Follow-Me Project

Congratulations on reaching the final project of the Robotics Nanodegree!

Previously, you worked on the Semantic Segmentation lab where you built a deep learning network that locates a particular human target within an image. For this project, you will utilize what you implemented and learned from that lab and extend it to train a deep learning model that will allow a simulated quadcopter to follow around the person that it detects!

Most of the code below is similar to the lab with some minor modifications. You can start with your existing solution, and modify and improve upon it to train the best possible model for this task.

You can click on any of the following to quickly jump to that part of this notebook:

Data Collection

We have provided you with a starting dataset for this project. Download instructions can be found in the README for this project's repo. Alternatively, you can collect additional data of your own to improve your model. Check out the "Collecting Data" section in the Project Lesson in the Classroom for more details!

In [24]:

```
import os
import glob
import sys
import tensorflow as tf

from scipy import misc
import numpy as np

from tensorflow.contrib.keras.python import keras
from tensorflow.contrib.keras.python.keras import layers, models

from tensorflow import image

from utils import scoring_utils
from utils.separable_conv2d import SeparableConv2DKeras, BilinearUpSampling
2D
from utils import data_iterator
from utils import plotting_tools
from utils import model_tools
```

FCN Layers

In the Classroom, we discussed the different layers that constitute a fully convolutional network (FCN). The following code will introduce you to the functions that you need to build your semantic segmentation model.

Separable Convolutions

The Encoder for your FCN will essentially require separable convolution layers, due to their advantages as explained in the classroom. The 1x1 convolution layer in the FCN, however, is a regular convolution. Implementations for both are provided below for your use. Each includes batch normalization with the ReLU activation function applied to the layers.

In [25]:
```
def separable_conv2d_batchnorm(input_layer, filters, strides=1):
    output_layer = SeparableConv2DKeras(filters=filters,kernel_size=3, stri
des=strides,
                             padding='same', activation='relu')(input_layer
)

    output_layer = layers.BatchNormalization()(output_layer)
    return output_layer

def conv2d_batchnorm(input_layer, filters, kernel_size=3, strides=1):
    output_layer = layers.Conv2D(filters=filters, kernel_size=kernel_size,
strides=strides,
                      padding='same', activation='relu')(input_layer)

    output_layer = layers.BatchNormalization()(output_layer)
    return output_layer
```

Bilinear Upsampling

The following helper function implements the bilinear upsampling layer. Upsampling by a factor of 2 is generally recommended, but you can try out different factors as well. Upsampling is used in the decoder block of the FCN.

In [26]:
```
def bilinear_upsample(input_layer):
    output_layer = BilinearUpSampling2D((2,2))(input_layer)
    return output_layer
```

Build the Model

In the following cells, you will build an FCN to train a model to detect and locate the hero target within an image. The steps are:

- Create an `encoder_block`
- Create a `decoder_block`
- Build the FCN consisting of encoder block(s), a 1x1 convolution, and decoder block(s). This step requires experimentation with different numbers of layers and filter sizes to build your model.

Encoder Block

Create an encoder block that includes a separable convolution layer using the `separable_conv2d_batchnorm()` function. The `filters` parameter defines the size or depth of the output layer. For example, 32 or 64.

In [27]:
```
def encoder_block(input_layer, filters, strides=1):

    # TODO Create a separable convolution layer using the separable_conv2d_
batchnorm() function.
    output_layer = separable_conv2d_batchnorm(input_layer, filters=filters,
strides=strides)
    return output_layer
```

Decoder Block

The decoder block is comprised of three parts:

- A bilinear upsampling layer using the upsample_bilinear() function. The current recommended factor for upsampling is set to 2.
- A layer concatenation step. This step is similar to skip connections. You will concatenate the upsampled small_ip_layer and the large_ip_layer.
- Some (one or two) additional separable convolution layers to extract some more spatial information from prior layers.

In [28]:
```
def decoder_block(small_ip_layer, large_ip_layer, filters):

    # TODO Upsample the small input layer using the bilinear_upsample() fun
ction.
    Upsampled_small_ip_layer = bilinear_upsample(small_ip_layer)
    # TODO Concatenate the upsampled and large input layers using layers.co
ncatenate
    concatenated_layers = layers.concatenate([Upsampled_small_ip_layer,larg
e_ip_layer])
    # TODO Add some number of separable convolution layers
    output_layer = encoder_block(concatenated_layers,filters=filters, strid
es=1)
    return output_layer
```

Model

Now that you have the encoder and decoder blocks ready, go ahead and build your FCN architecture!

There are three steps:

- Add encoder blocks to build the encoder layers. This is similar to how you added regular convolutional layers in your CNN lab.
- Add a 1x1 Convolution layer using the conv2d_batchnorm() function. Remember that 1x1 Convolutions require a kernel and stride of 1.
- Add decoder blocks for the decoder layers.

In [29]:
```
def fcn_model(inputs, num_classes):

    # TODO Add Encoder Blocks.
    # Remember that with each encoder layer, the depth of your model (the n
umber of filters) increases.
    print(inputs.get_shape())
    #Layer 1
    layer_1 = encoder_block(inputs, filters=32, strides=2)
    print(layer_1.get_shape())
    #Layer 2
    layer_2 = encoder_block(layer_1, filters=64, strides=2)
    print(layer_2.get_shape())
    layer_3 = encoder_block(layer_2, filters=128, strides=2)
    print(layer_3.get_shape())
    layer_4 = encoder_block(layer_3, filters=256, strides=2)
    print(layer_4.get_shape())
    # TODO Add 1x1 Convolution layer using conv2d_batchnorm().
    layer_1x1 = conv2d_batchnorm(layer_4, filters=1028, kernel_size=1, stri
des=1)
    print(layer_1x1.get_shape())
    # TODO: Add the same number of Decoder Blocks as the number of Encoder
Blocks
    decoder_1 = decoder_block(layer_1x1, layer_3, filters=128)
    print(decoder_1.get_shape())
    decoder_2 = decoder_block(decoder_1, layer_2, filters=64)
    print(decoder_2.get_shape())
    decoder_3 = decoder_block(decoder_2, layer_1, filters=32)
    print(decoder_3.get_shape())
    x = decoder_block(decoder_3, inputs, filters=num_classes)
    print(x.get_shape())
    # The function returns the output layer of your model. "x" is the final
layer obtained from the last decoder_block()
    return layers.Conv2D(num_classes, 3, activation='softmax', padding='sam
e')(x)
```

Training

The following cells will use the FCN you created and define an ouput layer based on the size of the processed image and the number of classes recognized. You will define the hyperparameters to compile and train your model.

Please Note: For this project, the helper code in `data_iterator.py` will resize the copter images to 160x160x3 to speed up training.

In [30]:
```
"""
DON'T MODIFY ANYTHING IN THIS CELL THAT IS BELOW THIS LINE
"""

image_hw = 160
image_shape = (image_hw, image_hw, 3)
inputs = layers.Input(image_shape)
num_classes = 3

# Call fcn_model()
output_layer = fcn_model(inputs, num_classes)
#print(output_layer.get_shape())
```

```
(?, 160, 160, 3)
(?, 80, 80, 32)
(?, 40, 40, 64)
(?, 20, 20, 128)
(?, 10, 10, 256)
(?, 10, 10, 1028)
(?, 20, 20, 128)
(?, 40, 40, 64)
(?, 80, 80, 32)
(?, 160, 160, 3)
```

Hyperparameters

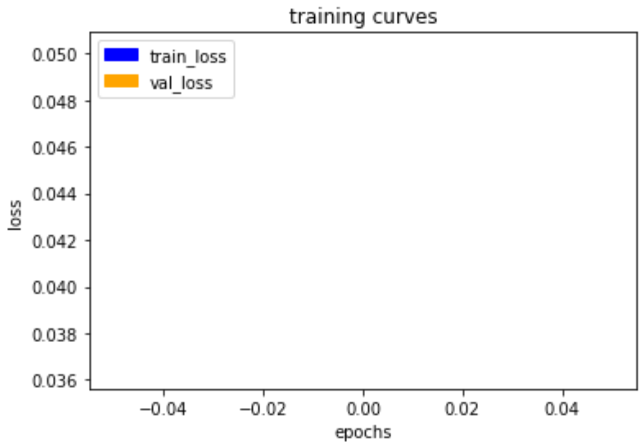
Define and tune your hyperparameters.

- **batch_size**: number of training samples/images that get propagated through the network in a single pass.
- **num_epochs**: number of times the entire training dataset gets propagated through the network.
- **steps_per_epoch**: number of batches of training images that go through the network in 1 epoch. We have provided you with a default value. One recommended value to try would be based on the total number of images in training dataset divided by the batch_size.
- **validation_steps**: number of batches of validation images that go through the network in 1 epoch. This is similar to steps_per_epoch, except validation_steps is for the validation dataset. We have provided you with a default value for this as well.
- **workers**: maximum number of processes to spin up. This can affect your training speed and is dependent on your hardware. We have provided a recommended value to work with.

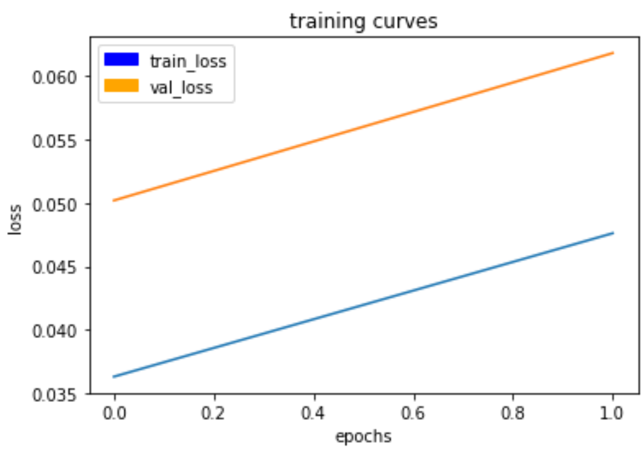
In [87]:
```
learning_rate = 0.001
batch_size = 10
num_epochs = 100
steps_per_epoch = 30
validation_steps = 50
workers = 2
```

In [88]:
```
"""
DON'T MODIFY ANYTHING IN THIS CELL THAT IS BELOW THIS LINE
"""
# Define the Keras model and compile it for training
model = models.Model(inputs=inputs, outputs=output_layer)

model.compile(optimizer=keras.optimizers.Adam(learning_rate), loss='categor
ical_crossentropy')

# Data iterators for loading the training and validation data
train_iter = data_iterator.BatchIteratorSimple(batch_size=batch_size,
                                               data_folder=os.path.join('..
', 'data', 'train'),
                                               image_shape=image_shape,
                                               shift_aug=True)

val_iter = data_iterator.BatchIteratorSimple(batch_size=batch_size,
                                             data_folder=os.path.join('..',
'data', 'validation'),
                                             image_shape=image_shape)

logger_cb = plotting_tools.LoggerPlotter()
callbacks = [logger_cb]

model.fit_generator(train_iter,
                    steps_per_epoch = steps_per_epoch, # the number of batc
hes per epoch,
                    epochs = num_epochs, # the number of epochs to train fo
r,
                    validation_data = val_iter, # validation iterator
                    validation_steps = validation_steps, # the number of ba
tches to validate on
                    callbacks=callbacks,
                    workers = workers)
```

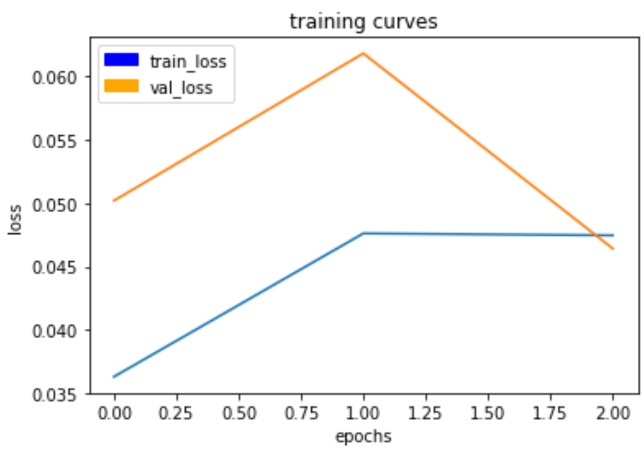
```
Epoch 1/100
29/30 [============================>.] - ETA: 2s - loss: 0.0368
```



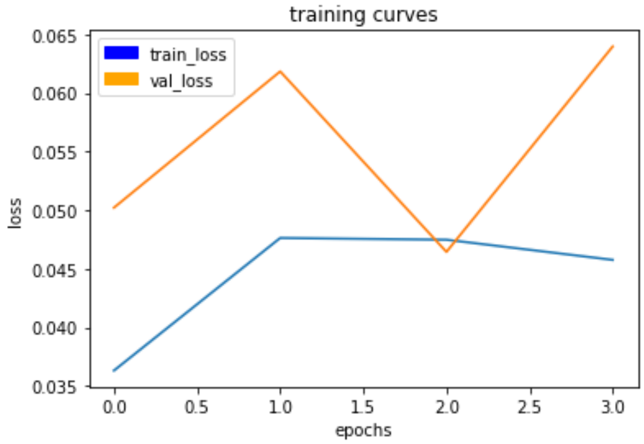

```
30/30 [==============================] - 94s - loss: 0.0363 - val_loss: 0.0
502
Epoch 2/100
29/30 [============================>.] - ETA: 2s - loss: 0.0477
```



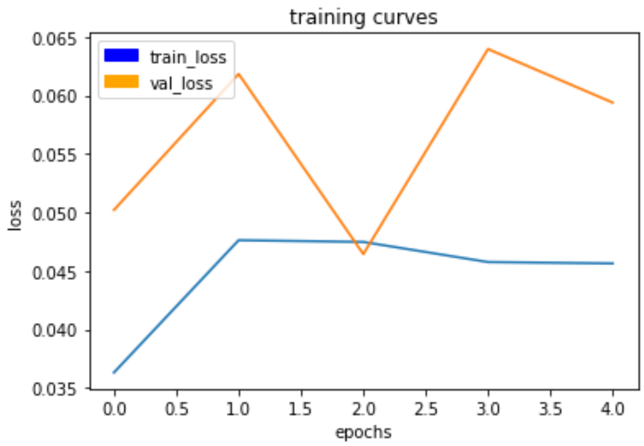

```
30/30 [==============================] - 88s - loss: 0.0476 - val_loss: 0.0
618
Epoch 3/100
29/30 [============================>.] - ETA: 2s - loss: 0.0478
```



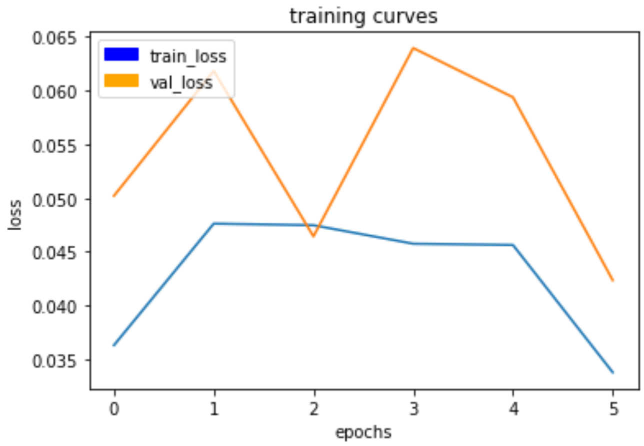
```
30/30 [==============================] - 91s - loss: 0.0475 - val_loss: 0.0
464
Epoch 4/100
29/30 [============================>.] - ETA: 2s - loss: 0.0463
```



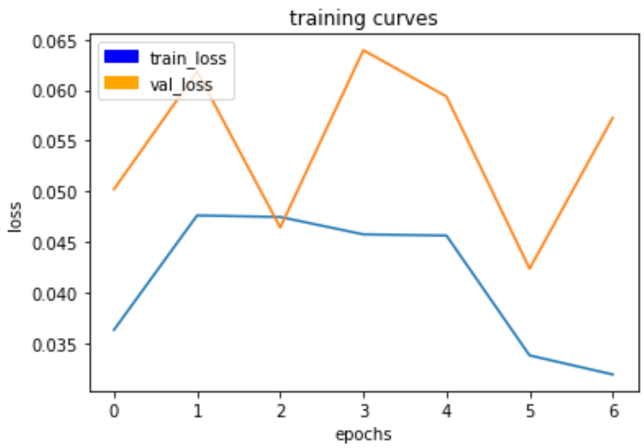

```
30/30 [==============================] - 89s - loss: 0.0458 - val_loss: 0.0
640
Epoch 5/100
29/30 [============================>.] - ETA: 2s - loss: 0.0455
```



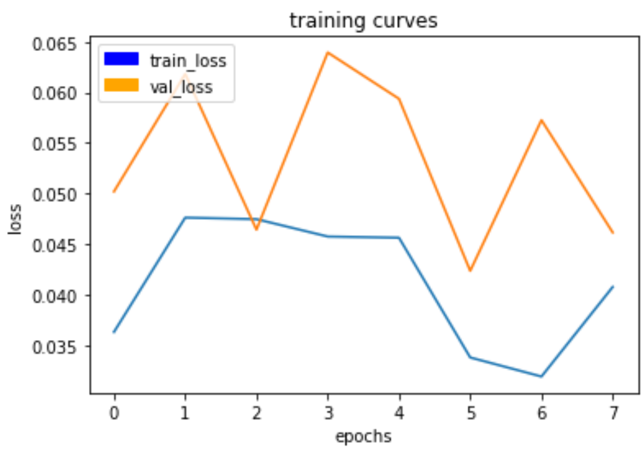

```
30/30 [==============================] - 89s - loss: 0.0456 - val_loss: 0.0
594
Epoch 6/100
29/30 [============================>.] - ETA: 2s - loss: 0.0342
```



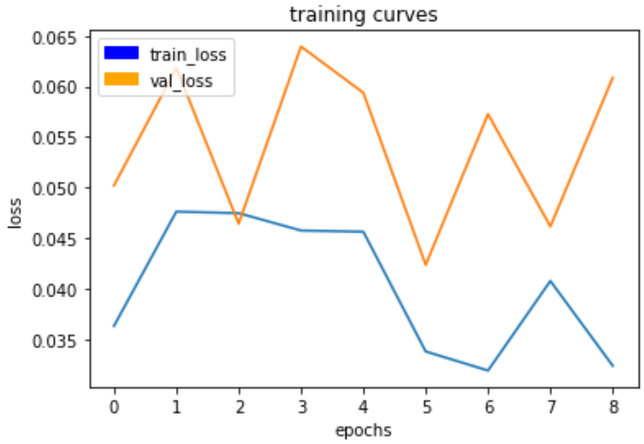

```
30/30 [==============================] - 90s - loss: 0.0338 - val_loss: 0.0
424
Epoch 7/100
29/30 [============================>.] - ETA: 2s - loss: 0.0321
```



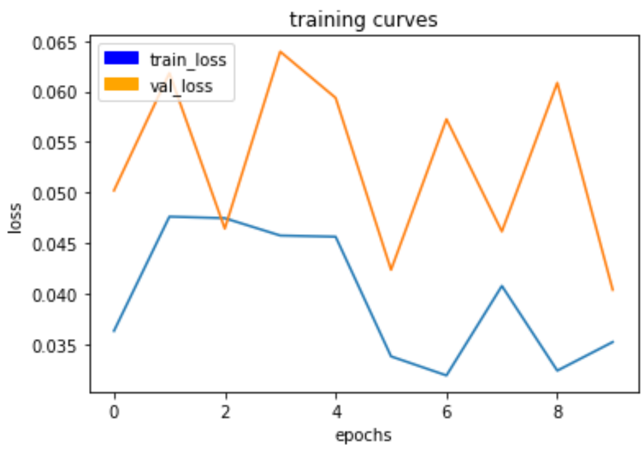

```
30/30 [==============================] - 90s - loss: 0.0319 - val_loss: 0.0
573
Epoch 8/100
29/30 [============================>.] - ETA: 2s - loss: 0.0409
```



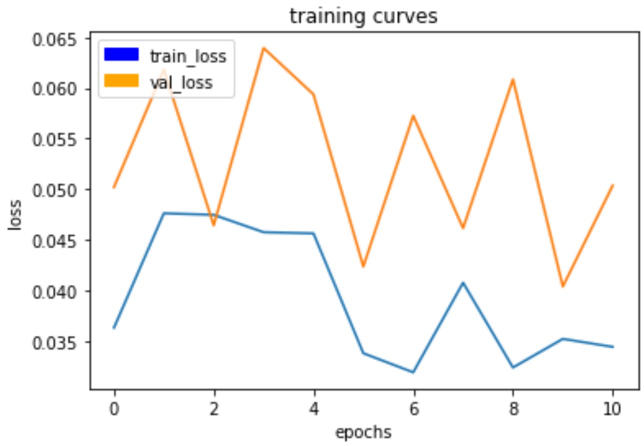
```
30/30 [==============================] - 94s - loss: 0.0408 - val_loss: 0.0
462
Epoch 9/100
29/30 [============================>.] - ETA: 2s - loss: 0.0322
```



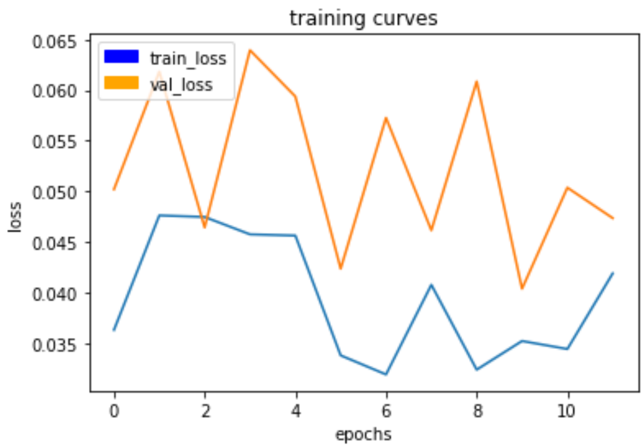

```
30/30 [==============================] - 89s - loss: 0.0324 - val_loss: 0.0
609
Epoch 10/100
29/30 [============================>.] - ETA: 2s - loss: 0.0355
```



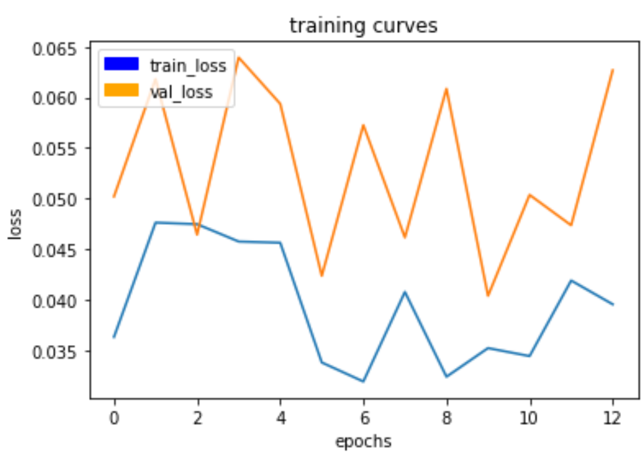

```
30/30 [==============================] - 88s - loss: 0.0352 - val_loss: 0.0
404
Epoch 11/100
29/30 [============================>.] - ETA: 2s - loss: 0.0349
```



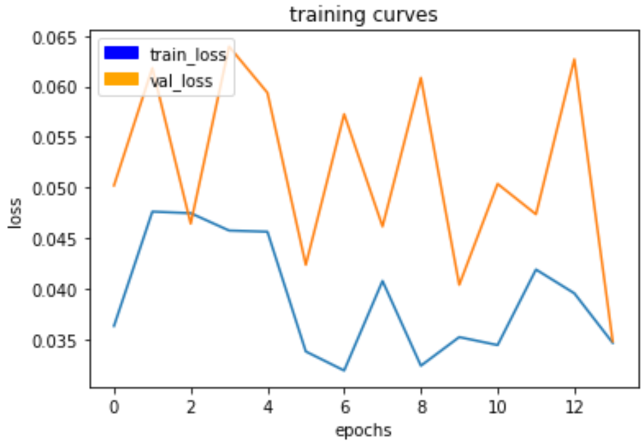

```
30/30 [==============================] - 89s - loss: 0.0344 - val_loss: 0.0
504
Epoch 12/100
29/30 [============================>.] - ETA: 2s - loss: 0.0425
```



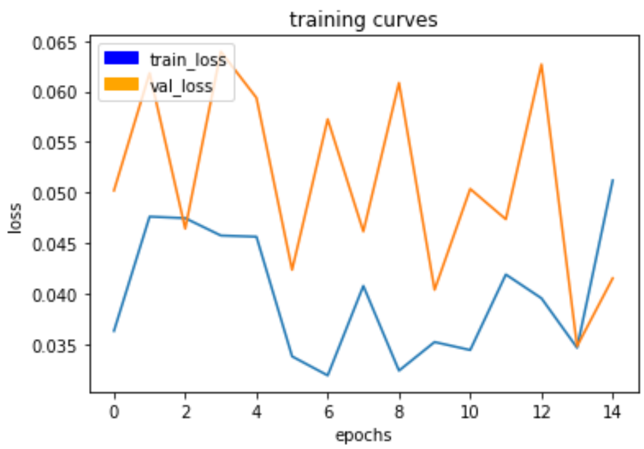

```
30/30 [==============================] - 87s - loss: 0.0419 - val_loss: 0.0
474
Epoch 13/100
29/30 [============================>.] - ETA: 2s - loss: 0.0401
```



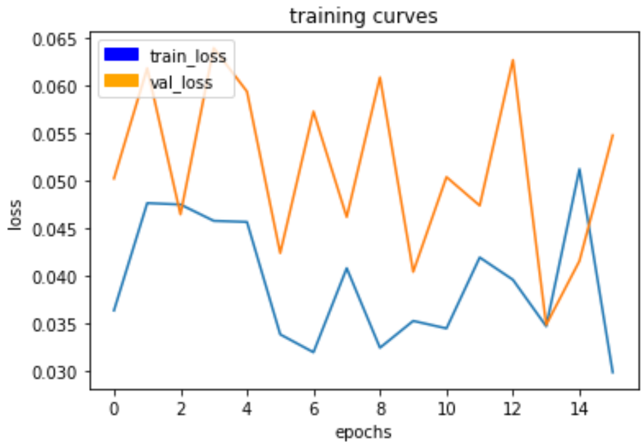
```
30/30 [==============================] - 87s - loss: 0.0395 - val_loss: 0.0
627
Epoch 14/100
29/30 [============================>.] - ETA: 2s - loss: 0.0344
```



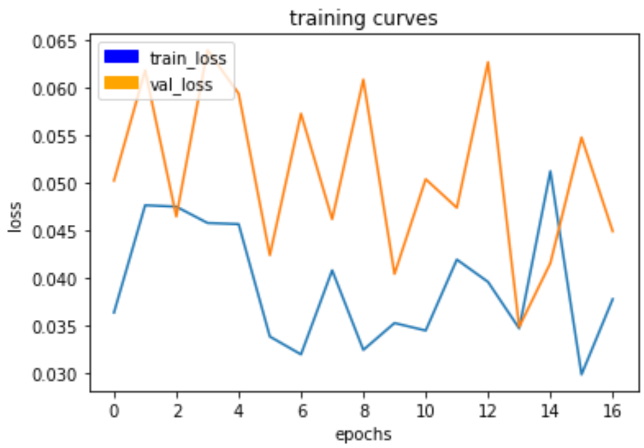

```
30/30 [==============================] - 89s - loss: 0.0343 - val_loss: 0.0
348
Epoch 15/100
29/30 [============================>.] - ETA: 2s - loss: 0.0514
```



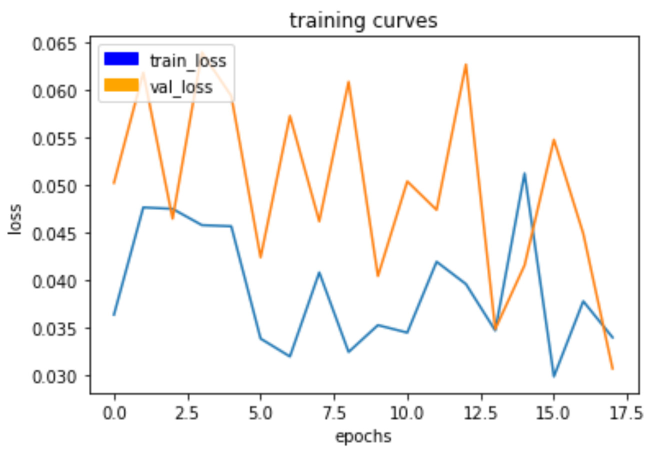

```
30/30 [==============================] - 88s - loss: 0.0512 - val_loss: 0.0
415
Epoch 16/100
29/30 [============================>.] - ETA: 2s - loss: 0.0301
```



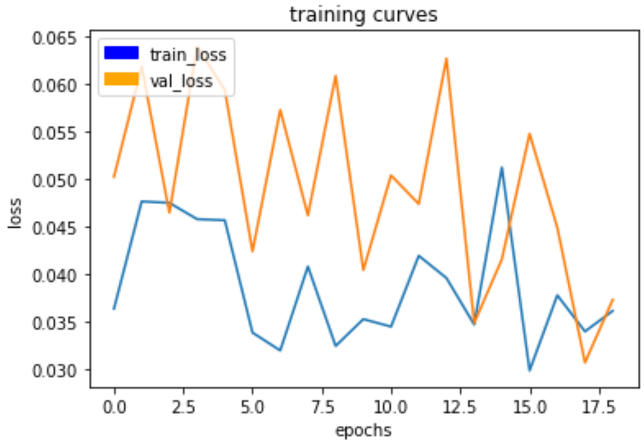

```
30/30 [==============================] - 87s - loss: 0.0298 - val_loss: 0.0
548
Epoch 17/100
29/30 [============================>.] - ETA: 2s - loss: 0.0379
```



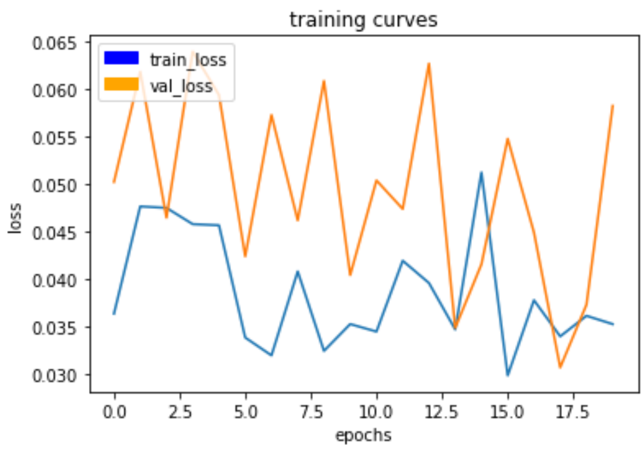

```
30/30 [==============================] - 88s - loss: 0.0377 - val_loss: 0.0
449
Epoch 18/100
29/30 [============================>.] - ETA: 2s - loss: 0.0341
```



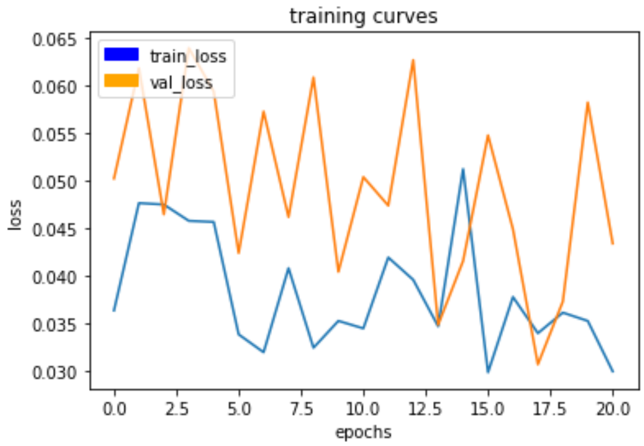
```
30/30 [==============================] - 87s - loss: 0.0339 - val_loss: 0.0
306
Epoch 19/100
29/30 [============================>.] - ETA: 2s - loss: 0.0367
```



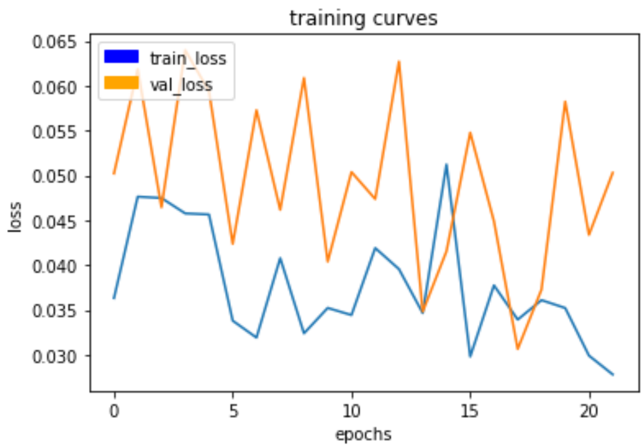

```
30/30 [==============================] - 87s - loss: 0.0361 - val_loss: 0.0
373
Epoch 20/100
29/30 [============================>.] - ETA: 2s - loss: 0.0353
```



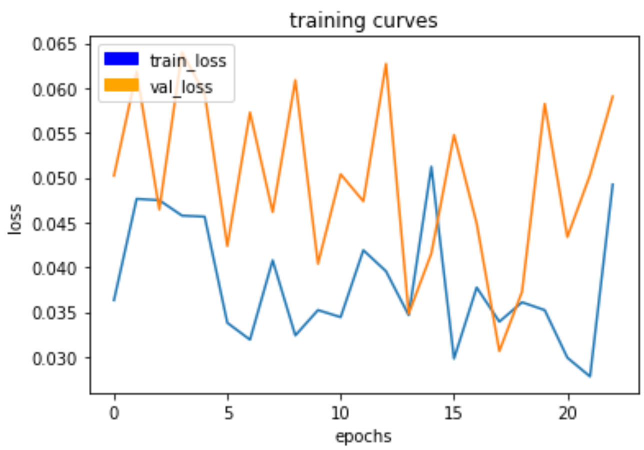

```
30/30 [==============================] - 87s - loss: 0.0352 - val_loss: 0.0
582
Epoch 21/100
29/30 [============================>.] - ETA: 2s - loss: 0.0301
```



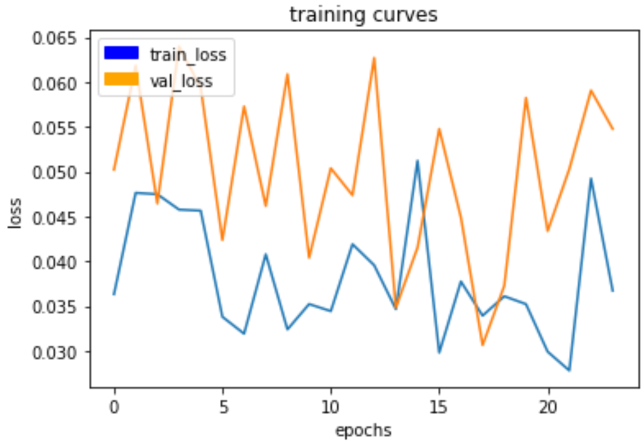

```
30/30 [==============================] - 91s - loss: 0.0299 - val_loss: 0.0
434
Epoch 22/100
29/30 [============================>.] - ETA: 2s - loss: 0.0277
```



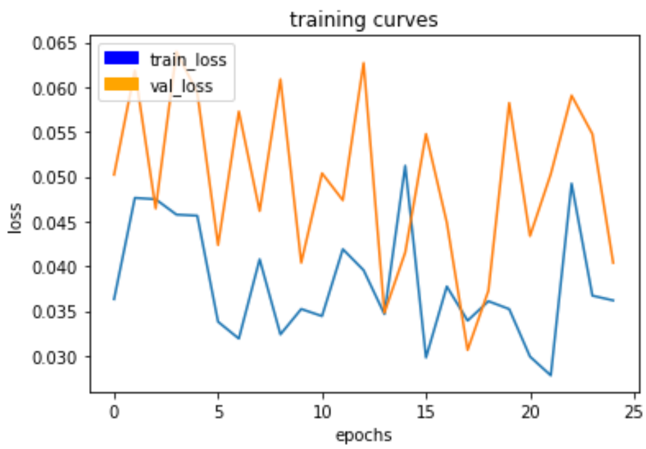

```
30/30 [==============================] - 89s - loss: 0.0278 - val_loss: 0.0
503
Epoch 23/100
29/30 [============================>.] - ETA: 2s - loss: 0.0473
```



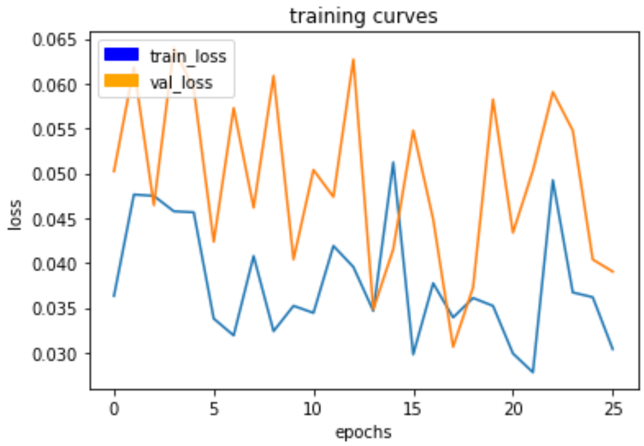
```
30/30 [==============================] - 91s - loss: 0.0492 - val_loss: 0.0
591
Epoch 24/100
29/30 [============================>.] - ETA: 2s - loss: 0.0370
```



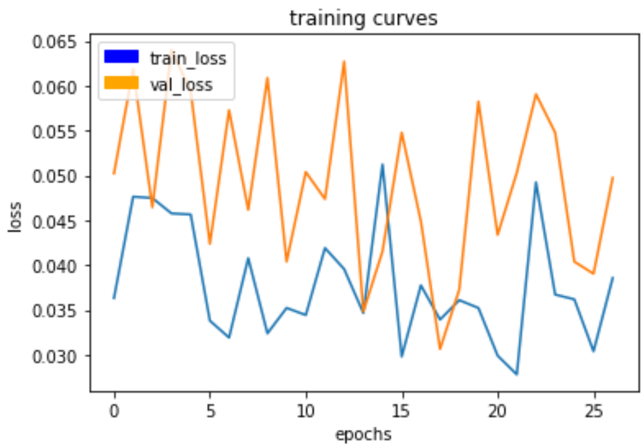

```
30/30 [==============================] - 87s - loss: 0.0367 - val_loss: 0.0
548
Epoch 25/100
29/30 [============================>.] - ETA: 2s - loss: 0.0363
```



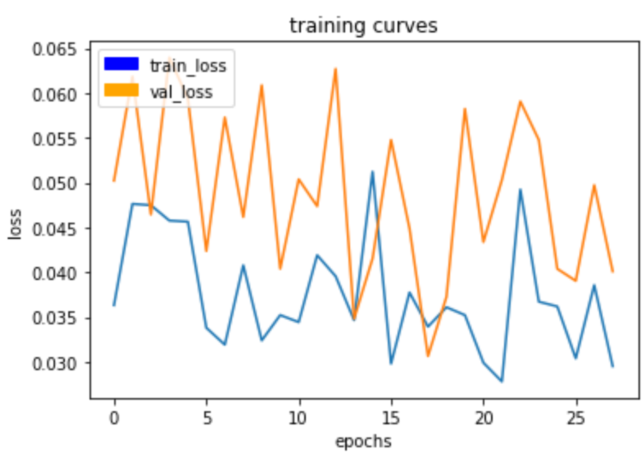

```
30/30 [==============================] - 90s - loss: 0.0362 - val_loss: 0.0
404
Epoch 26/100
29/30 [============================>.] - ETA: 2s - loss: 0.0307
```



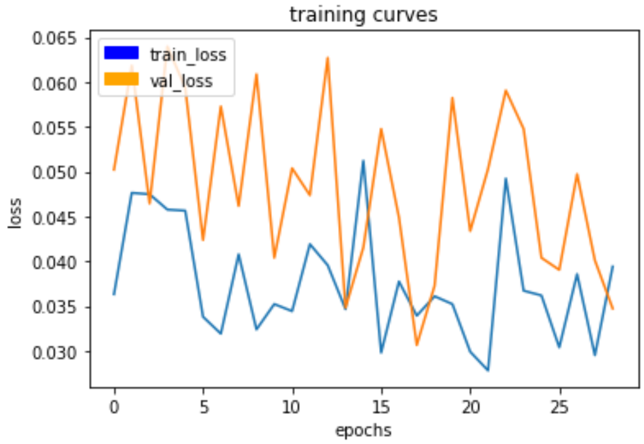

```
30/30 [==============================] - 92s - loss: 0.0304 - val_loss: 0.0
390
Epoch 27/100
29/30 [============================>.] - ETA: 2s - loss: 0.0387
```



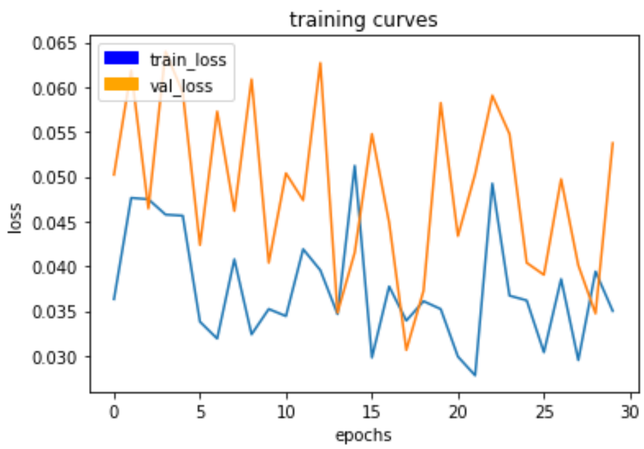

```
30/30 [==============================] - 92s - loss: 0.0386 - val_loss: 0.0
497
Epoch 28/100
29/30 [============================>.] - ETA: 2s - loss: 0.0303
```



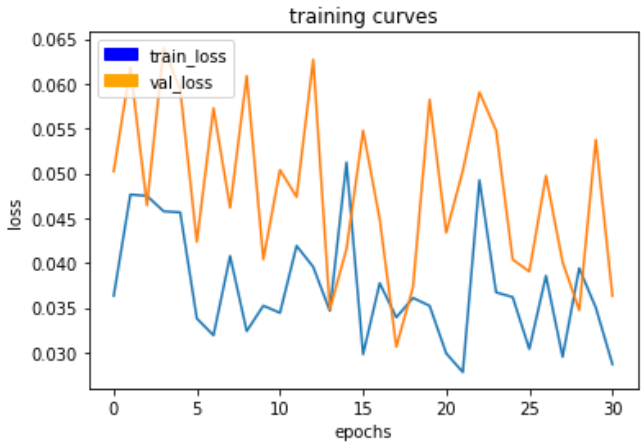
```
30/30 [==============================] - 86s - loss: 0.0299 - val_loss: 0.0
401
Epoch 29/100
29/30 [============================>.] - ETA: 2s - loss: 0.0393
```



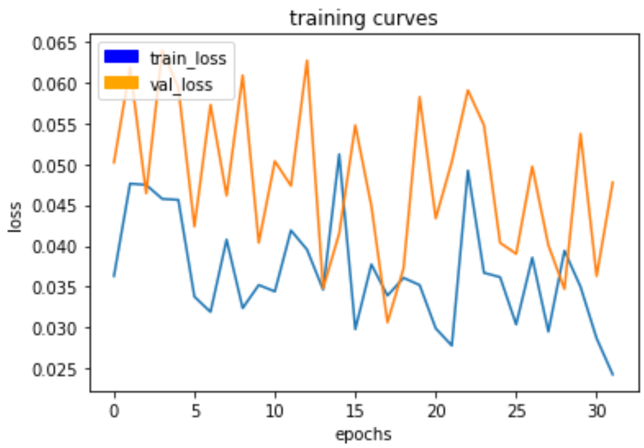

```
30/30 [==============================] - 88s - loss: 0.0394 - val_loss: 0.0
347
Epoch 30/100
29/30 [============================>.] - ETA: 2s - loss: 0.0352
```



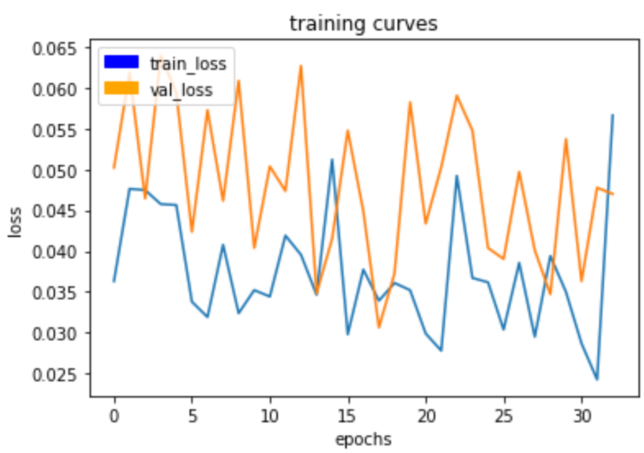

```
30/30 [==============================] - 88s - loss: 0.0350 - val_loss: 0.0
537
Epoch 31/100
29/30 [============================>.] - ETA: 2s - loss: 0.0289
```



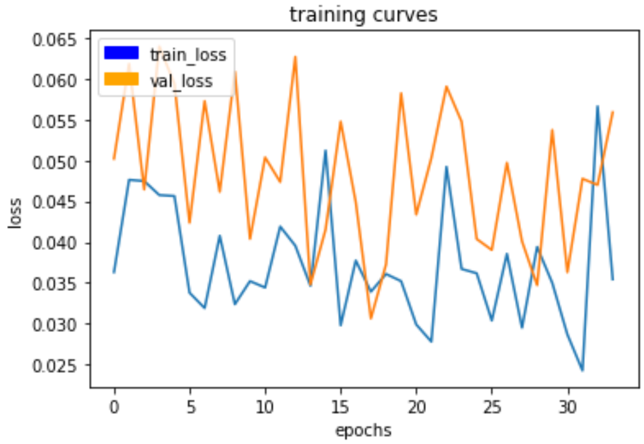

```
30/30 [==============================] - 88s - loss: 0.0287 - val_loss: 0.0
363
Epoch 32/100
29/30 [============================>.] - ETA: 2s - loss: 0.0240
```



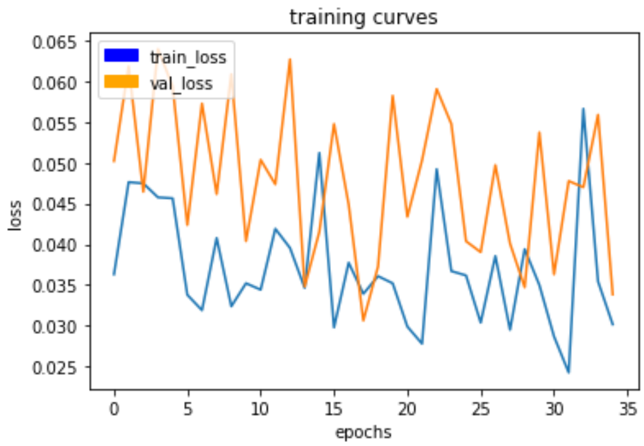

```
30/30 [==============================] - 87s - loss: 0.0243 - val_loss: 0.0
478
Epoch 33/100
29/30 [============================>.] - ETA: 2s - loss: 0.0572
```



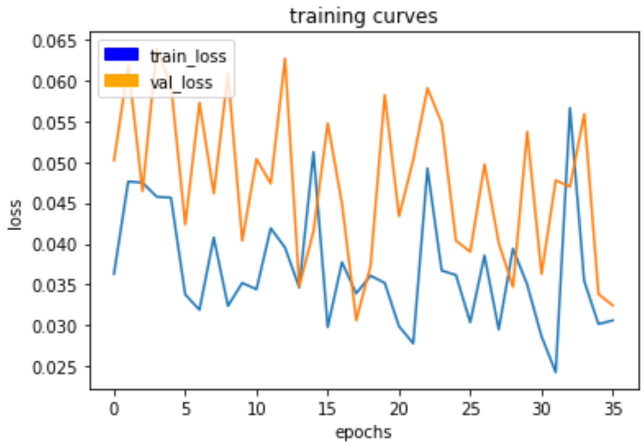
```
30/30 [==============================] - 89s - loss: 0.0566 - val_loss: 0.0
470
Epoch 34/100
29/30 [============================>.] - ETA: 2s - loss: 0.0359
```



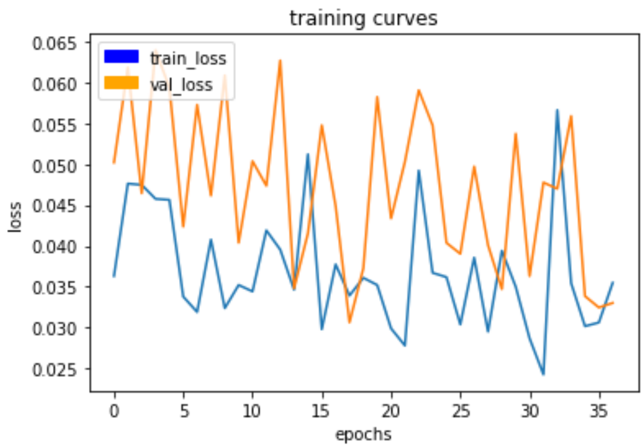

```
30/30 [==============================] - 92s - loss: 0.0354 - val_loss: 0.0
559
Epoch 35/100
29/30 [============================>.] - ETA: 2s - loss: 0.0302
```



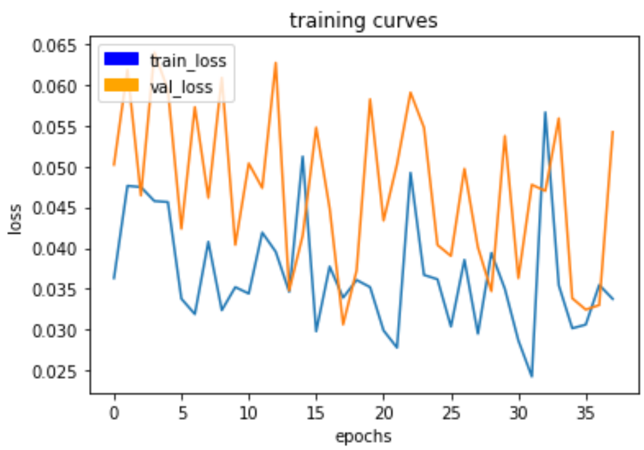

```
30/30 [==============================] - 90s - loss: 0.0302 - val_loss: 0.0
339
Epoch 36/100
29/30 [============================>.] - ETA: 2s - loss: 0.0307
```



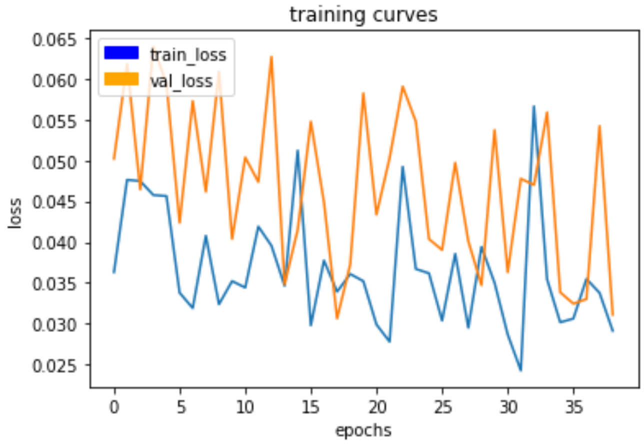

```
30/30 [==============================] - 92s - loss: 0.0306 - val_loss: 0.0
325
Epoch 37/100
29/30 [============================>.] - ETA: 2s - loss: 0.0357
```



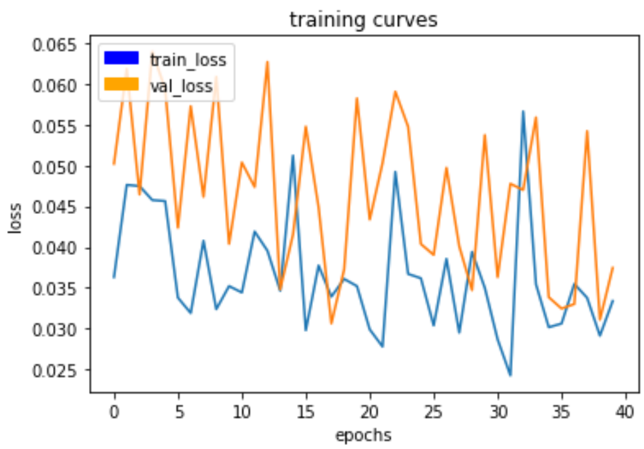

```
30/30 [==============================] - 88s - loss: 0.0355 - val_loss: 0.0
330
Epoch 38/100
29/30 [============================>.] - ETA: 2s - loss: 0.0342
```



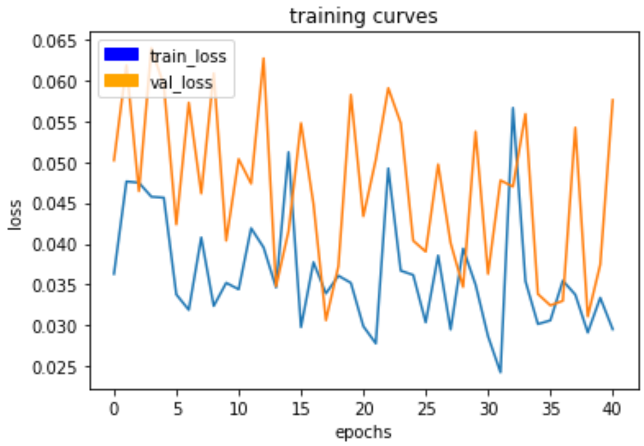
```
30/30 [==============================] - 89s - loss: 0.0338 - val_loss: 0.0
542
Epoch 39/100
29/30 [============================>.] - ETA: 2s - loss: 0.0287
```



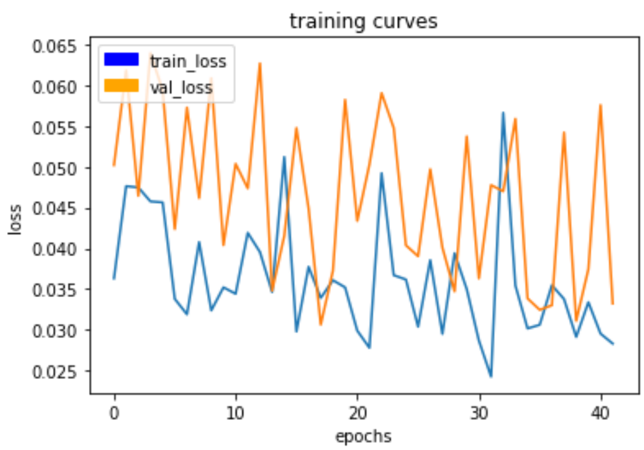

```
30/30 [==============================] - 88s - loss: 0.0291 - val_loss: 0.0
311
Epoch 40/100
29/30 [============================>.] - ETA: 2s - loss: 0.0337
```



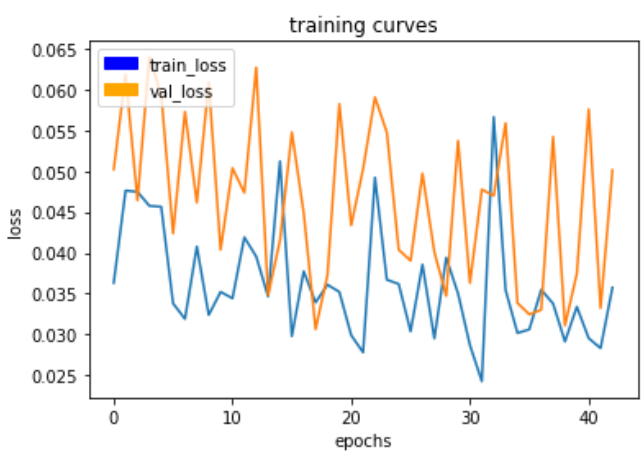

```
30/30 [==============================] - 87s - loss: 0.0334 - val_loss: 0.0
375
Epoch 41/100
29/30 [============================>.] - ETA: 2s - loss: 0.0294
```



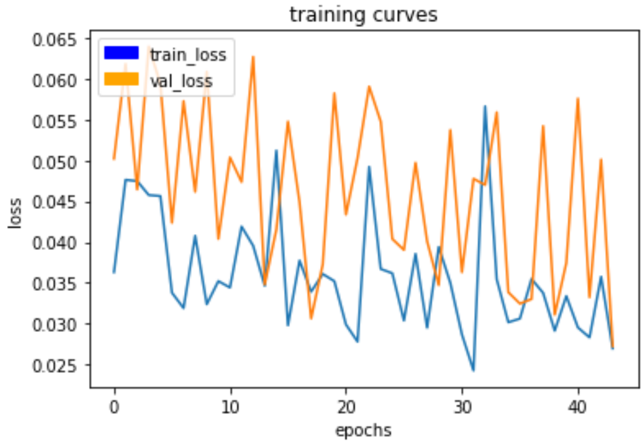

```
30/30 [==============================] - 89s - loss: 0.0295 - val_loss: 0.0
576
Epoch 42/100
29/30 [============================>.] - ETA: 1s - loss: 0.0283
```



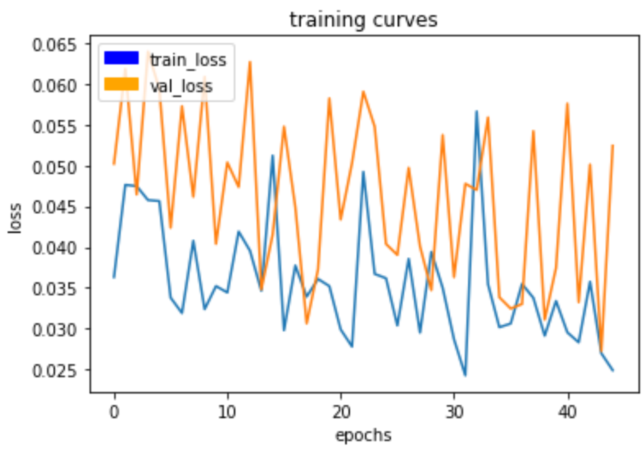

```
30/30 [==============================] - 86s - loss: 0.0280 - val_loss: 0.0
332
Epoch 43/100
29/30 [============================>.] - ETA: 2s - loss: 0.0360
```



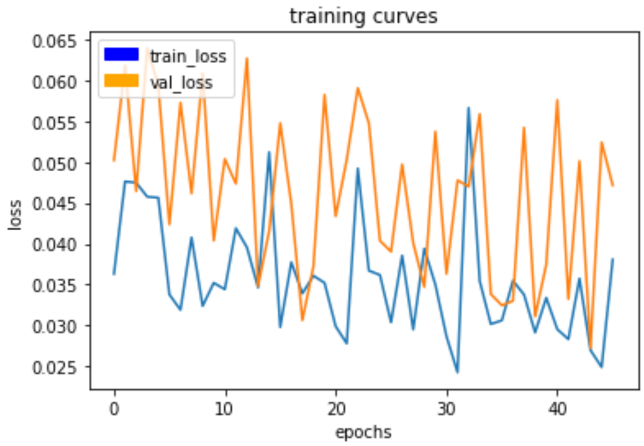
```
30/30 [==============================] - 87s - loss: 0.0358 - val_loss: 0.0
501
Epoch 44/100
29/30 [============================>.] - ETA: 2s - loss: 0.0269
```



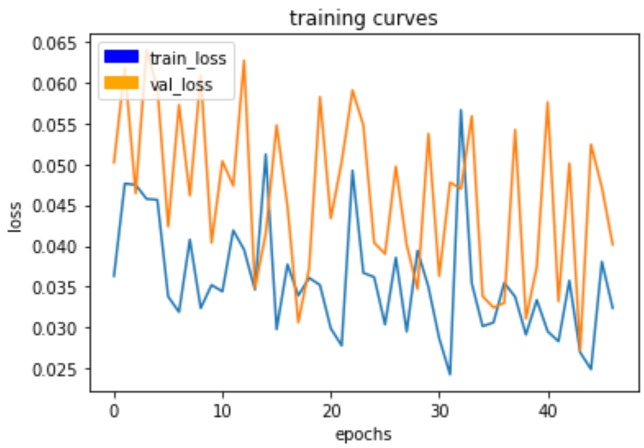

```
30/30 [==============================] - 89s - loss: 0.0270 - val_loss: 0.0
273
Epoch 45/100
29/30 [============================>.] - ETA: 2s - loss: 0.0245
```



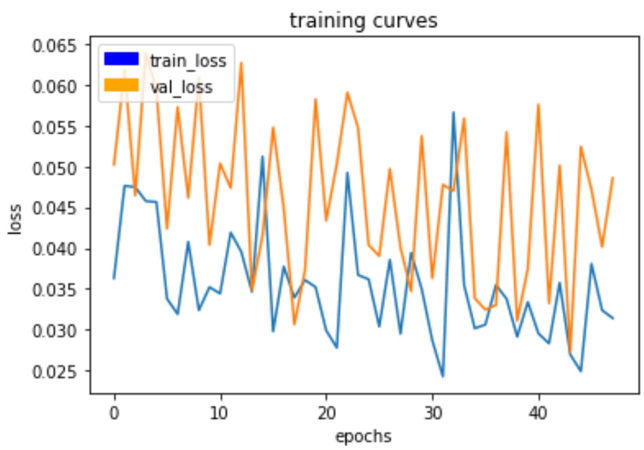

```
30/30 [==============================] - 91s - loss: 0.0249 - val_loss: 0.0
524
Epoch 46/100
29/30 [============================>.] - ETA: 2s - loss: 0.0262
```



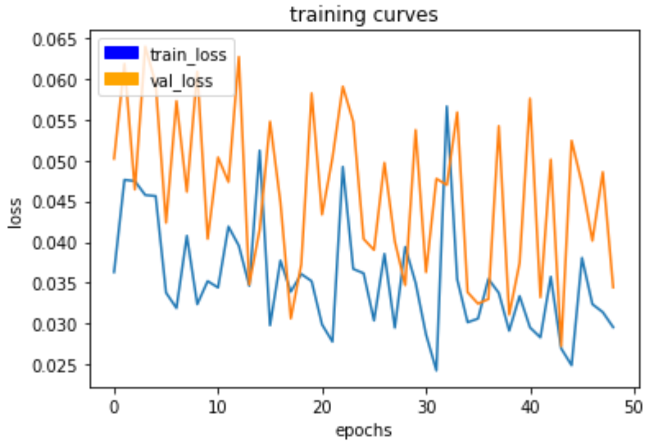

```
30/30 [==============================] - 99s - loss: 0.0381 - val_loss: 0.0
472
Epoch 47/100
29/30 [============================>.] - ETA: 2s - loss: 0.0317
```



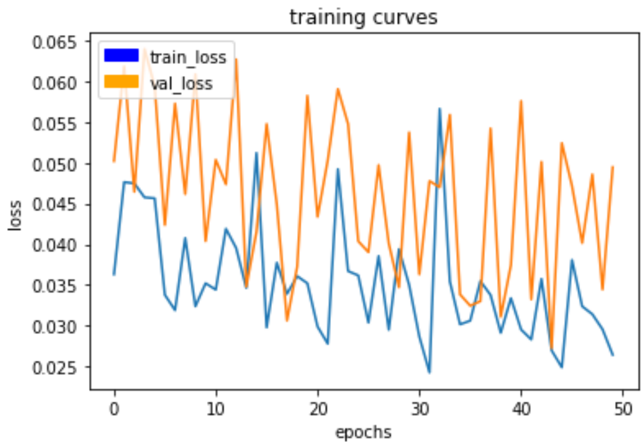

```
30/30 [==============================] - 93s - loss: 0.0324 - val_loss: 0.0
402
Epoch 48/100
29/30 [============================>.] - ETA: 2s - loss: 0.0311
```



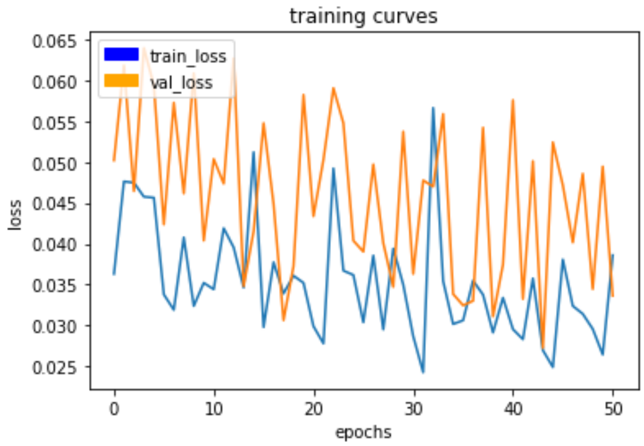
```
30/30 [==============================] - 98s - loss: 0.0314 - val_loss: 0.0
486
Epoch 49/100
29/30 [============================>.] - ETA: 2s - loss: 0.0289
```



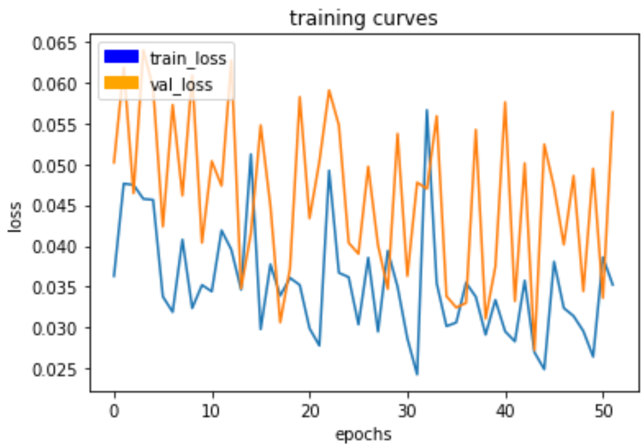

```
30/30 [==============================] - 89s - loss: 0.0296 - val_loss: 0.0
345
Epoch 50/100
29/30 [============================>.] - ETA: 2s - loss: 0.0265
```



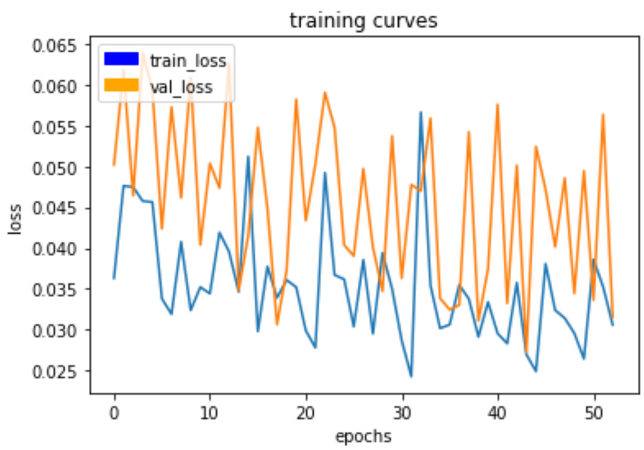

```
30/30 [==============================] - 95s - loss: 0.0264 - val_loss: 0.0
495
Epoch 51/100
29/30 [============================>.] - ETA: 2s - loss: 0.0308
```



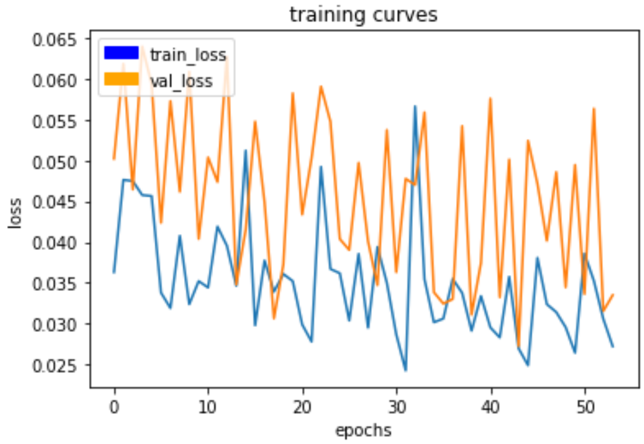

```
30/30 [==============================] - 100s - loss: 0.0386 - val_loss: 0.
0336
Epoch 52/100
29/30 [============================>.] - ETA: 2s - loss: 0.0357
```



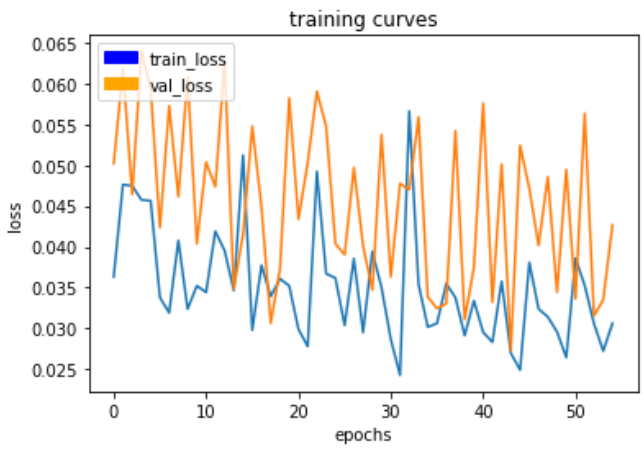

```
30/30 [==============================] - 90s - loss: 0.0352 - val_loss: 0.0
564
Epoch 53/100
29/30 [============================>.] - ETA: 2s - loss: 0.0310
```



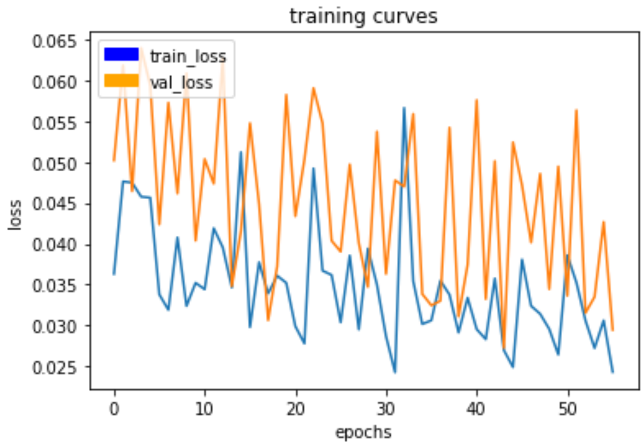
```
30/30 [==============================] - 109s - loss: 0.0306 - val_loss: 0.
0315
Epoch 54/100
29/30 [============================>.] - ETA: 2s - loss: 0.0274
```



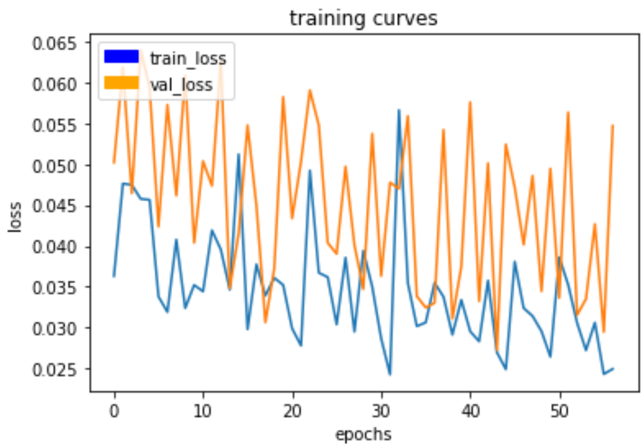

```
30/30 [==============================] - 95s - loss: 0.0272 - val_loss: 0.0
335
Epoch 55/100
29/30 [============================>.] - ETA: 2s - loss: 0.0309
```



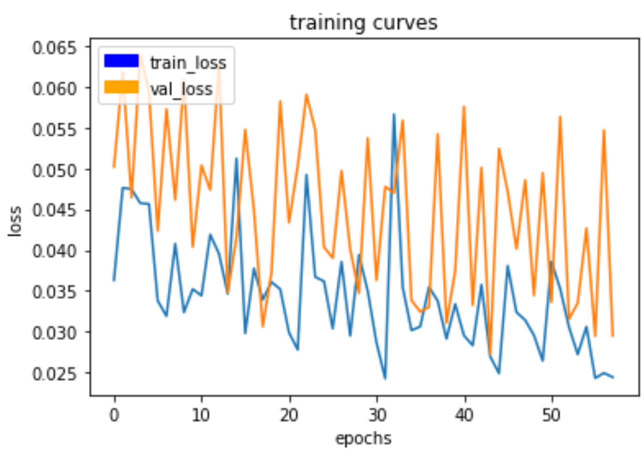

```
30/30 [==============================] - 97s - loss: 0.0306 - val_loss: 0.0
427
Epoch 56/100
29/30 [============================>.] - ETA: 2s - loss: 0.0234
```



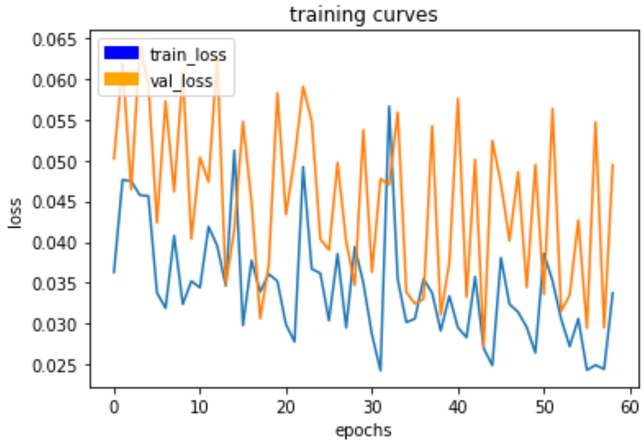

```
30/30 [==============================] - 91s - loss: 0.0241 - val_loss: 0.0
295
Epoch 57/100
29/30 [============================>.] - ETA: 2s - loss: 0.0250
```



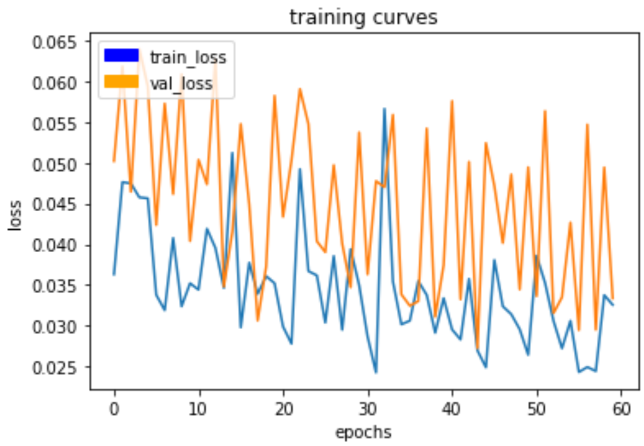

```
30/30 [==============================] - 92s - loss: 0.0249 - val_loss: 0.0
547
Epoch 58/100
29/30 [============================>.] - ETA: 2s - loss: 0.0242
```



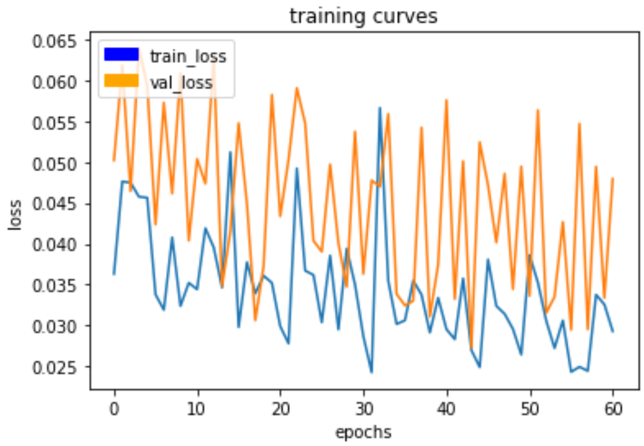
```
30/30 [==============================] - 106s - loss: 0.0244 - val_loss: 0.
0295
Epoch 59/100
29/30 [============================>.] - ETA: 2s - loss: 0.0339
```



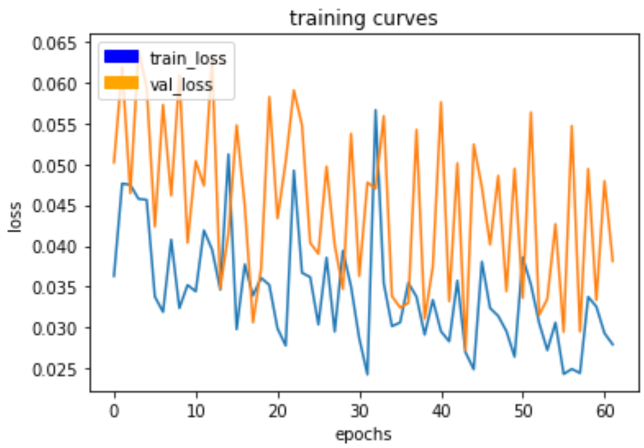

```
30/30 [==============================] - 108s - loss: 0.0338 - val_loss: 0.
0494
Epoch 60/100
29/30 [============================>.] - ETA: 2s - loss: 0.0330
```



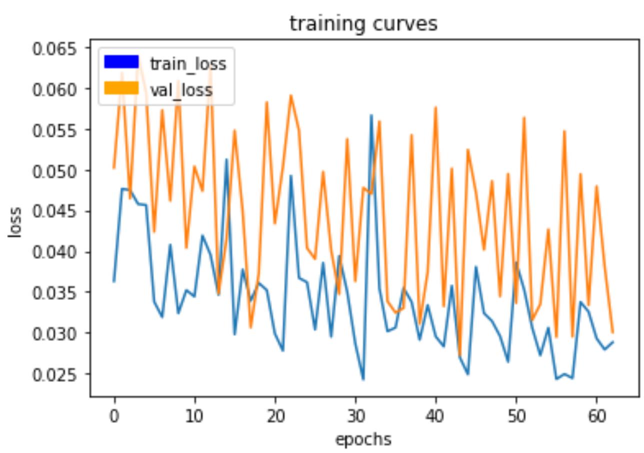

```
30/30 [==============================] - 89s - loss: 0.0326 - val_loss: 0.0
334
Epoch 61/100
29/30 [============================>.] - ETA: 2s - loss: 0.0295
```



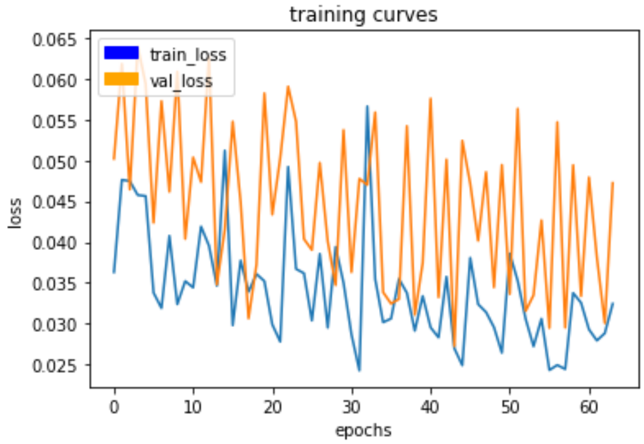

```
30/30 [==============================] - 99s - loss: 0.0293 - val_loss: 0.0
479
Epoch 62/100
29/30 [============================>.] - ETA: 2s - loss: 0.0282
```



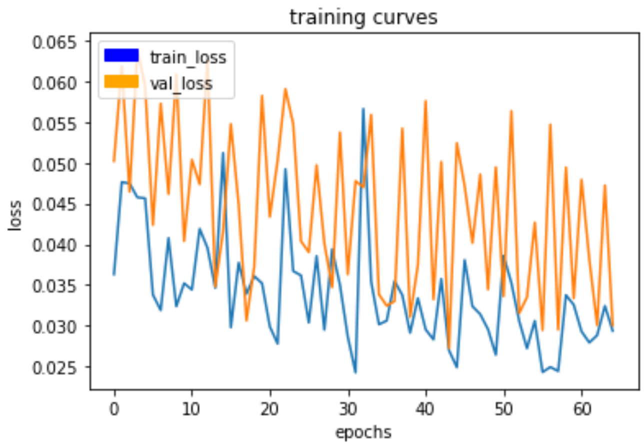

```
30/30 [==============================] - 93s - loss: 0.0279 - val_loss: 0.0
381
Epoch 63/100
29/30 [============================>.] - ETA: 2s - loss: 0.0291
```



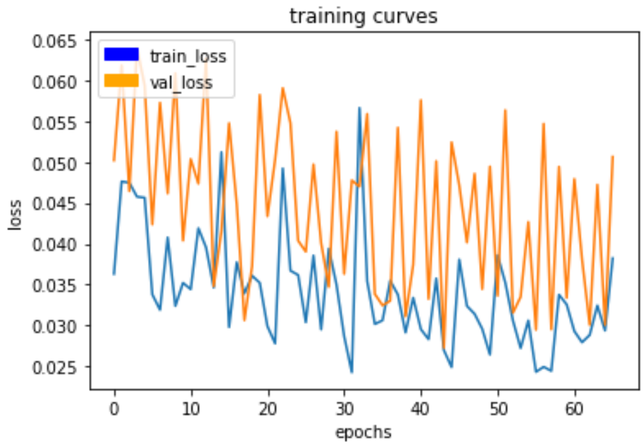
```
30/30 [==============================] - 89s - loss: 0.0288 - val_loss: 0.0
301
Epoch 64/100
29/30 [============================>.] - ETA: 2s - loss: 0.0327
```



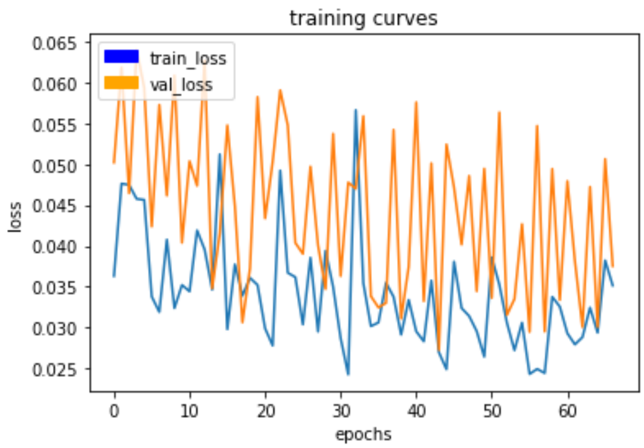

```
30/30 [==============================] - 87s - loss: 0.0324 - val_loss: 0.0
472
Epoch 65/100
29/30 [============================>.] - ETA: 2s - loss: 0.0298
```



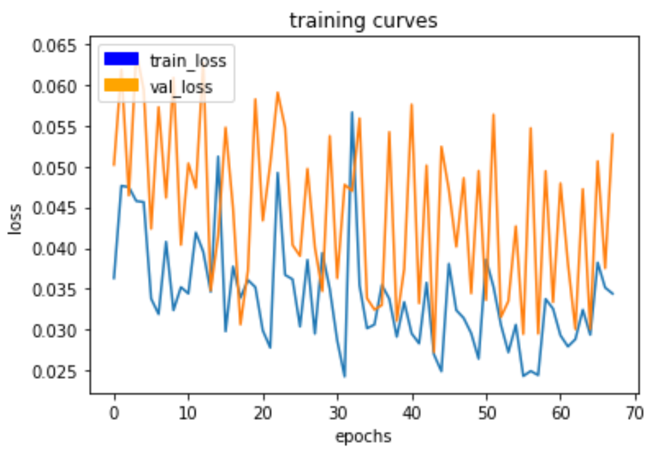

```
30/30 [==============================] - 87s - loss: 0.0294 - val_loss: 0.0
301
Epoch 66/100
29/30 [============================>.] - ETA: 2s - loss: 0.0389
```



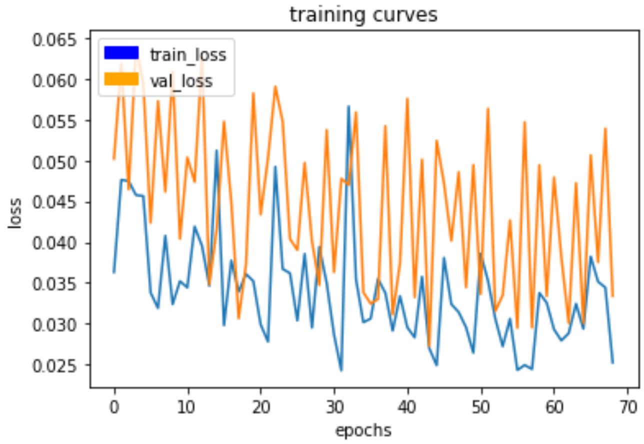

```
30/30 [==============================] - 88s - loss: 0.0382 - val_loss: 0.0
506
Epoch 67/100
29/30 [============================>.] - ETA: 2s - loss: 0.0352
```



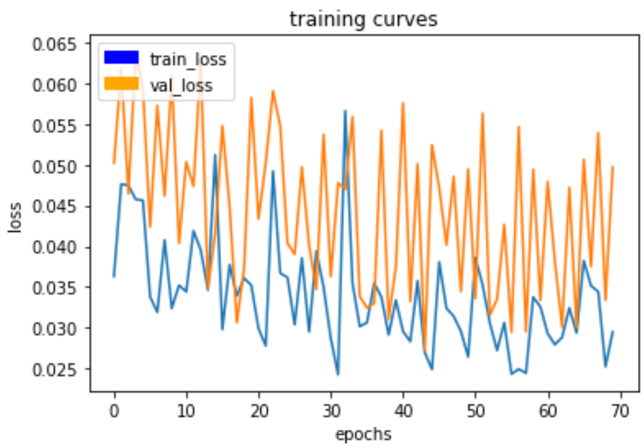

```
30/30 [==============================] - 87s - loss: 0.0352 - val_loss: 0.0
375
Epoch 68/100
29/30 [============================>.] - ETA: 2s - loss: 0.0347
```



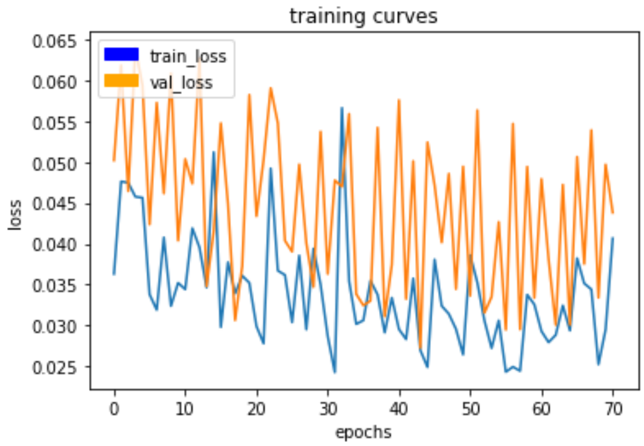
```
30/30 [==============================] - 89s - loss: 0.0344 - val_loss: 0.0
539
Epoch 69/100
29/30 [============================>.] - ETA: 1s - loss: 0.0252
```



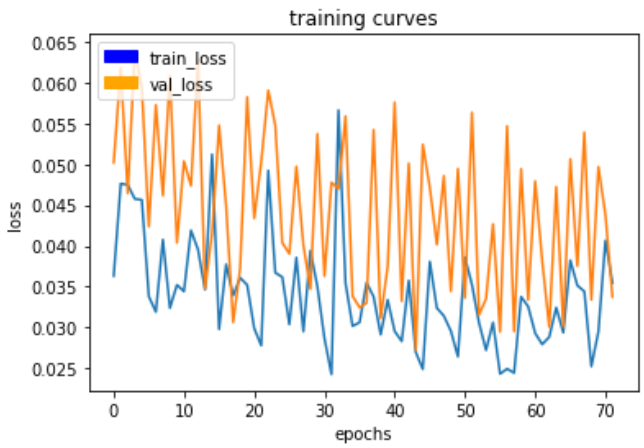

```
30/30 [==============================] - 85s - loss: 0.0253 - val_loss: 0.0
334
Epoch 70/100
29/30 [============================>.] - ETA: 2s - loss: 0.0299
```



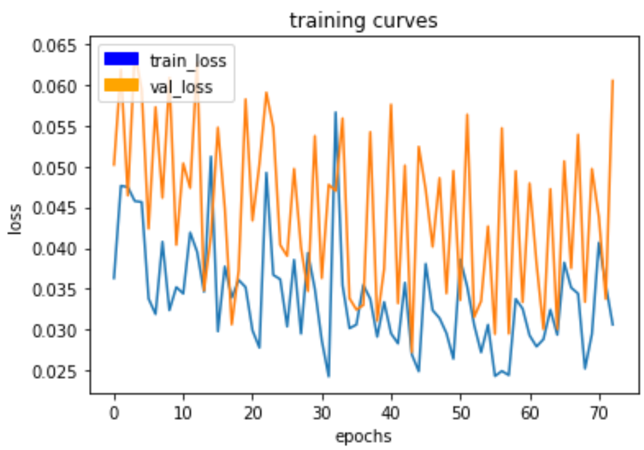

```
30/30 [==============================] - 87s - loss: 0.0295 - val_loss: 0.0
497
Epoch 71/100
29/30 [============================>.] - ETA: 2s - loss: 0.0411
```



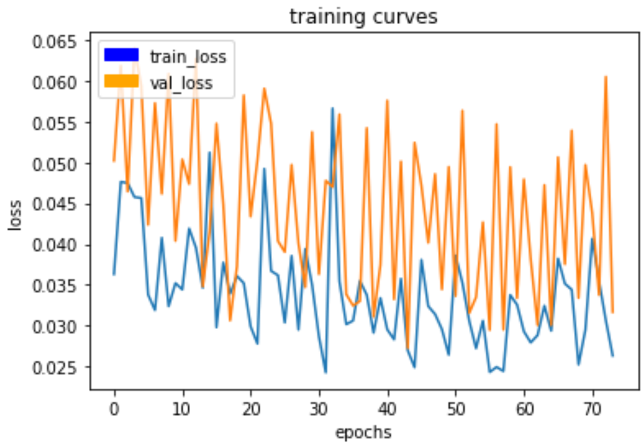

```
30/30 [==============================] - 90s - loss: 0.0407 - val_loss: 0.0
438
Epoch 72/100
29/30 [============================>.] - ETA: 2s - loss: 0.0356
```



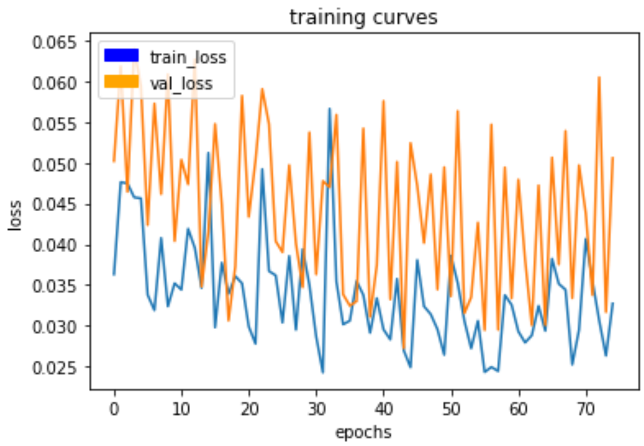

```
30/30 [==============================] - 94s - loss: 0.0355 - val_loss: 0.0
338
Epoch 73/100
29/30 [============================>.] - ETA: 2s - loss: 0.0309
```



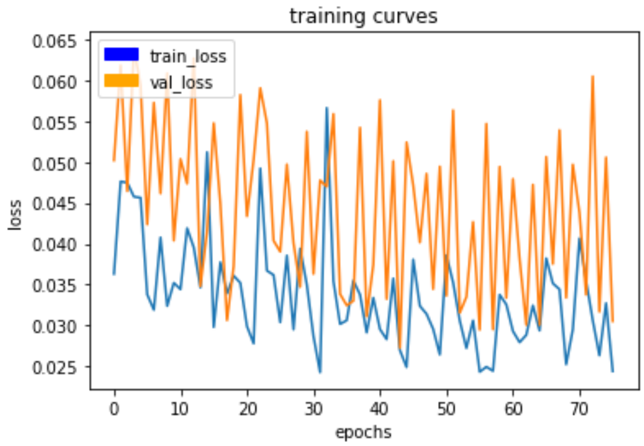
```
30/30 [==============================] - 89s - loss: 0.0306 - val_loss: 0.0
605
Epoch 74/100
29/30 [============================>.] - ETA: 2s - loss: 0.0265
```



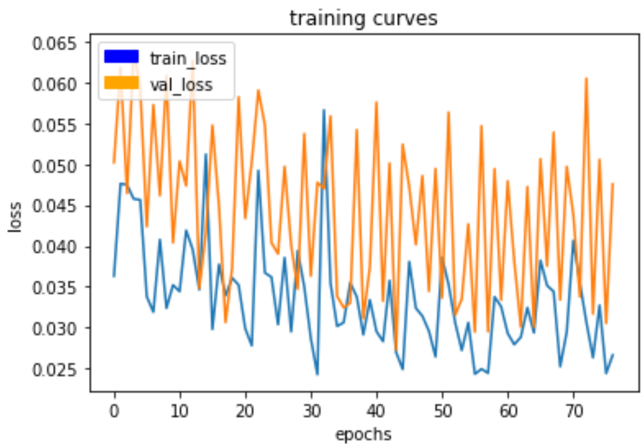

```
30/30 [==============================] - 88s - loss: 0.0263 - val_loss: 0.0
317
Epoch 75/100
29/30 [============================>.] - ETA: 2s - loss: 0.0331
```



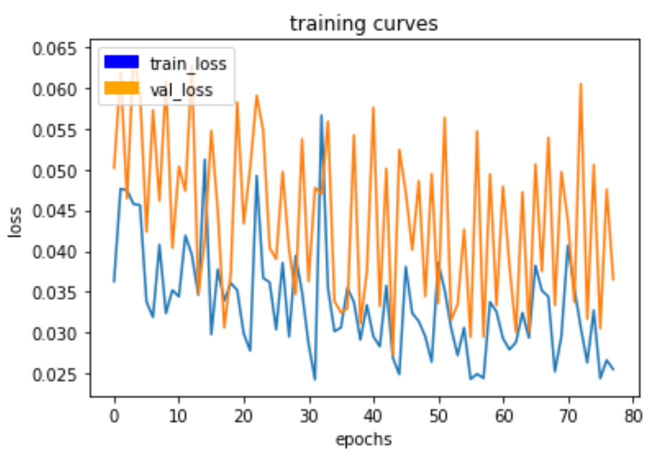

```
30/30 [==============================] - 86s - loss: 0.0327 - val_loss: 0.0
506
Epoch 76/100
29/30 [============================>.] - ETA: 2s - loss: 0.0245
```



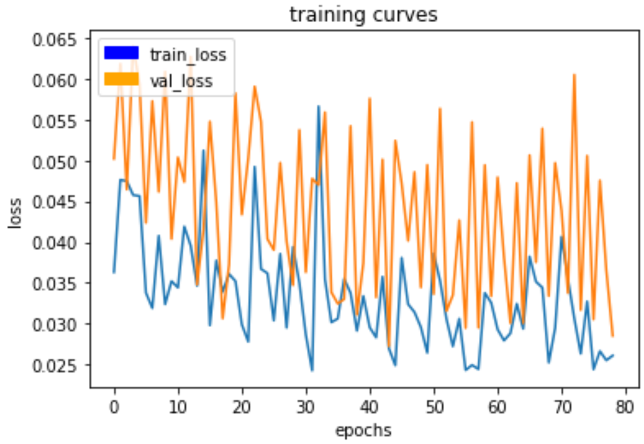

```
30/30 [==============================] - 87s - loss: 0.0244 - val_loss: 0.0
305
Epoch 77/100
29/30 [============================>.] - ETA: 2s - loss: 0.0259
```



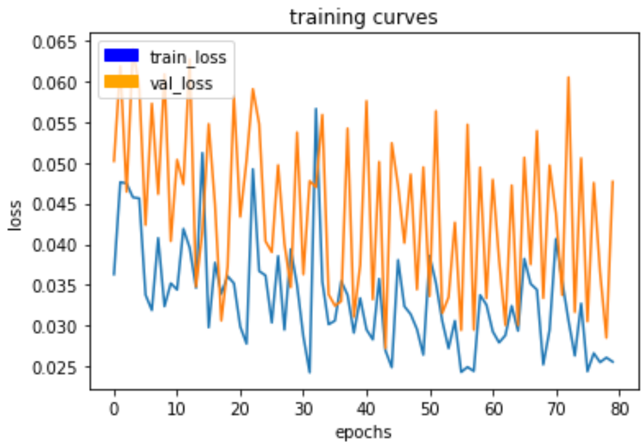

```
30/30 [==============================] - 86s - loss: 0.0266 - val_loss: 0.0
475
Epoch 78/100
29/30 [============================>.] - ETA: 2s - loss: 0.0258
```



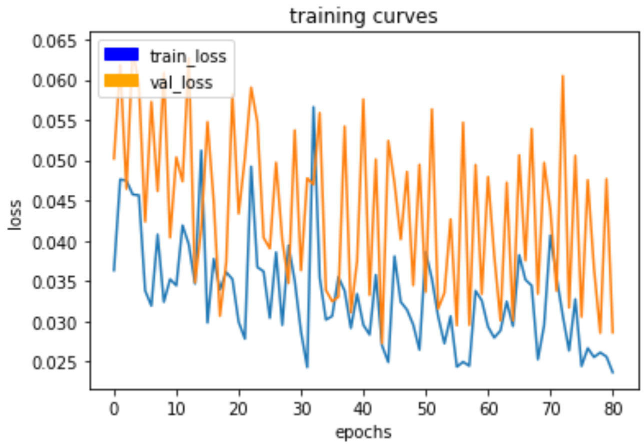
```
30/30 [==============================] - 87s - loss: 0.0255 - val_loss: 0.0
366
Epoch 79/100
29/30 [============================>.] - ETA: 2s - loss: 0.0262
```



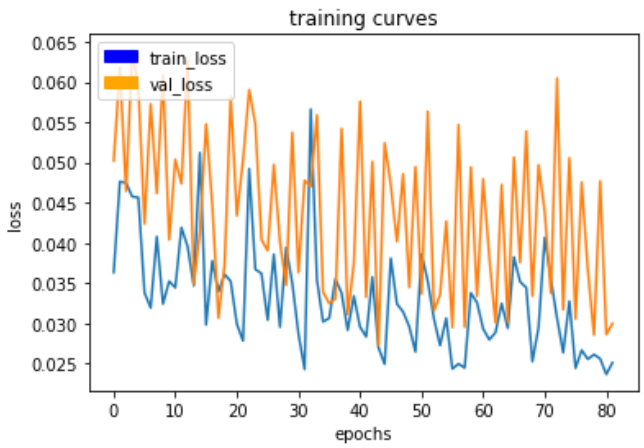

```
30/30 [==============================] - 87s - loss: 0.0261 - val_loss: 0.0
285
Epoch 80/100
29/30 [============================>.] - ETA: 2s - loss: 0.0256
```



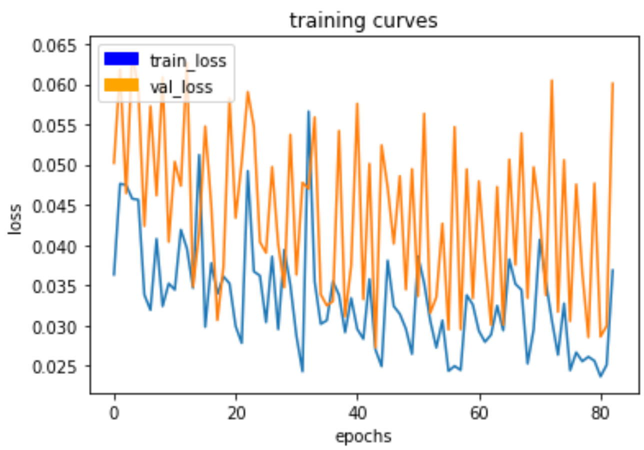

```
30/30 [==============================] - 87s - loss: 0.0256 - val_loss: 0.0
477
Epoch 81/100
29/30 [============================>.] - ETA: 2s - loss: 0.0237
```



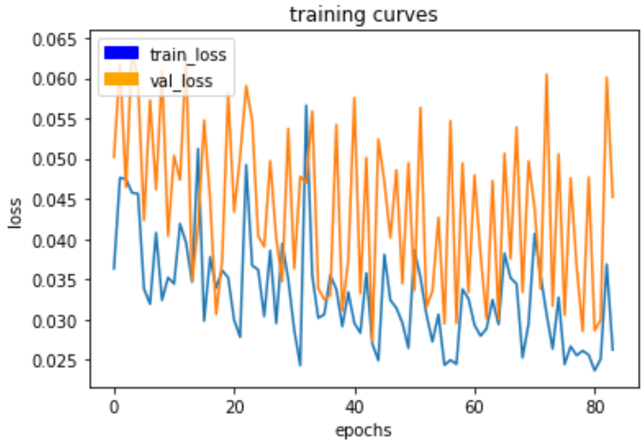

```
30/30 [==============================] - 87s - loss: 0.0236 - val_loss: 0.0
286
Epoch 82/100
29/30 [============================>.] - ETA: 2s - loss: 0.0253
```



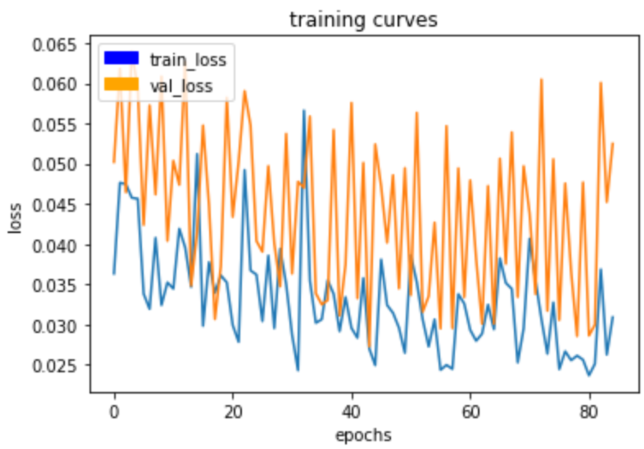

```
30/30 [==============================] - 89s - loss: 0.0251 - val_loss: 0.0
299
Epoch 83/100
29/30 [============================>.] - ETA: 1s - loss: 0.0376
```



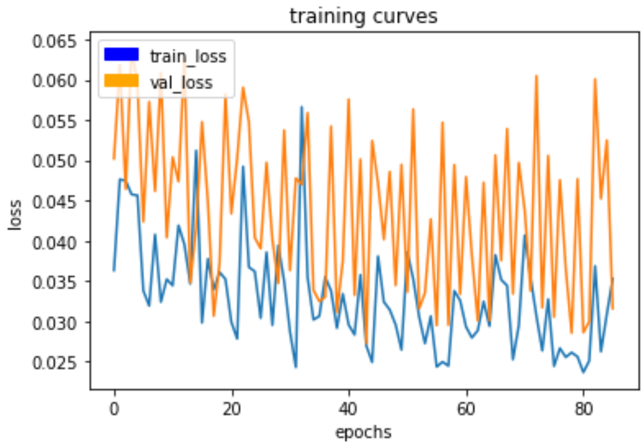
```
30/30 [==============================] - 86s - loss: 0.0374 - val_loss: 0.0
601
Epoch 84/100
29/30 [============================>.] - ETA: 2s - loss: 0.0264
```



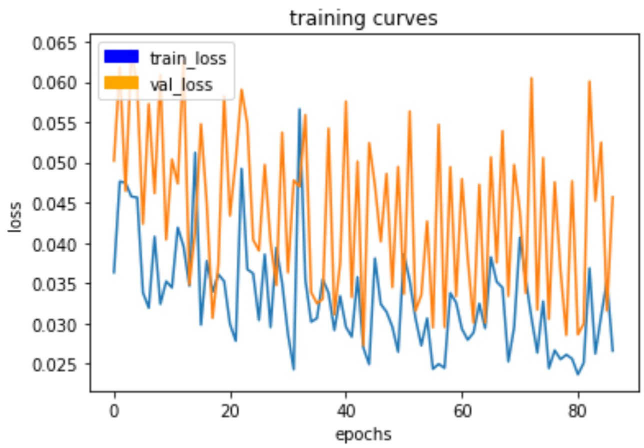

```
30/30 [==============================] - 88s - loss: 0.0262 - val_loss: 0.0
452
Epoch 85/100
29/30 [============================>.] - ETA: 2s - loss: 0.0312
```



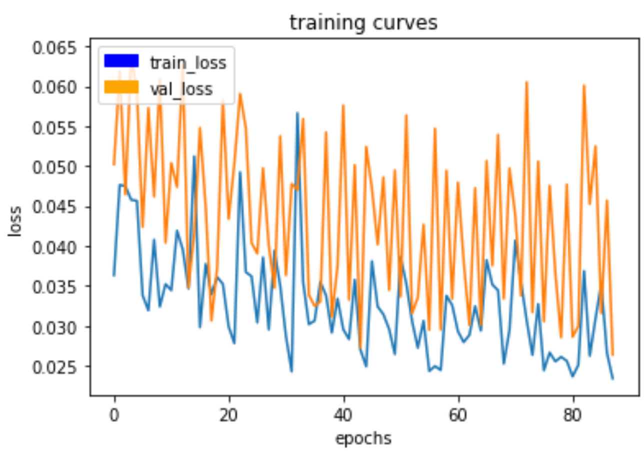

```
30/30 [==============================] - 90s - loss: 0.0309 - val_loss: 0.0
525
Epoch 86/100
29/30 [============================>.] - ETA: 2s - loss: 0.0357
```



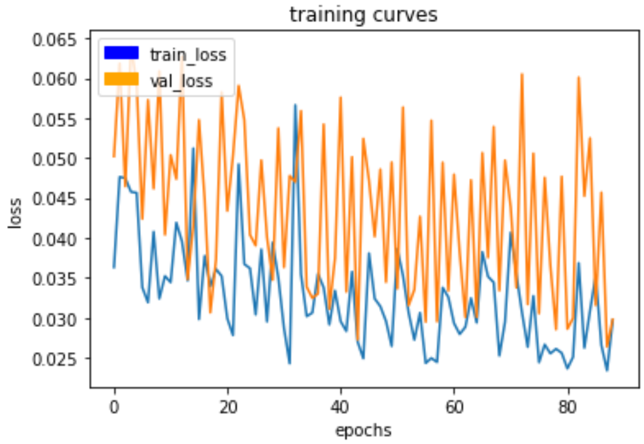

```
30/30 [==============================] - 88s - loss: 0.0353 - val_loss: 0.0
316
Epoch 87/100
29/30 [============================>.] - ETA: 2s - loss: 0.0265
```



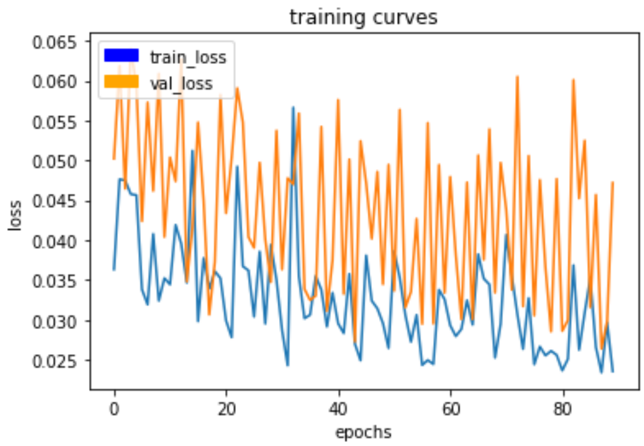

```
30/30 [==============================] - 88s - loss: 0.0266 - val_loss: 0.0
457
Epoch 88/100
29/30 [============================>.] - ETA: 2s - loss: 0.0236
```



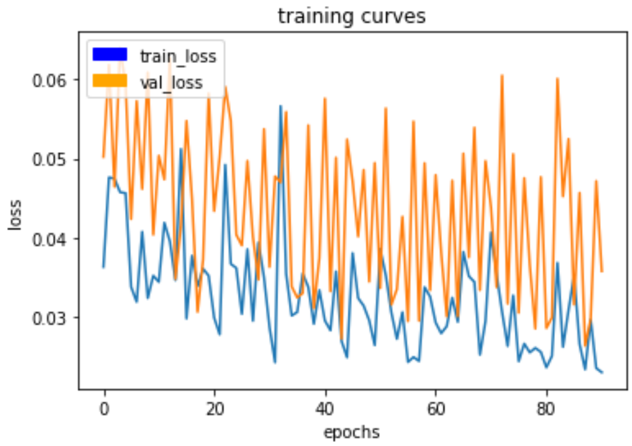
```
30/30 [==============================] - 91s - loss: 0.0234 - val_loss: 0.0
264
Epoch 89/100
29/30 [============================>.] - ETA: 2s - loss: 0.0296
```



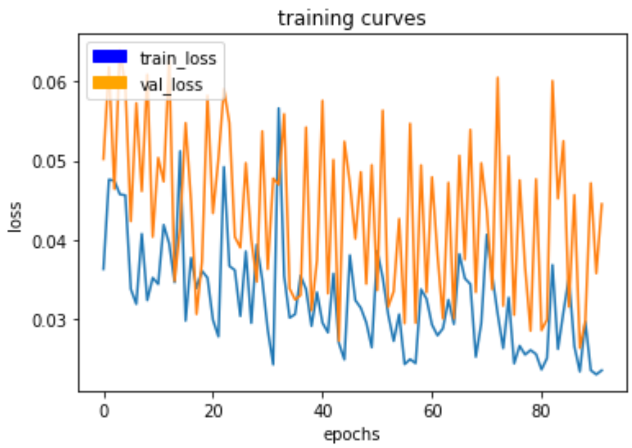

```
30/30 [==============================] - 95s - loss: 0.0297 - val_loss: 0.0
298
Epoch 90/100
29/30 [============================>.] - ETA: 2s - loss: 0.0238
```



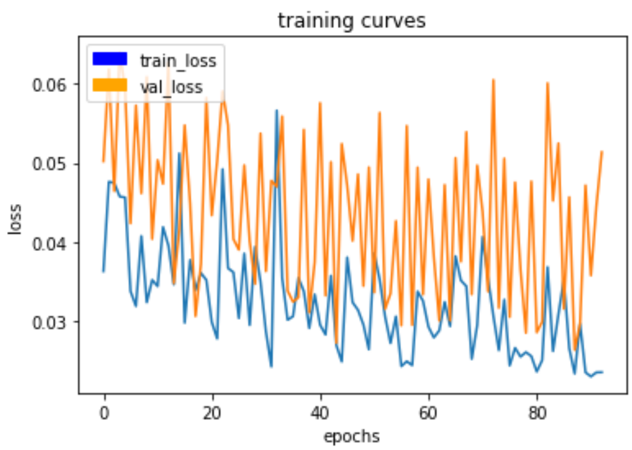

```
30/30 [==============================] - 89s - loss: 0.0235 - val_loss: 0.0
472
Epoch 91/100
29/30 [============================>.] - ETA: 2s - loss: 0.0229
```



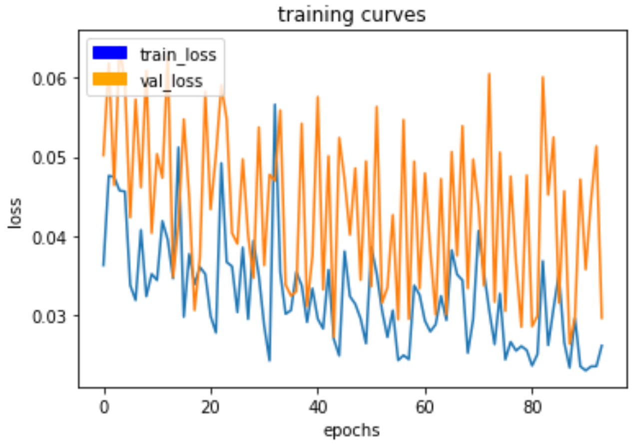

```
30/30 [==============================] - 98s - loss: 0.0230 - val_loss: 0.0
358
Epoch 92/100
29/30 [============================>.] - ETA: 2s - loss: 0.0238
```



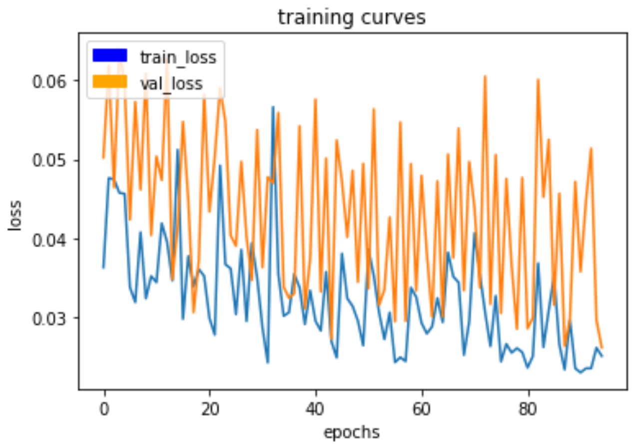

```
30/30 [==============================] - 99s - loss: 0.0235 - val_loss: 0.0
445
Epoch 93/100
29/30 [============================>.] - ETA: 2s - loss: 0.0214
```



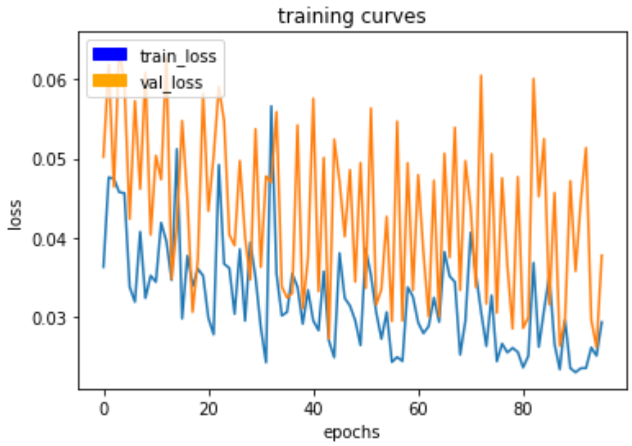
```
30/30 [==============================] - 99s - loss: 0.0236 - val_loss: 0.0
514
Epoch 94/100
29/30 [============================>.] - ETA: 2s - loss: 0.0263
```



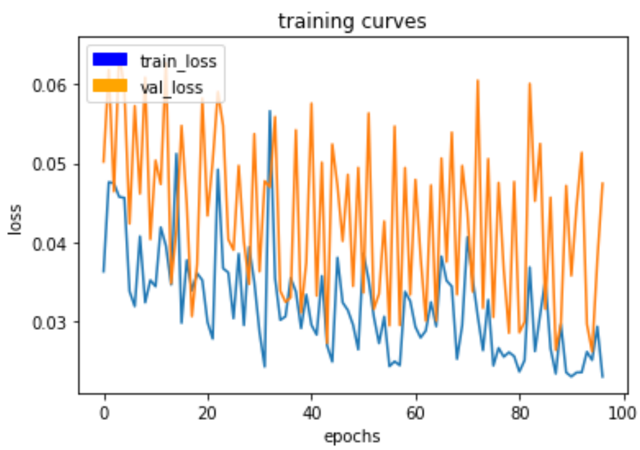

```
30/30 [==============================] - 94s - loss: 0.0262 - val_loss: 0.0
297
Epoch 95/100
29/30 [============================>.] - ETA: 2s - loss: 0.0244
```



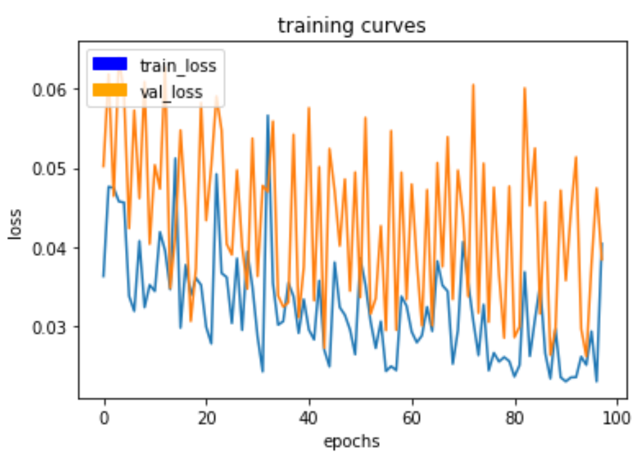

```
30/30 [==============================] - 87s - loss: 0.0251 - val_loss: 0.0
262
Epoch 96/100
29/30 [============================>.] - ETA: 2s - loss: 0.0257
```



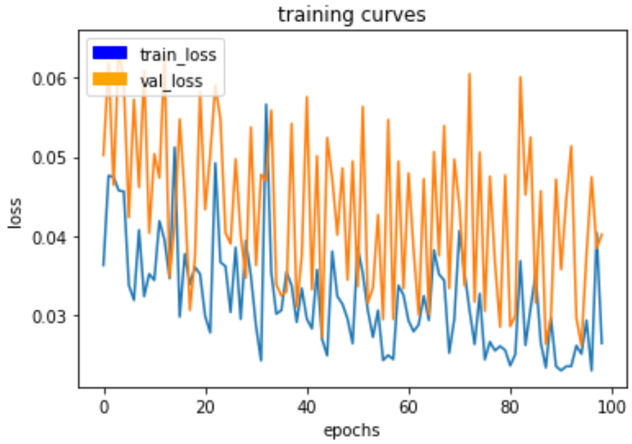

```
30/30 [==============================] - 95s - loss: 0.0294 - val_loss: 0.0
378
Epoch 97/100
29/30 [============================>.] - ETA: 2s - loss: 0.0228
```



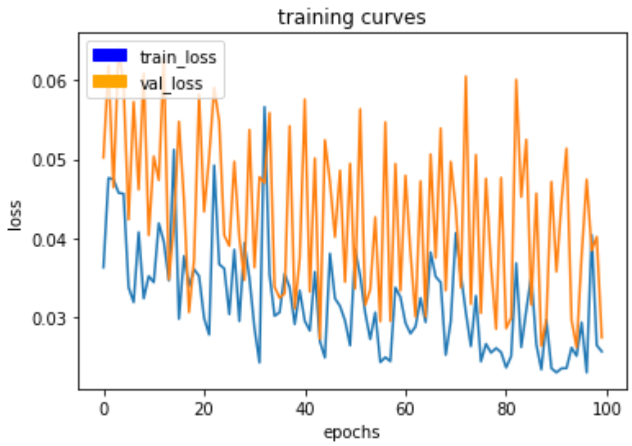

```
30/30 [==============================] - 92s - loss: 0.0229 - val_loss: 0.0
474
Epoch 98/100
29/30 [============================>.] - ETA: 2s - loss: 0.0407
```



```
30/30 [==============================] - 88s - loss: 0.0404 - val_loss: 0.0
384
Epoch 99/100
29/30 [============================>.] - ETA: 2s - loss: 0.0267
```




```
30/30 [==============================] - 88s - loss: 0.0265 - val_loss: 0.0
402
Epoch 100/100
29/30 [============================>.] - ETA: 2s - loss: 0.0259
```




```
30/30 [==============================] - 87s - loss: 0.0257 - val_loss: 0.0
274
```

Out[88]: <tensorflow.contrib.keras.python.keras.callbacks.History at 0x7f06f3d2d160>

In [89]:
```
# Save your trained model weights
weight_file_name = 'model_weights'
model_tools.save_network(model, weight_file_name)
```

Prediction

Now that you have your model trained and saved, you can make predictions on your validation dataset. These predictions can be compared to the mask images, which are the ground truth labels, to evaluate how well your model is doing under different conditions.

There are three different predictions available from the helper code provided:

- **patrol_with_targ**: Test how well the network can detect the hero from a distance.
- **patrol_non_targ**: Test how often the network makes a mistake and identifies the wrong person as the target.
- **following_images**: Test how well the network can identify the target while following them.

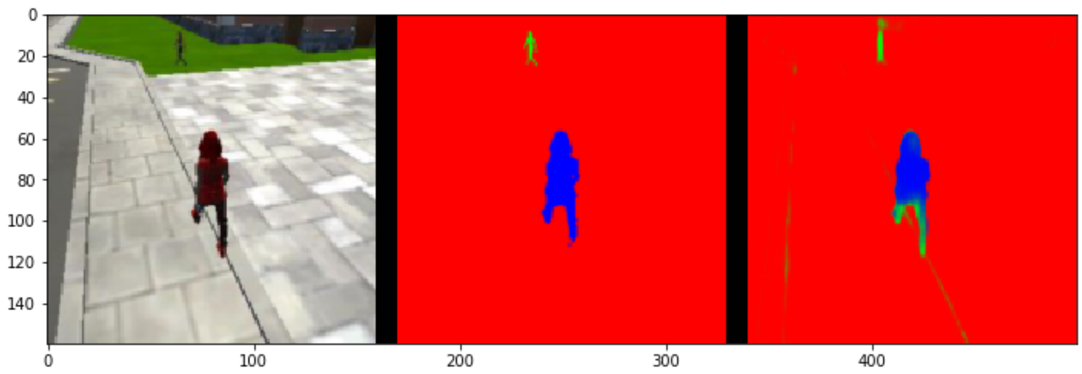
In [90]:
```
# If you need to load a model which you previously trained you can uncommen
t the codeline that calls the function below.
# Define the Keras model and compile it for training
#model = models.Model(inputs=inputs, outputs=output_layer)

weight_file_name = 'model_weights'
restored_model = model_tools.load_network(weight_file_name)
```

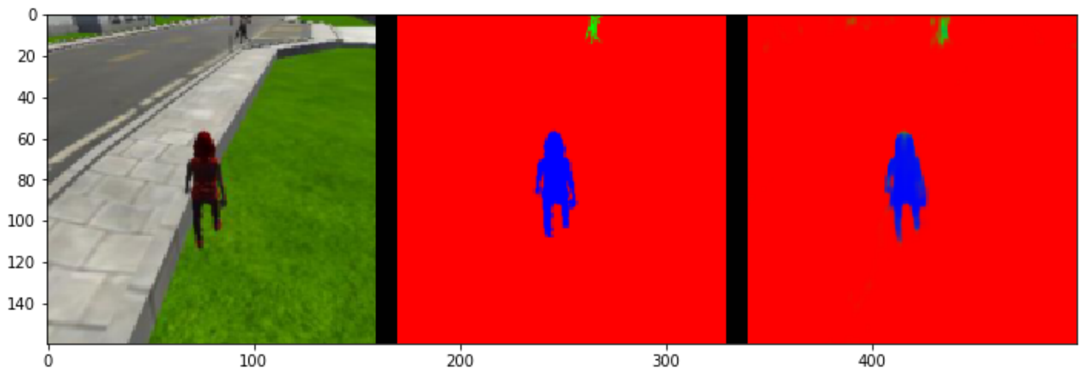
The following cell will write predictions to files and return paths to the appropriate directories. The `run_num` parameter is used to define or group all the data for a particular model run. You can change it for different runs. For example, 'run_1', 'run_2' etc.

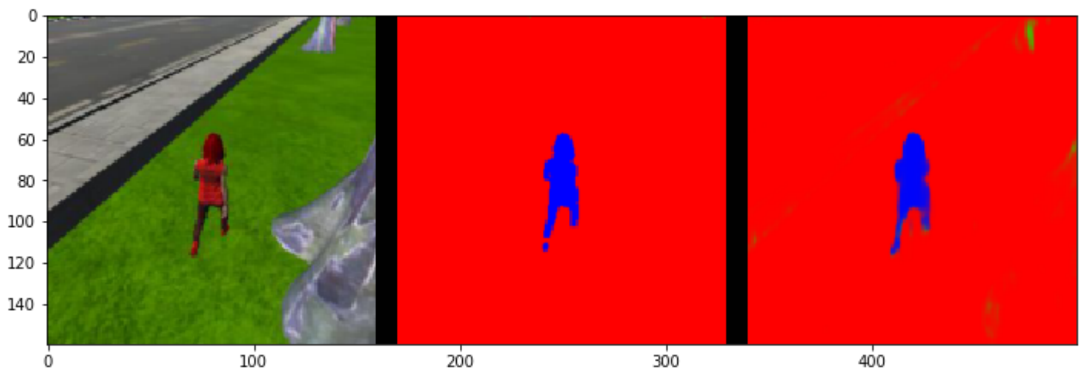
In [91]:
```
run_num = 'run_1'

val_with_targ, pred_with_targ = model_tools.write_predictions_grade_set(mod
el,
                                        run_num,'patrol_with_targ', 'sample
_evaluation_data')

val_no_targ, pred_no_targ = model_tools.write_predictions_grade_set(model,
                                        run_num,'patrol_non_targ', 'sample_
evaluation_data')

val_following, pred_following = model_tools.write_predictions_grade_set(mod
el,
                                        run_num,'following_images', 'sample
_evaluation_data')
```

Now lets look at your predictions, and compare them to the ground truth labels and original images. Run each of the following cells to visualize some sample images from the predictions in the validation set.

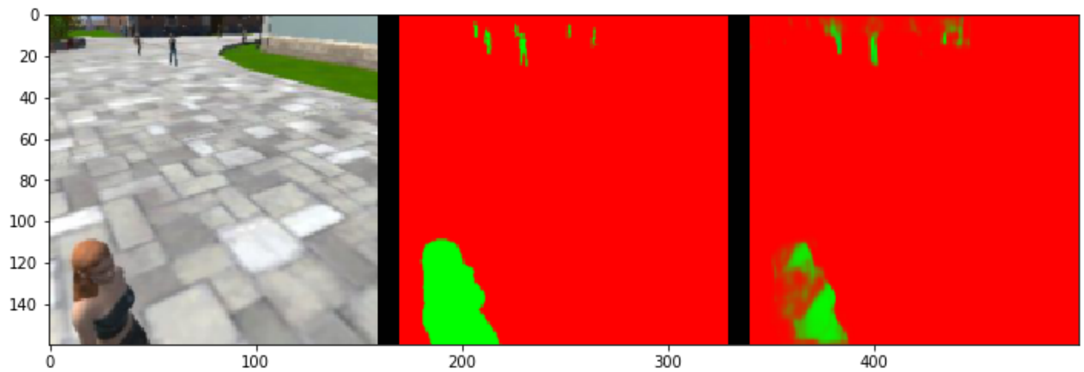
In [92]:
```
# images while following the target
im_files = plotting_tools.get_im_file_sample('sample_evaluation_data','foll
owing_images', run_num)
for i in range(3):
    im_tuple = plotting_tools.load_images(im_files[i])
    plotting_tools.show_images(im_tuple)
```

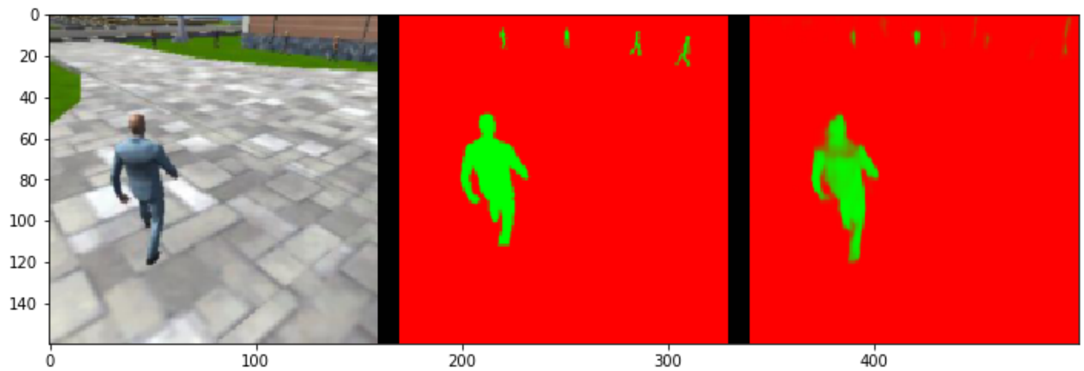


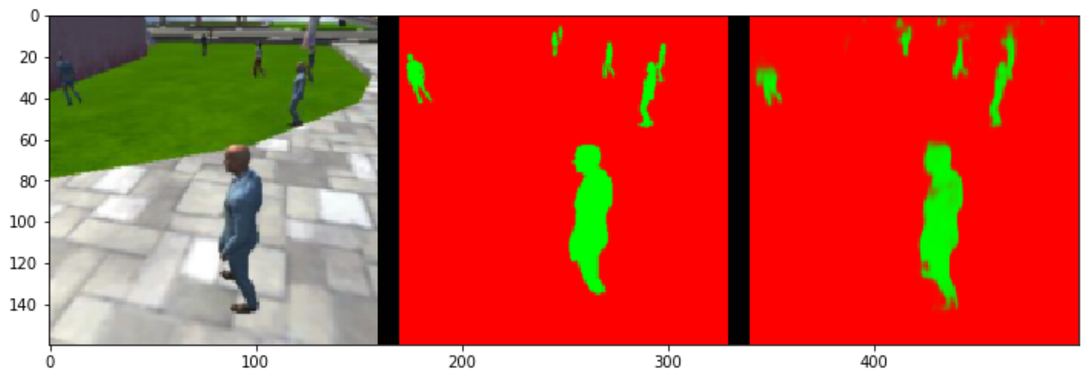




In [93]:
```
# images while at patrol without target
im_files = plotting_tools.get_im_file_sample('sample_evaluation_data','patr
ol_non_targ', run_num)
for i in range(3):
    im_tuple = plotting_tools.load_images(im_files[i])
    plotting_tools.show_images(im_tuple)
```

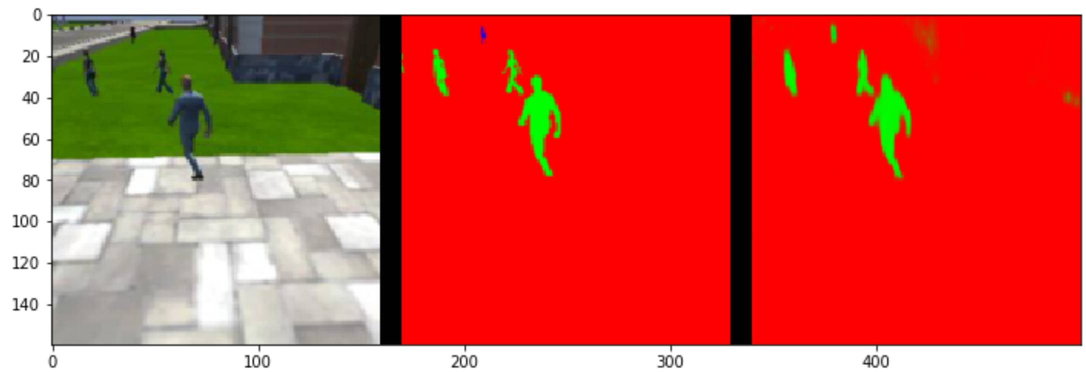


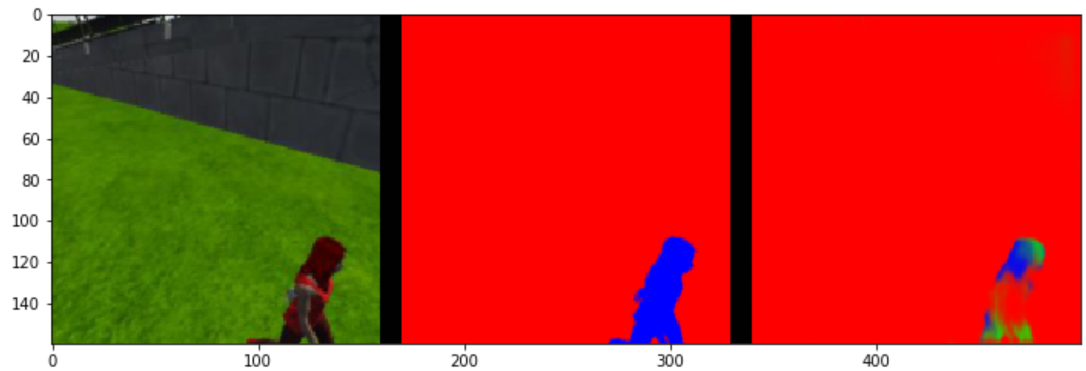


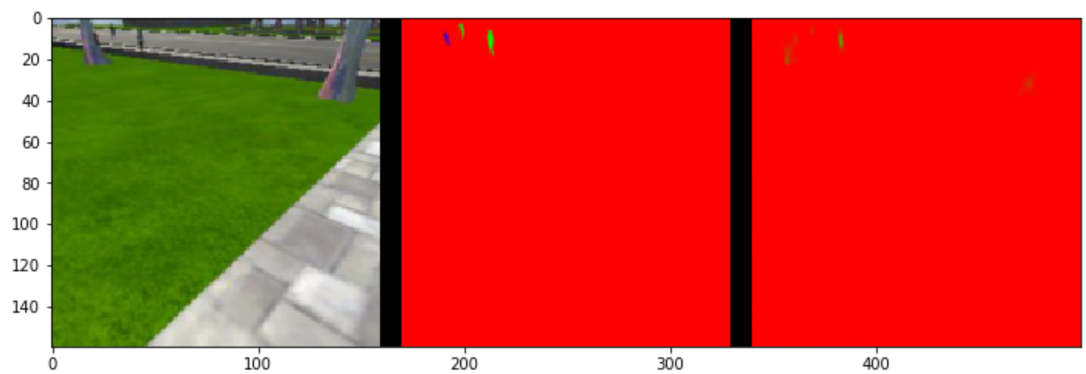


In [95]:

```
# images while at patrol with target
im_files = plotting_tools.get_im_file_sample('sample_evaluation_data','patr
ol_with_targ', run_num)
for i in range(3):
    im_tuple = plotting_tools.load_images(im_files[i])
    plotting_tools.show_images(im_tuple)
```







Evaluation

Evaluate your model! The following cells include several different scores to help you evaluate your model under the different conditions discussed during the Prediction step.

In [96]:
```
# Scores for while the quad is following behind the target.
true_pos1, false_pos1, false_neg1, iou1 = scoring_utils.score_run_iou(val_f
ollowing, pred_following)
```

```
number of validation samples intersection over the union evaulated on 542
average intersection over union for background is 0.9924605911732084
average intersection over union for other people is 0.2852216962389277
average intersection over union for the hero is 0.8535975454677739
number true positives: 539, number false positives: 0, number false negativ
es: 0
```

In [97]:
```
# Scores for images while the quad is on patrol and the target is not visab
le
true_pos2, false_pos2, false_neg2, iou2 = scoring_utils.score_run_iou(val_n
o_targ, pred_no_targ)
```

```
number of validation samples intersection over the union evaulated on 270
average intersection over union for background is 0.9811944667573824
average intersection over union for other people is 0.6335903978606923
average intersection over union for the hero is 0.0
number true positives: 0, number false positives: 21, number false negative
s: 0
```

In [98]:
```
# This score measures how well the neural network can detect the target fro
m far away
true_pos3, false_pos3, false_neg3, iou3 = scoring_utils.score_run_iou(val_w
ith_targ, pred_with_targ)
```

```
number of validation samples intersection over the union evaulated on 322
average intersection over union for background is 0.9949171023896637
average intersection over union for other people is 0.3514637841240545
average intersection over union for the hero is 0.05016522480198239
number true positives: 48, number false positives: 0, number false negative
s: 253
```

In [99]:
```
# Sum all the true positives, etc from the three datasets to get a weight f
or the score
true_pos = true_pos1 + true_pos2 + true_pos3
false_pos = false_pos1 + false_pos2 + false_pos3
false_neg = false_neg1 + false_neg2 + false_neg3

weight = true_pos/(true_pos+false_neg+false_pos)
print(weight)
```

```
0.6817653890824622
```

In [100]:
```
# The IoU for the dataset that never includes the hero is excluded from gra
ding
final_IoU = (iou1 + iou3)/2
print(final_IoU)
```

```
0.45188138513487813
```

In [101]:
```
# And the final grade score is
final_score = final_IoU * weight
print(final_score)
```

```
0.30807708835560216
```