}, 'magnetic_fi
eld_strength_1au': {'distribution': 'fixed', 'default_value': 25.0}, 'back
ground_drag': {'distribution': 'fixed', 'default_value': 1.0}, 'background
_velocity': {'distribution': 'fixed', 'default_value': 500.0}}}
ESW_high



{'ensemble_size': 1, 'iparams': {'cme_longitude': {'distribution': 'fixe
d', 'default_value': 0.0}, 'cme_latitude': {'distribution': 'fixed', 'defa
ult_value': 0.0}, 'cme_inclination': {'distribution': 'fixed', 'default_va
lue': 270.0}, 'cme_diameter_1au': {'distribution': 'fixed', 'default_valu
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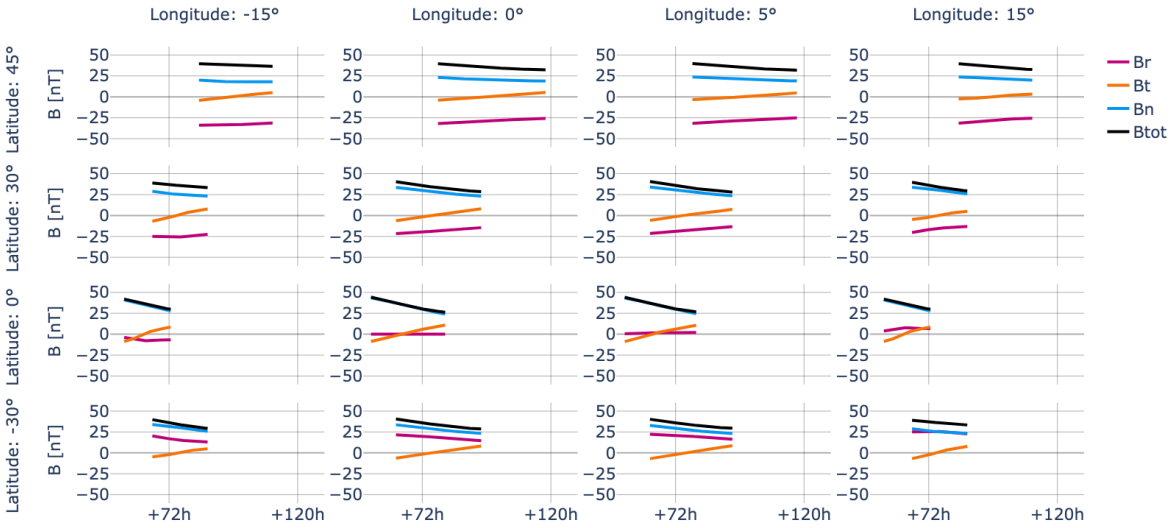
ENW_high



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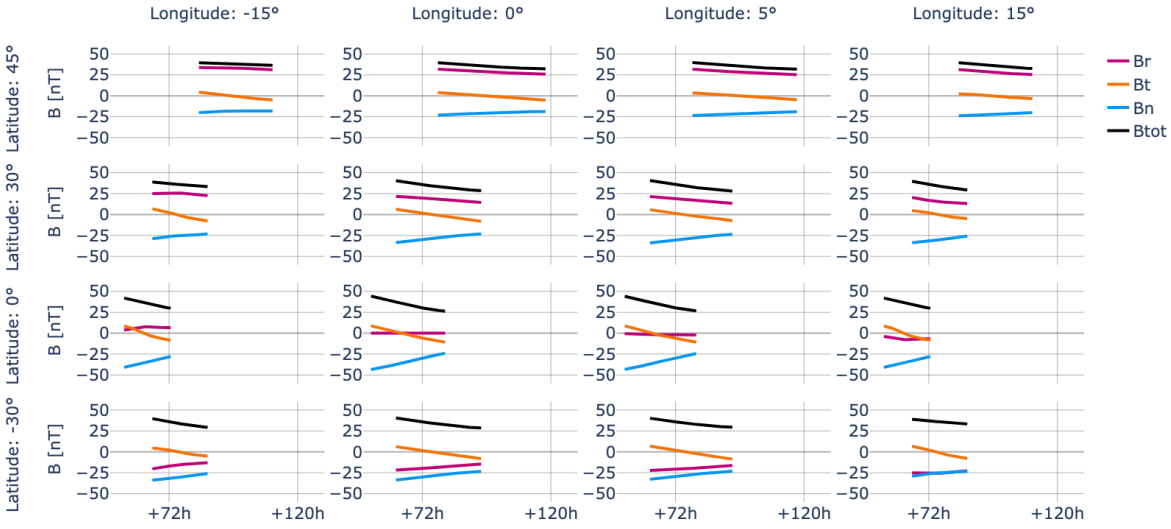
WSE_high



righthanded: NES

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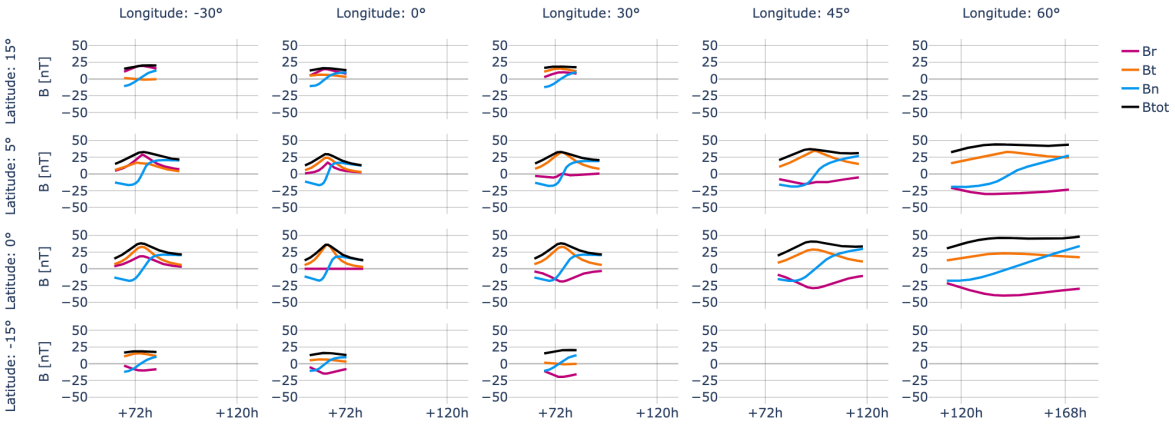
SWN_low



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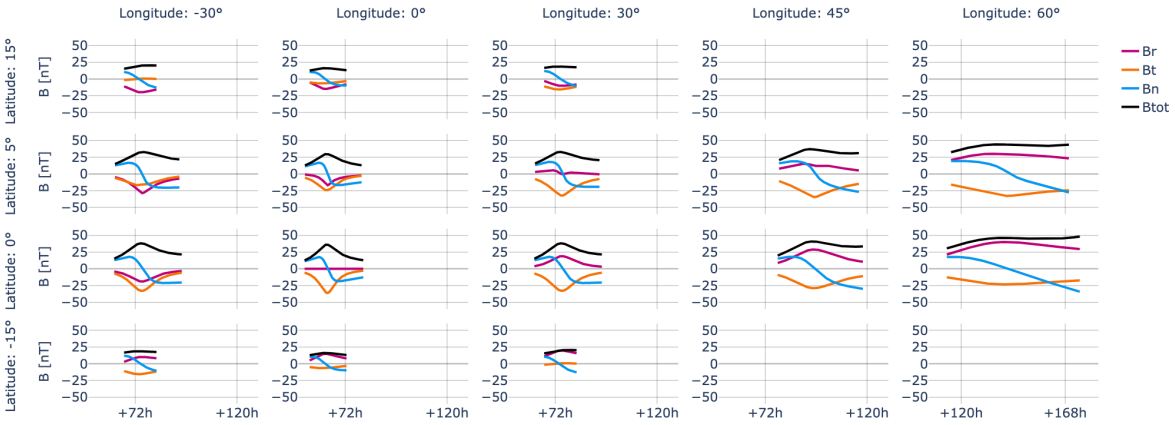
NES_low



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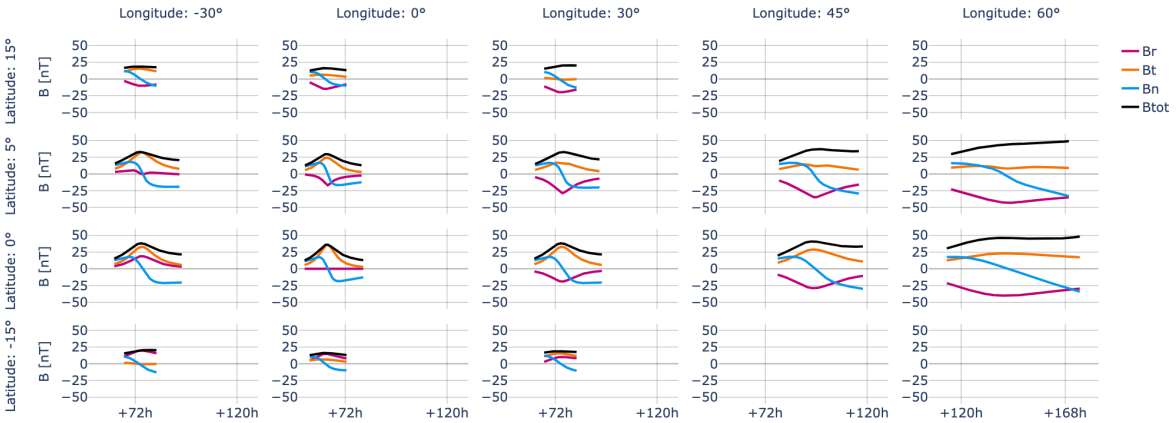
NWS_low



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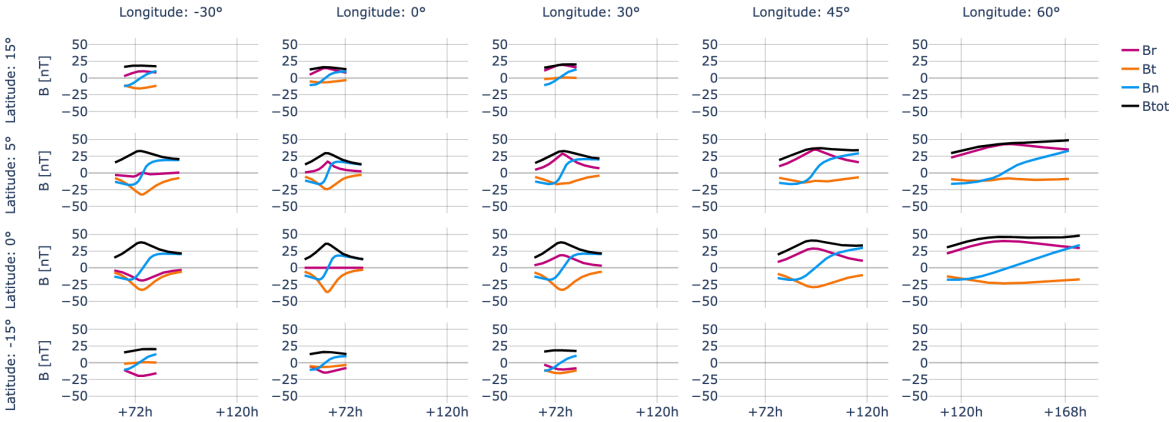
SEN_low



High Inclination!
righthanded: ENW
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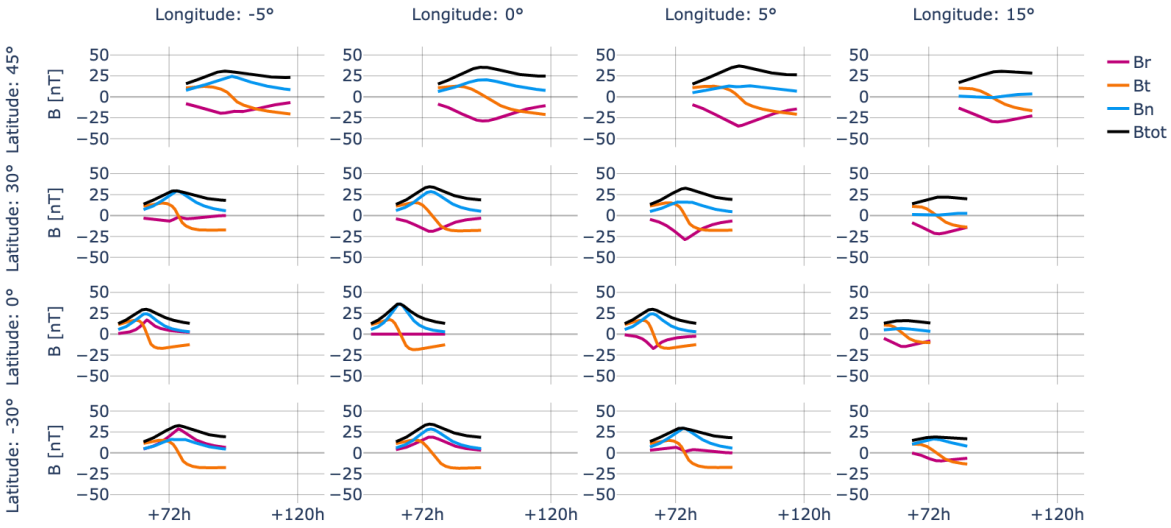
decay_rate': {'distribution': 'fixed', 'default_value': 1.64}, 'magnetic_f
ield_strength_1au': {'distribution': 'fixed', 'default_value': 25.0}, 'bac
kground_drag': {'distribution': 'fixed', 'default_value': 1.0}, 'backgroun
d_velocity': {'distribution': 'fixed', 'default_value': 500.0}}}
WNE_high



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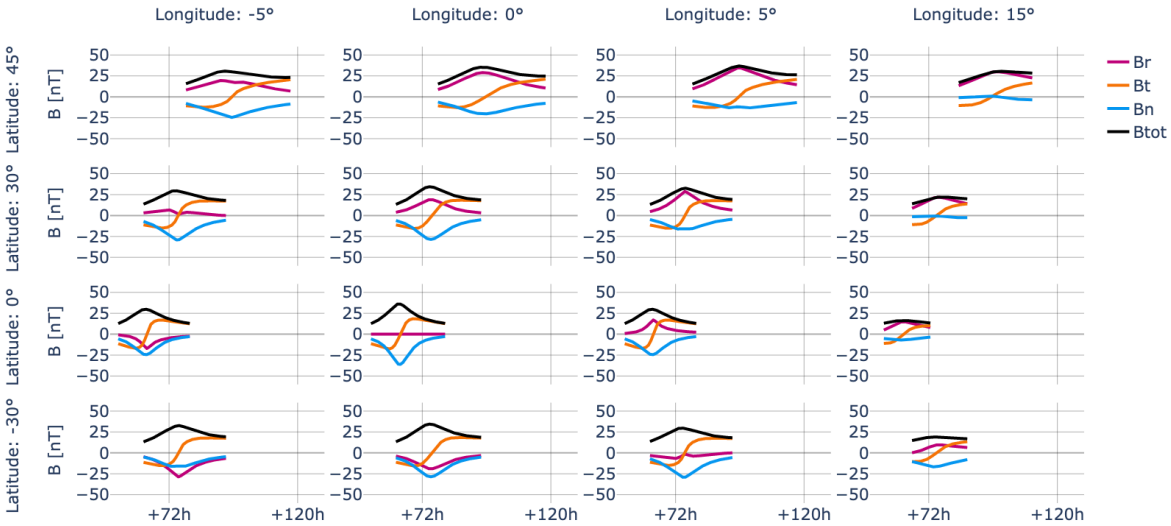
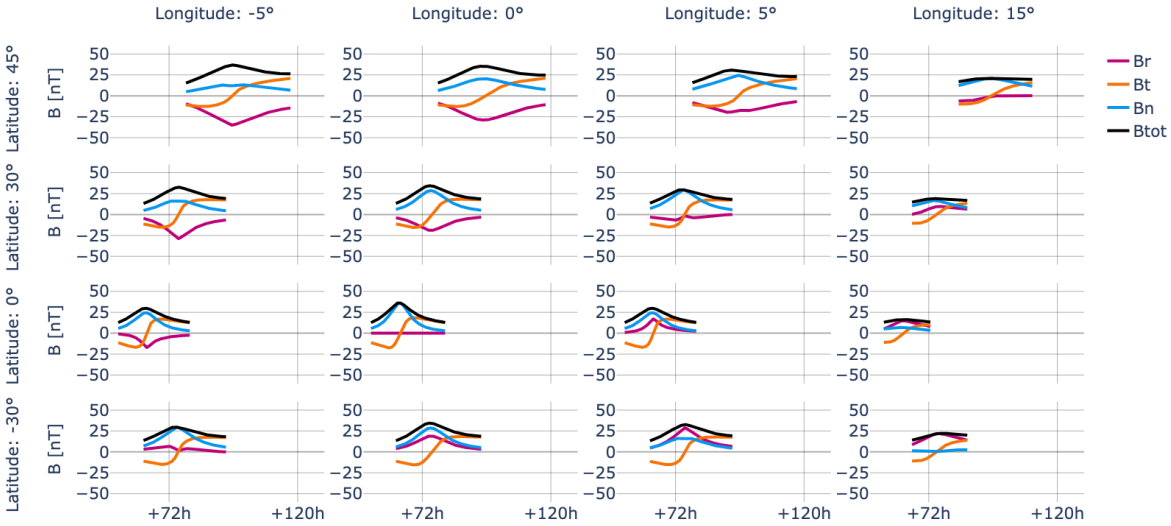
ield_strength_1au': {'distribution': 'fixed', 'default_value': 25.0}, 'bac
kground_drag': {'distribution': 'fixed', 'default_value': 1.0}, 'backgroun
d_velocity': {'distribution': 'fixed', 'default_value': 500.0}}}
ESW_high



{'ensemble_size': 1, 'iparams': {'cme_longitude': {'distribution': 'fixed', 'default_value': 0.0}, 'cme_latitude': {'distribution': 'fixed', 'default_value': 0.0}, 'cme_inclination': {'distribution': 'fixed', 'default_value': 270.0}, 'cme_diameter_1au': {'distribution': 'fixed', 'default_value': 0.3}, 'cme_aspect_ratio': {'distribution': 'fixed', 'default_value': 2.0}, 'cme_launch_radius': {'distribution': 'fixed', 'default_value': 20.0}, 'cme_launch_velocity': {'distribution': 'fixed', 'default_value': 600.0}, 't_factor': {'distribution': 'fixed', 'default_value': −50.0}, 'cme_expansion_rate': {'distribution': 'fixed', 'default_value': 1.14}, 'magnetic_decay_rate': {'distribution': 'fixed', 'default_value': 1.64}, 'magnetic_field_strength_1au': {'distribution': 'fixed', 'default_value': 25.0}, 'background_drag': {'distribution': 'fixed', 'default_value': 1.0}, 'background_velocity': {'distribution': 'fixed', 'default_value': 500.0}}}
ENW_high



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WSE_high