ESMPy Documentation

Release 8.4.0

ESMPy

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CONTENTS

1 Overview **3**

2 Important Links **5**

3 Installation **7**
- 3.1 Requirements . . . 7
- 3.2 Getting the code . . . 7
  - 3.2.1 Anaconda Packages . . . 7
- 3.3 Installing ESMPy from Source . . . 8
- 3.4 Importing ESMPy . . . 8
- 3.5 Validation . . . 8
- 3.6 Limitations . . . 9

4 Tutorials **11**
- 4.1 Hello World . . . 11
- 4.2 Regridding Helper Functions . . . 11
  - 4.2.1 LocStream Create . . . 11
  - 4.2.2 LocStream Create Parallel . . . 12
  - 4.2.3 Create a 2D Grid . . . 13
  - 4.2.4 Create a 3D Grid . . . 14
  - 4.2.5 Create a Periodic Grid . . . 16
  - 4.2.6 Create a 5 Element Mesh . . . 17
  - 4.2.7 Create a Field . . . 19
  - 4.2.8 Initialize an Analytic Field . . . 19
  - 4.2.9 Run ESMPy Regridding . . . 19
  - 4.2.10 Compute Field Mass . . . 20
- 4.3 Regridding . . . 20
  - 4.3.1 Grid, Mesh and Field Created from File . . . 21
  - 4.3.2 Read and Write a Weight File . . . 22
  - 4.3.3 Grid to LocStream . . . 25
  - 4.3.4 Mesh to LocStream . . . 28
  - 4.3.5 LocStream to Grid . . . 29
  - 4.3.6 Using MPI.Spawn() from a Serial Python Driver . . . 31

5 API **35**
- 5.1 Classes . . . 35
- 5.2 Named Constants . . . 35
- 5.3 Manager . . . 36
  - 5.3.1 Resource Allocation . . . 36
  - 5.3.2 Logging . . . 36

5.3.3 Memory management . . . 37
5.3.4 MOAB Mesh backend . . . 37
5.4 Spatial Discretization Objects . . . 37
5.4.1 Grid . . . 37
5.4.2 Mesh . . . 40
5.4.3 LocStream . . . 43
5.5 Create a Grid or Mesh from File . . . 43
5.5.1 File Formats . . . 43
5.5.2 Meshes from File . . . 44
5.5.3 Grids from File . . . 44
5.6 Regridding . . . 45
5.6.1 Great Circle Cells . . . 45
5.7 Masking . . . 45
5.8 Numpy Slicing and Indexing . . . 46
5.8.1 Dimension Ordering . . . 46
5.9 Parallel Execution . . . 47
5.9.1 mpirun vs. MPI.Spawn . . . 48

6 Appendices **51**
6.1 Class APIs . . . 51
6.1.1 Manager . . . 51
6.1.2 Field . . . 52
6.1.3 Grid . . . 55
6.1.4 Mesh . . . 60
6.1.5 LocStream . . . 64
6.1.6 Regrid . . . 65
6.1.7 RegridFromFile . . . 68
6.2 Named Constants . . . 69
6.2.1 CoordSys . . . 69
6.2.2 ExtrapMethod . . . 70
6.2.3 FileFormat . . . 70
6.2.4 FileMode . . . 71
6.2.5 GridItem . . . 71
6.2.6 LineType . . . 71
6.2.7 LogKind . . . 72
6.2.8 MeshElemType . . . 72
6.2.9 MeshLoc . . . 72
6.2.10 NormType . . . 72
6.2.11 PoleKind . . . 73
6.2.12 PoleMethod . . . 73
6.2.13 Region . . . 74
6.2.14 RegridMethod . . . 74
6.2.15 StaggerLoc . . . 75
6.2.16 TypeKind . . . 76
6.2.17 UnmappedAction . . . 76
6.3 References . . . 76

Bibliography **77**

Python Module Index **79**

Index **81**

Welcome to ESMPy - The ESMF Python Interface!

CHAPTER

ONE

OVERVIEW

ESMPy is a Python interface to the Earth System Modeling Framework (ESMF) regridding utility. ESMF is software for building and coupling weather, climate, and related models. ESMF has a robust, parallel and scalable remapping package, used to generate remapping weights. It can handle a wide variety of grids and options: logically rectangular grids, unstructured meshes and sets of unconnected points; regional or global grids; 2D or 3D; and pole and masking options. ESMF also has capabilities to read grid information from NetCDF files in a variety of formats, including the Climate and Forecast (CF) V1.6 (a.k.a GridSpec), UGRID, ESMF Unstructured and SCRIP conventions. Information on these last two conventions can be found in the ESMF Reference Manual.

ESMPy provides a *Grid* to represent single-tile logically rectangular coordinate data, a *Mesh* for unstructured coordinates, and a *LocStream* for collections of unconnected points like observational data streams. ESMPy supports bilinear, nearest neighbor, higher order patch recovery, first-order conservative and second-order conservative regridding. There is also an option to ignore unmapped destination points, mask out points on either the source or destination, choose straight line or great circle paths when using spherical coordinates and extrapolate data to points outside of the destination domain. Regridding on the sphere takes place in 3D Cartesian space, so the pole problem is not an issue as it commonly is with many Earth system grid remapping softwares. *Grid* and *Mesh* objects can be created in 2D or 3D space, and 3D conservative regridding is fully supported.

Regridding, also called remapping or interpolation, is the process of changing the grid underneath field data values while preserving the qualities of the original data. Different kinds of transformations are appropriate for different problems. Regridding may be needed when communicating data between Earth system modeling components such as land and atmosphere, or between different data sets to support analysis or visualization.

Regridding can be broken into two stages. The first stage is generation of an interpolation weight matrix that describes how points in the source grid contribute to points in the destination grid. The second stage is the multiplication of values on the source grid by the interpolation weight matrix to produce the appropriate values on the destination grid. ESMPy provides access to both stages through two separate interfaces.

There are many different interpolation methods, suitable for different problems. In ESMPy, the basic bilinear option is a two dimensional variant of linear interpolation. The higher order patch recovery is a second degree polynomial regridding method, which uses a least squares algorithm to calculate the polynomial. This method gives better derivatives in the resulting destination field than the bilinear. There are two nearest-neighbor methods which map the points from one grid to the nearest corresponding point on the other grid, from either source to destination or vice versa. These are useful for extrapolation or categorical fields.

The first-order conservative regridding is a method designed to preserve the integral of the field across the interpolation from source to destination. It uses the proportion of the area of the overlapping source and destination cells to determine appropriate weights. The second-order conservative method also preserves the integral, but uses the source gradient to give a smoother result than the first-order conservative. All of these methods can be broken down to a simple sparse matrix multiplication operation between interpolation weights and data values.

CHAPTER

TWO

IMPORTANT LINKS

The ESMPy home page has the latest information on the ESMPy project including release notes, known bugs, supported platforms, and download information.

Please see the ESMF home page for more information on ESMF in general.

The ESMF Regridding webpage gives a nice overview of the ESMF regridding functionality, including an overview of the functionality that is available through various interfaces to ESMF regridding.

The ESMF_RegridWeightGen application is a command-line version of the functionality that is available through ESMPy. The Regid class gives a thorough overview of the regridding engine that is used by ESMPy. Information on these can be found in the ESMF Reference Manual.

Please contact esmf_support@ucar.edu with any questions or problems.

CHAPTER

THREE

INSTALLATION

3.1 Requirements

The following packages are *required* to work with ESMPy:

- ESMF installation
- python, minimum version 3.7
- numpy

The following packages are *optional*:

- **ESMF installation with NetCDF - required to create *Grids* and *Meshes* from file**
  - NetCDF must be built as a shared library for ESMPy installation to succeed
- mpi4py- python bindings to MPI, needed to run some of the parallel regridding examples
- pytest - for testing

3.2 Getting the code

The ESMPy source code can be downloaded from the ESMF git repository.

The ESMF User's Guide contains information on building and installing esmpy.

The ESMF Reference Manual contains information on the architecture of ESMF, example code, and details of the API (Application Programming Interface).

3.2.1 Anaconda Packages

ESMPy conda packages are available through the conda-forge channel:

```
conda create -n esmpy -c conda-forge esmpy
```

Specific versions of the conda package can be installed like this:

```
conda create -n esmpy -c conda-forge esmpy=8.1.0
```

Development versions can be found in the `esmpy_dev` channel:

```
conda create -n esmpy -c conda-forge -c esmpy_dev esmpy
```

3.3 Installing ESMPy from Source

When installing from source, ESMPy uses pip to build and install the package. This requires setting an environment variable pointing to a file named esmf.mk that is generated during an ESMF installation. The path of this file is:

```
<ESMF_INSTALL_DIR>/lib/lib<g<or>0>/<platform>/esmf.mk
```

If `ESMFMKFILE` is set when building ESMPy then it will not need to be referenced again.

An installation of ESMPy in the default location for Python packages can be done with the following command issued from the top level ESMPy directory:

```
python3 -m pip install .
```

Please contact esmf_support@ucar.edu with any questions.

3.4 Importing ESMPy

To use ESMPy in an external program, import it with:

```
import esmpy
```

3.5 Validation

The ESMPy testing is done with the pytest package, both in serial and parallel. Basic unit tests can be run with the following command:

```
python3 -m pytest
```

There are a few other pytest targets available for a wider range of testing if greater test coverage is desired:

```
make test_unit

make test_examples

make test_unit_parallel

make test_examples_parallel

make test_regrid_from_file
```

Note: The `regrid_from_file` and `example` tests can take up a lot of memory and bandwidth. The `download_regrid_from_file` and `download_examples` commands will simply download the test files without actually running them (allowing the stress on the machine to be applied to bandwidth first, and then memory).

3.6 Limitations

ESMPy doesn't include many aspects of ESMF, including components, field bundles, time management, etc. The limitations listed here are relative to ESMF offline and integrated regridding capabilities.

- ESMPy cannot use an ESMF installation that is built with external LAPACK support.
- Coordinates cannot be retrieved from the elements of a *Mesh*. This can affect the ability to set *Field* values on a source *Mesh* created from file when using conservative regridding.
- Multi-tile *Grid* support is limited to cubed-sphere grids created on 6 processors. A cubed-sphere grid can be created on any number of processors, but only when it is created on 6 processors will the coordinates be retrievable for the entire object. A *Field* created from a cubed-sphere *Grid* cannot be written to file in parallel.
- There is no `FieldBundle` class, only single *Fields*.

Testing related:

- Nightly regression testing is limited to a small subset of the ESMF test platforms, including Darwin and Linux running gfortran with openMPI.

CHAPTER

FOUR

TUTORIALS

4.1 Hello World

```
import esmpy

# This call enables debug logging
# esmpy = esmpy.Manager(debug=True)

print ("Hello ESMPy World from PET (processor) {0}!".format(esmpy.local_pet()))
```

4.2 Regridding Helper Functions

The following code snippets demonstrate how to build all of the pieces necessary to regrid data between *Fields* built on *Grids*, *Meshes* and *LocStreams*.

4.2.1 LocStream Create

```
def create_locstream_spherical_16(coord_sys=esmpy.CoordSys.SPH_DEG, domask=False):
    """
    :param coord_sys: the coordinate system of the LocStream
    :param domask: a boolean to tell whether or not to add a mask
    :return: LocStream
    """
    if esmpy.pet_count() != 1:
        raise ValueError("processor count must be 1 to use this function")

    locstream = esmpy.LocStream(16, coord_sys=coord_sys)

    deg_rad = pi
    if coord_sys == esmpy.CoordSys.SPH_DEG:
        deg_rad = 180

    locstream["ESMF:Lon"] = [0.0, 0.5*deg_rad, 1.5*deg_rad, 2*deg_rad, 0.0, 0.5*deg_rad,␣
↪1.5*deg_rad, 2*deg_rad, 0.0, 0.5*deg_rad, 1.5*deg_rad, 2*deg_rad, 0.0, 0.5*deg_rad, 1.
↪5*deg_rad, 2*deg_rad]
    locstream["ESMF:Lat"] = [deg_rad/-2.0, deg_rad/-2.0, deg_rad/-2.0, deg_rad/-2.0, -0.
↪25*deg_rad, -0.25*deg_rad, -0.25*deg_rad, -0.25*deg_rad, 0.25*deg_rad, 0.25*deg_rad, 0.
```

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```
↪25*deg_rad, 0.25*deg_rad, deg_rad/2.0, deg_rad/2.0, deg_rad/2.0, deg_rad/2.0]
    if domask:
        locstream["ESMF:Mask"] = np.array([1, 0, 0, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1,␣
↪1], dtype=np.int32)

    return locstream
```

4.2.2 LocStream Create Parallel

```
def create_locstream_spherical_16_parallel(coord_sys=esmpy.CoordSys.SPH_DEG,␣
↪domask=False):
    """
    :param coord_sys: the coordinate system of the LocStream
    :param domask: a boolean to tell whether or not to add a mask
    :return: LocStream
    """
    if esmpy.pet_count() != 4:
        raise ValueError("processor count must be 4 to use this function")

    deg_rad = pi
    if coord_sys == esmpy.CoordSys.SPH_DEG:
        deg_rad = 180.0

    locstream = None
    if esmpy.local_pet() == 0:
        locstream = esmpy.LocStream(4, coord_sys=coord_sys)
        locstream["ESMF:Lon"] = [0.0, 0.5*deg_rad, 0.0, 0.5*deg_rad]
        locstream["ESMF:Lat"] = [deg_rad/-2.0, deg_rad/-2.0, -0.25*deg_rad, -0.25*deg_
↪rad]
        if domask:
            locstream["ESMF:Mask"] = np.array([1, 0, 1, 1], dtype=np.int32)
    elif esmpy.local_pet() == 1:
        locstream = esmpy.LocStream(4, coord_sys=coord_sys)
        locstream["ESMF:Lon"] = [1.5*deg_rad, 2*deg_rad, 1.5*deg_rad, 2*deg_rad]
        locstream["ESMF:Lat"] = [deg_rad/-2.0, deg_rad/-2.0, -0.25*deg_rad, -0.25*deg_
↪rad]
        if domask:
            locstream["ESMF:Mask"] = np.array([0, 1, 1, 1], dtype=np.int32)
    elif esmpy.local_pet() == 2:
        locstream = esmpy.LocStream(4, coord_sys=coord_sys)
        locstream["ESMF:Lon"] = [0.0, 0.5*deg_rad, 0.0, 0.5*deg_rad]
        locstream["ESMF:Lat"] = [0.25*deg_rad, 0.25*deg_rad, deg_rad/2.0, deg_rad/2.0]
        if domask:
            locstream["ESMF:Mask"] = np.array([1, 1, 1, 1], dtype=np.int32)
    elif esmpy.local_pet() == 3:
        locstream = esmpy.LocStream(4, coord_sys=coord_sys)
        locstream["ESMF:Lon"] = [1.5*deg_rad, 2*deg_rad, 1.5*deg_rad, 2*deg_rad]
        locstream["ESMF:Lat"] = [0.25*deg_rad, 0.25*deg_rad, deg_rad/2.0, deg_rad/2.0]
        if domask:
            locstream["ESMF:Mask"] = np.array([1, 1, 1, 1], dtype=np.int32)
```

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```
    return locstream
```

4.2.3 Create a 2D Grid

```
def grid_create_from_coordinates(xcoords, ycoords, xcorners=False,␣
↪ycorners=False, corners=False, domask=False, doarea=False, ctk=esmpy.
↪TypeKind.R8):
    """
    Create a 2 dimensional Grid using the bounds of the x and y coordiantes.
    :param xcoords: The 1st dimension or 'x' coordinates at cell centers, as a␣
↪Python list or numpy Array
    :param ycoords: The 2nd dimension or 'y' coordinates at cell centers, as a␣
↪Python list or numpy Array
    :param xcorners: The 1st dimension or 'x' coordinates at cell corners, as a␣
↪Python list or numpy Array
    :param ycorners: The 2nd dimension or 'y' coordinates at cell corners, as a␣
↪Python list or numpy Array
    :param domask: boolean to determine whether to set an arbitrary mask or not
    :param doarea: boolean to determine whether to set an arbitrary area␣
↪values or not
    :param ctk: the coordinate typekind
    :return: grid
    """
    [x, y] = [0, 1]

    # create a grid given the number of grid cells in each dimension, the␣
↪center stagger location is allocated, the
    # Cartesian coordinate system and type of the coordinates are specified
    max_index = np.array([len(xcoords), len(ycoords)])
    grid = esmpy.Grid(max_index, staggerloc=[esmpy.StaggerLoc.CENTER], coord_
↪sys=esmpy.CoordSys.CART, coord_typekind=ctk)

    # set the grid coordinates using numpy arrays, parallel case is handled␣
↪using grid bounds
    gridXCenter = grid.get_coords(x)
    x_par = xcoords[grid.lower_bounds[esmpy.StaggerLoc.CENTER][x]:grid.upper_
↪bounds[esmpy.StaggerLoc.CENTER][x]]
    gridXCenter[...] = x_par.reshape((x_par.size, 1))

    gridYCenter = grid.get_coords(y)
    y_par = ycoords[grid.lower_bounds[esmpy.StaggerLoc.CENTER][y]:grid.upper_
↪bounds[esmpy.StaggerLoc.CENTER][y]]
    gridYCenter[...] = y_par.reshape((1, y_par.size))

    # create grid corners in a slightly different manner to account for the␣
↪bounds format common in CF-like files
    if corners:
        grid.add_coords([esmpy.StaggerLoc.CORNER])
        lbx = grid.lower_bounds[esmpy.StaggerLoc.CORNER][x]
```

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```
        ubx = grid.upper_bounds[esmpy.StaggerLoc.CORNER][x]
        lby = grid.lower_bounds[esmpy.StaggerLoc.CORNER][y]
        uby = grid.upper_bounds[esmpy.StaggerLoc.CORNER][y]

        gridXCorner = grid.get_coords(x, staggerloc=esmpy.StaggerLoc.CORNER)
        for i0 in range(ubx - lbx - 1):
            gridXCorner[i0, :] = xcorners[i0+lbx, 0]
        gridXCorner[i0 + 1, :] = xcorners[i0+lbx, 1]

        gridYCorner = grid.get_coords(y, staggerloc=esmpy.StaggerLoc.CORNER)
        for i1 in range(uby - lby - 1):
            gridYCorner[:, i1] = ycorners[i1+lby, 0]
        gridYCorner[:, i1 + 1] = ycorners[i1+lby, 1]

    # add an arbitrary mask
    if domask:
        mask = grid.add_item(esmpy.GridItem.MASK)
        mask[:] = 1
        mask[np.where((1.75 <= gridXCenter.any() < 2.25) &
                      (1.75 <= gridYCenter.any() < 2.25))] = 0

    # add arbitrary areas values
    if doarea:
        area = grid.add_item(esmpy.GridItem.AREA)
        area[:] = 5.0

    return grid
```

4.2.4 Create a 3D Grid

```
def grid_create_from_coordinates_3d(xcoords, ycoords, zcoords, xcorners=False,␣
↪ycorners=False, zcorners=False, corners=False, domask=False, doarea=False):
    """
    Create a 3 dimensional Grid using the xcoordinates, ycoordinates and␣
↪zcoordinates.
    :param xcoords: The 1st dimension or 'x' coordinates at cell centers, as a␣
↪Python list or numpy Array
    :param ycoords: The 2nd dimension or 'y' coordinates at cell centers, as a␣
↪Python list or numpy Array
    :param zcoords: The 3rd dimension or 'z' coordinates at cell centers, as a␣
↪Python list or numpy Array
    :param xcorners: The 1st dimension or 'x' coordinates at cell corners, as a␣
↪Python list or numpy Array
    :param ycorners: The 2nd dimension or 'y' coordinates at cell corners, as a␣
↪Python list or numpy Array
    :param zcorners: The 3rd dimension or 'z' coordinates at cell corners, as a␣
↪Python list or numpy Array
    :param corners: boolean to determine whether or not to add corner␣
↪coordinates to this grid
    :param domask: boolean to determine whether to set an arbitrary mask or not
```

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```
    :param doarea: boolean to determine whether to set an arbitrary area␣
↪values or not
    :return: grid
    """
    [x, y, z] = [0, 1, 2]

    # create a grid given the number of grid cells in each dimension, the␣
↪center stagger location is allocated and the
    # Cartesian coordinate system is specified
    max_index = np.array([len(xcoords), len(ycoords), len(zcoords)])
    grid = esmpy.Grid(max_index, staggerloc=[esmpy.StaggerLoc.CENTER_VCENTER],␣
↪coord_sys=esmpy.CoordSys.CART)

    # set the grid coordinates using numpy arrays, parallel case is handled␣
↪using grid bounds
    gridXCenter = grid.get_coords(x)
    x_par = xcoords[grid.lower_bounds[esmpy.StaggerLoc.CENTER_VCENTER][x]:grid.
↪upper_bounds[esmpy.StaggerLoc.CENTER_VCENTER][x]]
    gridXCenter[...] = x_par.reshape(x_par.size, 1, 1)

    gridYCenter = grid.get_coords(y)
    y_par = ycoords[grid.lower_bounds[esmpy.StaggerLoc.CENTER_VCENTER][y]:grid.
↪upper_bounds[esmpy.StaggerLoc.CENTER_VCENTER][y]]
    gridYCenter[...] = y_par.reshape(1, y_par.size, 1)

    gridZCenter = grid.get_coords(z)
    z_par = zcoords[grid.lower_bounds[esmpy.StaggerLoc.CENTER_VCENTER][z]:grid.
↪upper_bounds[esmpy.StaggerLoc.CENTER_VCENTER][z]]
    gridZCenter[...] = z_par.reshape(1, 1, z_par.size)

    # create grid corners in a slightly different manner to account for the␣
↪bounds format common in CF-like files
    if corners:
        grid.add_coords([esmpy.StaggerLoc.CORNER_VFACE])
        lbx = grid.lower_bounds[esmpy.StaggerLoc.CORNER_VFACE][x]
        ubx = grid.upper_bounds[esmpy.StaggerLoc.CORNER_VFACE][x]
        lby = grid.lower_bounds[esmpy.StaggerLoc.CORNER_VFACE][y]
        uby = grid.upper_bounds[esmpy.StaggerLoc.CORNER_VFACE][y]
        lbz = grid.lower_bounds[esmpy.StaggerLoc.CORNER_VFACE][z]
        ubz = grid.upper_bounds[esmpy.StaggerLoc.CORNER_VFACE][z]

        gridXCorner = grid.get_coords(x, staggerloc=esmpy.StaggerLoc.CORNER_
↪VFACE)
        for i0 in range(ubx - lbx - 1):
            gridXCorner[i0, :, :] = xcorners[i0+lbx, 0]
        gridXCorner[i0 + 1, :, :] = xcorners[i0+lbx, 1]

        gridYCorner = grid.get_coords(y, staggerloc=esmpy.StaggerLoc.CORNER_
↪VFACE)
        for i1 in range(uby - lby - 1):
            gridYCorner[:, i1, :] = ycorners[i1+lby, 0]
        gridYCorner[:, i1 + 1, :] = ycorners[i1+lby, 1]
```

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```
        gridZCorner = grid.get_coords(z, staggerloc=esmpy.StaggerLoc.CORNER_
↪VFACE)
        for i2 in range(ubz - lbz - 1):
            gridZCorner[:, :, i2] = zcorners[i2+lbz, 0]
        gridZCorner[:, :, i2 + 1] = zcorners[i2+lbz, 1]

    # add an arbitrary mask
    if domask:
        mask = grid.add_item(esmpy.GridItem.MASK)
        mask[:] = 1
        mask[np.where((1.75 < gridXCenter.data < 2.25) &
                      (1.75 < gridYCenter.data < 2.25) &
                      (1.75 < gridZCenter.data < 2.25))] = 0

    # add arbitrary areas values
    if doarea:
        area = grid.add_item(esmpy.GridItem.AREA)
        area[:] = 5.0

    return grid
```

4.2.5 Create a Periodic Grid

```
def grid_create_from_coordinates_periodic(longitudes, latitudes, lon_
↪corners=False, lat_corners=False, corners=False, domask=False):
    """
    Create a 2 dimensional periodic Grid using the 'longitudes' and 'latitudes'.
    :param longitudes: longitude coordinate values at cell centers
    :param latitudes: latitude coordinate values at cell centers
    :param lon_corners: longitude coordinate values at cell corners
    :param lat_corners: latitude coordinate values at cell corners
    :param corners: boolean to determine whether or not to add corner␣
↪coordinates to this grid
    :param domask: boolean to determine whether to set an arbitrary mask or not
    :return: grid
    """
    [lon, lat] = [0, 1]

    # create a grid given the number of grid cells in each dimension the␣
↪center stagger location is allocated
    max_index = np.array([len(longitudes), len(latitudes)])
    grid = esmpy.Grid(max_index, num_peri_dims=1, staggerloc=[esmpy.StaggerLoc.
↪CENTER])

    # set the grid coordinates using numpy arrays, parallel case is handled␣
↪using grid bounds
    gridXCenter = grid.get_coords(lon)
    lon_par = longitudes[grid.lower_bounds[esmpy.StaggerLoc.CENTER][lon]:grid.
↪upper_bounds[esmpy.StaggerLoc.CENTER][lon]]
```

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```
    gridXCenter[...] = lon_par.reshape((lon_par.size, 1))

    gridYCenter = grid.get_coords(lat)
    lat_par = latitudes[grid.lower_bounds[esmpy.StaggerLoc.CENTER][lat]:grid.
↪upper_bounds[esmpy.StaggerLoc.CENTER][lat]]
    gridYCenter[...] = lat_par.reshape((1, lat_par.size))

    # create grid corners in a slightly different manner to account for the␣
↪bounds format common in CF-like files
    if corners:
        grid.add_coords([esmpy.StaggerLoc.CORNER])
        lbx = grid.lower_bounds[esmpy.StaggerLoc.CORNER][lon]
        ubx = grid.upper_bounds[esmpy.StaggerLoc.CORNER][lon]
        lby = grid.lower_bounds[esmpy.StaggerLoc.CORNER][lat]
        uby = grid.upper_bounds[esmpy.StaggerLoc.CORNER][lat]

        gridXCorner = grid.get_coords(lon, staggerloc=esmpy.StaggerLoc.CORNER)
        for i0 in range(ubx - lbx - 1):
            gridXCorner[i0, :] = lon_corners[i0+lbx, 0]
        gridXCorner[i0 + 1, :] = lon_corners[i0+lbx, 1]

        gridYCorner = grid.get_coords(lat, staggerloc=esmpy.StaggerLoc.CORNER)
        for i1 in range(uby - lby - 1):
            gridYCorner[:, i1] = lat_corners[i1+lby, 0]
        gridYCorner[:, i1 + 1] = lat_corners[i1+lby, 1]

    # add an arbitrary mask
    if domask:
        mask = grid.add_item(esmpy.GridItem.MASK)
        mask[:] = 1
        mask[np.where((1.75 <= gridXCenter.any() < 2.25) &
                      (1.75 <= gridYCenter.any() < 2.25))] = 0

    return grid
```

4.2.6 Create a 5 Element Mesh

```
def mesh_create_5():
    """
    PRECONDITIONS: None
    POSTCONDITIONS: A 5 element Mesh has been created.
    RETURN VALUES: \n Mesh :: mesh \n

      4.0   31 ------ 32 ------ 33
            |         |  22  /   |
            |    21   |     /    |
            |         |   /  23  |
      2.0   21 ------ 22 ------ 23
            |         |          |
            |    11   |    12    |
```

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```
            |          |          |
      0.0   11 ------ 12 ------ 13

            0.0        2.0        4.0

          Node Ids at corners
          Element Ids in centers

    Note: This mesh is not parallel, it can only be used in serial
    """
    # Two parametric dimensions, and two spatial dimensions
    mesh = esmpy.Mesh(parametric_dim=2, spatial_dim=2)

    num_node = 9
    num_elem = 5
    nodeId = np.array([11,12,13,21,22,23,31,32,33])
    nodeCoord = np.array([0.0,0.0,  # node 11
                          2.0,0.0,  # node 12
                          4.0,0.0,  # node 13
                          0.0,2.0,  # node 21
                          2.0,2.0,  # node 22
                          4.0,2.0,  # node 23
                          0.0,4.0,  # node 31
                          2.0,4.0,  # node 32
                          4.0,4.0]) # node 33
    nodeOwner = np.zeros(num_node)

    elemId = np.array([11,12,21,22,23])
    elemType=np.array([esmpy.MeshElemType.QUAD,
                       esmpy.MeshElemType.QUAD,
                       esmpy.MeshElemType.QUAD,
                       esmpy.MeshElemType.TRI,
                       esmpy.MeshElemType.TRI])
    elemConn=np.array([0,1,4,3, # element 11
                       1,2,5,4, # element 12
                       3,4,7,6, # element 21
                       4,8,7,   # element 22
                       4,5,8])  # element 23
    elemCoord = np.array([1.0, 1.0,
                          3.0, 1.0,
                          1.0, 3.0,
                          2.5, 3.5,
                          3.5, 2.5])

    mesh.add_nodes(num_node,nodeId,nodeCoord,nodeOwner)

    mesh.add_elements(num_elem,elemId,elemType,elemConn, element_
↪coords=elemCoord)

    return mesh, nodeCoord, nodeOwner, elemType, elemConn, elemCoord
```

4.2.7 Create a Field

```
    def create_field(gml, name):
        '''
        PRECONDITIONS: An Grid, Mesh or LocStream has been created, and 'name'␣
↪is a string that
                       will be used to initialize the name of a new Field.\n
        POSTCONDITIONS: A Field has been created.\n
        RETURN VALUES: \n Field :: field \n
        '''
        field = Field(gml, name=name)

        return field
```

4.2.8 Initialize an Analytic Field

```
def initialize_field_grid_periodic(field):
    """
    PRECONDITIONS: A Field has been created as 'field' with a 'grid'
                   where coordinates have been set on both
                   the center and corner stagger locations. \n
    POSTCONDITIONS: The 'field' has been initialized to an analytic
                    field.\n
    RETURN VALUES: \n Field :: field \n
    """
    DEG2RAD = 3.141592653589793/180.0

    # get the coordinate pointers and set the coordinates
    [x,y] = [0, 1]
    gridXCoord = field.grid.get_coords(x, esmpy.StaggerLoc.CENTER)
    gridYCoord = field.grid.get_coords(y, esmpy.StaggerLoc.CENTER)

    field.data[:] = 2.0 + np.cos(DEG2RAD*gridXCoord)**2 * \
                          np.cos(2.0*DEG2RAD*(90.0 - gridYCoord))

    return field
```

4.2.9 Run ESMPy Regridding

```
    def run_regridding(srcfield, dstfield, srcfracfield, dstfracfield):
        # This is for documentation. Do not modify.
        '''
        PRECONDITIONS: Two Fields have been created and a regridding
                       operation is desired from 'srcfield' to 'dstfield'.
                       The 'srcfracfield' and 'dstfractfield' are Fields
                       created to hold the fractions of the source and
                       destination fields which contribute to conservative
                       regridding.\n
        POSTCONDITIONS: A regridding operation has set the data on
                        'dstfield', 'srcfracfield', and 'dstfracfield'.\n
```

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```
        RETURN VALUES: \n Field :: dstfield \n
                       Field :: srcfracfield \n
                       Field :: dstfracfield \n
        '''
        # call the regridding functions
        regridSrc2Dst = esmpy.Regrid(srcfield, dstfield,
                                     regrid_method=esmpy.RegridMethod.CONSERVE,
                                     unmapped_action=esmpy.UnmappedAction.ERROR,
                                     src_frac_field=srcfracfield,
                                     dst_frac_field=dstfracfield)
        dstfield = regridSrc2Dst(srcfield, dstfield)

        return dstfield, srcfracfield, dstfracfield
```

4.2.10 Compute Field Mass

```
def compute_mass_grid(valuefield, dofrac=False, fracfield=None,
                      uninitval=422397696.):
    """
    PRECONDITIONS: 'fracfield' contains the fractions of each cell
                   which contributed to a regridding operation involving
                   'valuefield.  'dofrac' is a boolean value that gives
                   the option to not use the 'fracfield'.\n
    POSTCONDITIONS: The mass of the data field is computed.\n
    RETURN VALUES: float :: mass \n
    """
    mass = 0.0
    areafield = esmpy.Field(valuefield.grid, name='areafield')
    areafield.get_area()

    ind = np.where(valuefield.data != uninitval)

    if dofrac:
        mass = np.sum(areafield.data[ind] * valuefield.data[ind] * fracfield.
↪data[ind])
    else:
        mass = np.sum(areafield.data[ind] * valuefield.data[ind])

    return mass
```

4.3 Regridding

The following stand alone scripts demonstrate how to use regridding between *Fields* built on *Grids*, *Meshes* and *LocStreams*. These scripts can be run in serial or parallel with no modification.

4.3.1 Grid, Mesh and Field Created from File

```
# This example demonstrates how to create ESMPy Grid, Mesh and Field objects
# from file and use them for regridding.
# The data files can be retrieved from the ESMF data repository by␣
↪uncommenting the
# following block of code:
#
# import os
# DD = os.path.join(os.getcwd(), "examples/data")
# if not os.path.isdir(DD):
#     os.makedirs(DD)
# from esmpy.util.cache_data import cache_data_file
# cache_data_file(os.path.join(DD, "so_Omon_GISS-E2.nc"))
# cache_data_file(os.path.join(DD, "mpas_uniform_10242_dual_counterclockwise.nc
↪"))

import os
import esmpy

from esmpy.util.cache_data import DATA_DIR
from esmpy.util.exceptions import DataMissing

# This call enables debug logging
# esmpy.Manager(debug=True)

datafile = os.path.join(DATA_DIR, "so_Omon_GISS-E2.nc")
if not os.path.exists(datafile):
    raise DataMissing("Data not available, try 'make download'.")
meshfile = os.path.join(DATA_DIR, "mpas_uniform_10242_dual_counterclockwise.nc
↪")
if not os.path.exists(meshfile):
    raise DataMissing("Data not available, try 'make download'.")


# Create a  global grid from a GRIDSPEC formatted file
grid = esmpy.Grid(filename=os.path.join(DATA_DIR, datafile),
                  filetype=esmpy.FileFormat.GRIDSPEC)

# Create a field on the centers of the grid, with extra dimensions
srcfield = esmpy.Field(grid, staggerloc=esmpy.StaggerLoc.CENTER, ndbounds=[33,␣
↪2])

# Read the field data from file
srcfield.read(filename=os.path.join(DATA_DIR, datafile),
              variable="so", timeslice=2)

# Create an ESMF formatted unstructured mesh with clockwise cells removed
mesh = esmpy.Mesh(filename=os.path.join(DATA_DIR, meshfile),
                  filetype=esmpy.FileFormat.ESMFMESH)

# Create a field on the nodes of the mesh
dstfield = esmpy.Field(mesh, meshloc=esmpy.MeshLoc.NODE, ndbounds=[33, 2])
```

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```
dstfield.data[:] = 1e20

# compute the weight matrix for regridding
regrid = esmpy.Regrid(srcfield, dstfield,
                      regrid_method=esmpy.RegridMethod.BILINEAR,
                      unmapped_action=esmpy.UnmappedAction.IGNORE)

# calculate the regridding from source to destination field
dstfield = regrid(srcfield, dstfield)

if esmpy.local_pet() == 0:
    print ("Fields created from file regridded successfully :)")
```

4.3.2 Read and Write a Weight File

```
# This example demonstrates how to regrid between a Grid and a Mesh.
# The data files can be retrieved from the ESMF data repository by␣
↪uncommenting the
# following block of code:
#
# import os
# DD = os.path.join(os.getcwd(), "examples/data")
# if not os.path.isdir(DD):
#     os.makedirs(DD)
# from esmpy.util.cache_data import cache_data_file
# cache_data_file(os.path.join(DD, "ll2.5deg_grid.nc"))
# cache_data_file(os.path.join(DD, "mpas_uniform_10242_dual_counterclockwise.nc
↪"))

import esmpy
import numpy

import esmpy.util.helpers as helpers
import esmpy.api.constants as constants

# This call enables debug logging
mg = esmpy.Manager(debug=True)

# ESMPy uses Fortran style dimension ordering (as of November 2017)
[lat,lon] = [1,0]

# Create the source grid from memory with periodic dimension specified.
lons = numpy.arange(5, 350.1, 10)
lats  = numpy.arange(-85, 85.1, 10)
srcgrid = esmpy.Grid(numpy.array([lons.size, lats.size]),
                     coord_sys=esmpy.CoordSys.SPH_DEG,
                     staggerloc=esmpy.StaggerLoc.CENTER,
                     num_peri_dims=1, periodic_dim=0, pole_dim=1)
```

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```
# Get and set the source grid coordinates.
srcGridCoordLon = srcgrid.get_coords(lon)
srcGridCoordLat = srcgrid.get_coords(lat)

slons_par = lons[srcgrid.lower_bounds[esmpy.StaggerLoc.CENTER][0]:srcgrid.
↪upper_bounds[esmpy.StaggerLoc.CENTER][0]]
slats_par = lats[srcgrid.lower_bounds[esmpy.StaggerLoc.CENTER][1]:srcgrid.
↪upper_bounds[esmpy.StaggerLoc.CENTER][1]]

# make sure to use indexing='ij' as ESMPy backend uses matrix indexing (not␣
↪Cartesian)
lonm, latm = numpy.meshgrid(slons_par, slats_par, indexing='ij')

srcGridCoordLon[:] = lonm
srcGridCoordLat[:] = latm

# Create the dest grid from memory with periodic dimension specified.
lons = numpy.arange(2.5, 357.6, 5)
lats = numpy.arange(-87.5, 87.6, 5)
dstgrid = esmpy.Grid(numpy.array([lons.size, lats.size]),
                     coord_sys=esmpy.CoordSys.SPH_DEG,
                     staggerloc=esmpy.StaggerLoc.CENTER,
                     num_peri_dims=1, periodic_dim=1, pole_dim=0)

# Get and set the source grid coordinates.
dstGridCoordLat = dstgrid.get_coords(lat)
dstGridCoordLon = dstgrid.get_coords(lon)

dlons_par = lons[dstgrid.lower_bounds[esmpy.StaggerLoc.CENTER][0]:dstgrid.
↪upper_bounds[esmpy.StaggerLoc.CENTER][0]]
dlats_par = lats[dstgrid.lower_bounds[esmpy.StaggerLoc.CENTER][1]:dstgrid.
↪upper_bounds[esmpy.StaggerLoc.CENTER][1]]

# make sure to use indexing='ij' as ESMPy backend uses matrix indexing (not␣
↪Cartesian)
lonm, latm = numpy.meshgrid(dlons_par, dlats_par, indexing='ij')

dstGridCoordLon[:] = lonm
dstGridCoordLat[:] = latm

# Create a field on the centers of the source grid with the mask applied.
srcfield = esmpy.Field(srcgrid, name="srcfield", staggerloc=esmpy.StaggerLoc.
↪CENTER)

# Create a field on the centers of the source grid with the mask applied.
dstfield = esmpy.Field(dstgrid, name="dstfield", staggerloc=esmpy.StaggerLoc.
↪CENTER)
xctfield = esmpy.Field(dstgrid, name="xctfield", staggerloc=esmpy.StaggerLoc.
↪CENTER)

gridLon = srcfield.grid.get_coords(lon, esmpy.StaggerLoc.CENTER)
gridLat = srcfield.grid.get_coords(lat, esmpy.StaggerLoc.CENTER)
```

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```
# wave = lambda x,k:  numpy.sin(x*k*numpy.pi/180.0)
# srcfield.data[...] = numpy.outer(wave(slons_par,3), wave(slats_par,3)) + 2

srcfield.data[:,:] = 2.0 + numpy.cos(numpy.radians(srcGridCoordLat)[...])**2 *␣
↪\
                           numpy.cos(2.0*numpy.radians(srcGridCoordLon)[...])

# wave = lambda x,k:  numpy.sin(x*k*numpy.pi/180.0)
# xctfield.data[...] = numpy.outer(wave(dlons_par,3), wave(dlats_par,3)) + 2

xctfield.data[:,:] = 2.0 + numpy.cos(numpy.radians(dstGridCoordLat)[...])**2 *␣
↪\
                           numpy.cos(2.0*numpy.radians(dstGridCoordLon)[...])

dstfield.data[:] = 1e20

# write regridding weights to file
filename = "esmpy_example_weight_file.nc"
if esmpy.local_pet() == 0:
    import os
    if os.path.isfile(
        os.path.join(os.getcwd(), filename)):
        os.remove(os.path.join(os.getcwd(), filename))

mg.barrier()
regrid = esmpy.Regrid(srcfield, dstfield, filename=filename,
                      regrid_method=esmpy.RegridMethod.BILINEAR,
                      unmapped_action=esmpy.UnmappedAction.IGNORE)


# # create a regrid object from file
regrid = esmpy.RegridFromFile(srcfield, dstfield, filename)

# calculate the regridding from source to destination field
dstfield = regrid(srcfield, dstfield)

# compute the mean relative error
num_nodes = numpy.prod(xctfield.data.shape[:])
relerr = 0
meanrelerr = 0
if num_nodes != 0:
    relerr = numpy.sum(numpy.abs(dstfield.data - xctfield.data) /
                       numpy.abs(xctfield.data))
    meanrelerr = relerr / num_nodes

# handle the parallel case
if esmpy.pet_count() > 1:
    relerr = helpers.reduce_val(relerr, op=constants.Reduce.SUM)
    num_nodes = helpers.reduce_val(num_nodes, op=constants.Reduce.SUM)

# output the results from one processor only
```

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```
if esmpy.local_pet() == 0:
    meanrelerr = relerr / num_nodes
    print ("ESMPy Grid Mesh Regridding Example")
    print ("  interpolation mean relative error = {0}".format(meanrelerr))

    if os.path.isfile(os.path.join(os.getcwd(), filename)):
        os.remove(os.path.join(os.getcwd(), filename))

# set to 1 to output results
# if esmpy.pet_count() == 0:
#     import matplotlib.pyplot as plt
#     fig = plt.figure(1, (15, 6))
#     fig.suptitle('ESMPy Periodic Grids', fontsize=14, fontweight='bold')
#
#     ax = fig.add_subplot(1, 2, 1)
#     im = ax.imshow(srcfield.data, vmin=1, vmax=3, cmap='gist_ncar', aspect=
↪'auto',
#                    extent=[min(slons_par), max(slons_par), min(slats_par),␣
↪max(slats_par)])
#     ax.set_xbound(lower=min(slons_par), upper=max(slons_par))
#     ax.set_ybound(lower=min(slats_par), upper=max(slats_par))
#     ax.set_xlabel("Longitude")
#     ax.set_ylabel("Latitude")
#     ax.set_title("Source Data")
#
#     ax = fig.add_subplot(1, 2, 2)
#     im = ax.imshow(dstfield.data, vmin=1, vmax=3, cmap='gist_ncar', aspect=
↪'auto',
#                    extent=[min(dlons_par), max(dlons_par), min(dlats_par),␣
↪max(dlats_par)])
#     ax.set_xlabel("Longitude")
#     ax.set_ylabel("Latitude")
#     ax.set_title("Regrid Solution")
#
#     fig.subplots_adjust(right=0.8)
#     cbar_ax = fig.add_axes([0.9, 0.1, 0.01, 0.8])
#     fig.colorbar(im, cax=cbar_ax)
#
#     plt.show()
```

4.3.3 Grid to LocStream

```
# This example demonstrates how to regrid between a Grid and a LocStream.
# The data files can be retrieved from the ESMF data repository by␣
↪uncommenting the
# following block of code:
#
# import os
# DD = os.path.join(os.getcwd(), "examples/data")
# if not os.path.isdir(DD):
```

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```
#     os.makedirs(DD)
# from esmpy.util.cache_data import cache_data_file
# cache_data_file(os.path.join(DD, "ll1deg_grid.nc"))

import esmpy
import numpy

import os

import esmpy.util.helpers as helpers
import esmpy.api.constants as constants
from esmpy.util.cache_data import DATA_DIR
from esmpy.util.exceptions import DataMissing

# This call enables debug logging
esmpy.Manager(debug=True)

grid1 = os.path.join(DATA_DIR, "ll1deg_grid.nc")
if not os.path.exists(grid1):
    raise DataMissing("Data not available, try 'make download'.")

from esmpy.util.locstream_utilities import create_locstream_spherical_16,␣
↪create_locstream_spherical_16_parallel
coord_sys=esmpy.CoordSys.SPH_DEG
domask=True
if esmpy.pet_count() == 1:
    locstream = create_locstream_spherical_16(coord_sys=coord_sys,␣
↪domask=domask)
else:
    locstream = create_locstream_spherical_16_parallel(coord_sys=coord_sys,␣
↪domask=domask)

grid = esmpy.Grid(filename=grid1, filetype=esmpy.FileFormat.SCRIP)

# create a field
srcfield = esmpy.Field(grid, name='srcfield')

dstfield = esmpy.Field(locstream, name='dstfield')
xctfield = esmpy.Field(locstream, name='xctfield')

# initialize the fields
[x, y] = [0, 1]
deg2rad = 3.14159/180

gridXCoord = srcfield.grid.get_coords(x)
gridYCoord = srcfield.grid.get_coords(y)
srcfield.data[...] = 10.0 + numpy.cos(gridXCoord * deg2rad) ** 2 + numpy.cos(2␣
↪* gridYCoord * deg2rad)

gridXCoord = locstream["ESMF:Lon"]
gridYCoord = locstream["ESMF:Lat"]
if coord_sys == esmpy.CoordSys.SPH_DEG:
```

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```
    xctfield.data[...] = 10.0 + numpy.cos(gridXCoord * deg2rad) ** 2 + numpy.
↪cos(2 * gridYCoord * deg2rad)
elif coord_sys == esmpy.CoordSys.SPH_RAD:
    xctfield.data[...] = 10.0 + numpy.cos(gridXCoord) ** 2 + numpy.cos(2 *␣
↪gridYCoord)
else:
    raise ValueError("coordsys value does not work in this example")

dstfield.data[...] = 1e20

# create an object to regrid data from the source to the destination field
dst_mask_values=None
if domask:
    dst_mask_values=numpy.array([0])

regrid = esmpy.Regrid(srcfield, dstfield,
                      regrid_method=esmpy.RegridMethod.BILINEAR,
                      unmapped_action=esmpy.UnmappedAction.ERROR,
                      dst_mask_values=dst_mask_values)

# do the regridding from source to destination field
dstfield = regrid(srcfield, dstfield, zero_region=esmpy.Region.SELECT)

# compute the mean relative error
num_nodes = numpy.prod(xctfield.data.shape[:])
relerr = 0
meanrelerr = 0

dstfield = numpy.ravel(dstfield.data)
xctfield = numpy.ravel(xctfield.data)

if num_nodes != 0:
    ind = numpy.where((dstfield != 1e20) & (xctfield != 0))[0]
    relerr = numpy.sum(numpy.abs(dstfield[ind] - xctfield[ind]) / numpy.
↪abs(xctfield[ind]))
    meanrelerr = relerr / num_nodes

# handle the parallel case
if esmpy.pet_count() > 1:
    relerr = helpers.reduce_val(relerr, op=constants.Reduce.SUM)
    num_nodes = helpers.reduce_val(num_nodes, op=constants.Reduce.SUM)

# output the results from one processor only
if esmpy.local_pet() == 0:
    meanrelerr = relerr / num_nodes
    print ("ESMPy Grid LocStream Regridding Example")
    print ("  interpolation mean relative error = {0}".format(meanrelerr))

    assert (meanrelerr < 2e-2)
```

4.3.4 Mesh to LocStream

```
# This example demonstrates how to regrid between a mesh and a locstream.

import esmpy
import numpy

import esmpy.util.helpers as helpers
import esmpy.api.constants as constants

# This call enables debug logging
# esmpy.Manager(debug=True)

from esmpy.util.mesh_utilities import mesh_create_5, mesh_create_5_parallel
from esmpy.util.locstream_utilities import create_locstream_16, create_
↪locstream_16_parallel
if esmpy.pet_count() == 1:
    mesh, _, _, _, _, _ = mesh_create_5()
    locstream = create_locstream_16()
else:
    mesh, _, _, _, _ = mesh_create_5_parallel()
    locstream = create_locstream_16_parallel()

# create a field
srcfield = esmpy.Field(mesh, name='srcfield')#, meshloc=esmpy.MeshLoc.ELEMENT)

# create a field on the locstream
dstfield = esmpy.Field(locstream, name='dstfield')
xctfield = esmpy.Field(locstream, name='xctfield')

# initialize the fields
[x, y] = [0, 1]
deg2rad = 3.14159/180

gridXCoord = srcfield.grid.get_coords(x)
gridYCoord = srcfield.grid.get_coords(y)
srcfield.data[...] = 10.0 + (gridXCoord * deg2rad) ** 2 + (gridYCoord *␣
↪deg2rad) ** 2

gridXCoord = locstream["ESMF:X"]
gridYCoord = locstream["ESMF:Y"]
xctfield.data[...] = 10.0 + (gridXCoord * deg2rad) ** 2 + (gridYCoord *␣
↪deg2rad) ** 2

dstfield.data[...] = 1e20

# create an object to regrid data from the source to the destination field
# TODO: this example seems to fail occasionally with UnmappedAction.ERROR,␣
↪probably due to a tolerance issue - ask Bob
regrid = esmpy.Regrid(srcfield=srcfield, dstfield=dstfield, regrid_
↪method=esmpy.RegridMethod.BILINEAR,
                      unmapped_action=esmpy.UnmappedAction.IGNORE)
```

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```
# do the regridding from source to destination field
dstfield = regrid(srcfield, dstfield)

# compute the mean relative error
num_nodes = numpy.prod(xctfield.data.shape[:])
relerr = 0
meanrelerr = 0
if num_nodes != 0:
    ind = numpy.where((dstfield.data != 1e20) & (xctfield.data != 0))[0]
    relerr = numpy.sum(numpy.abs(dstfield.data[ind] - xctfield.data[ind]) /␣
↪numpy.abs(xctfield.data[ind]))
    meanrelerr = relerr / num_nodes

# handle the parallel case
if esmpy.pet_count() > 1:
    relerr = helpers.reduce_val(relerr, op=constants.Reduce.SUM)
    num_nodes = helpers.reduce_val(num_nodes, op=constants.Reduce.SUM)

# output the results from one processor only
if esmpy.local_pet() == 0:
    meanrelerr = relerr / num_nodes
    print ("ESMPy Grid Mesh Regridding Example")
    print ("  interpolation mean relative error = {0}".format(meanrelerr))

    assert (meanrelerr < 3e-5)
```

4.3.5 LocStream to Grid

```
# This example demonstrates how to regrid between a LocStream and a Grid.
# The data files can be retrieved from the ESMF data repository by␣
↪uncommenting the
# following block of code:
#
# import os
# DD = os.path.join(os.getcwd(), "examples/data")
# if not os.path.isdir(DD):
#     os.makedirs(DD)
# from esmpy.util.cache_data import cache_data_file
# cache_data_file(os.path.join(DD, "ll1deg_grid.nc"))

import esmpy
import numpy

import os

import esmpy.util.helpers as helpers
import esmpy.api.constants as constants
from esmpy.util.cache_data import DATA_DIR
from esmpy.util.exceptions import DataMissing
```

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```
# This call enables debug logging
esmpy.Manager(debug=True)

grid1 = os.path.join(DATA_DIR, "ll1deg_grid.nc")
if not os.path.exists(grid1):
    raise DataMissing("Data not available, try 'make download'.")

grid = esmpy.Grid(filename=grid1, filetype=esmpy.FileFormat.SCRIP)

from esmpy.util.locstream_utilities import create_locstream_spherical_16,␣
↪create_locstream_spherical_16_parallel
coord_sys=esmpy.CoordSys.SPH_DEG
domask=True
if esmpy.pet_count() == 1:
    locstream = create_locstream_spherical_16(coord_sys=coord_sys,␣
↪domask=domask)
else:
    locstream = create_locstream_spherical_16_parallel(coord_sys=coord_sys,␣
↪domask=domask)

# create a field
srcfield = esmpy.Field(locstream, name='srcfield')

dstfield = esmpy.Field(grid, name='dstfield')
xctfield = esmpy.Field(grid, name='xctfield')

# initialize the fields
[x, y] = [0, 1]
deg2rad = 3.14159/180

gridXCoord = locstream["ESMF:Lon"]
gridYCoord = locstream["ESMF:Lat"]
if coord_sys == esmpy.CoordSys.SPH_DEG:
    srcfield.data[...] = 10.0 + numpy.cos(gridXCoord * deg2rad) ** 2 + numpy.
↪cos(2 * gridYCoord * deg2rad)
elif coord_sys == esmpy.CoordSys.SPH_RAD:
    srcfield.data[...] = 10.0 + numpy.cos(gridXCoord) ** 2 + numpy.cos(2 *␣
↪gridYCoord)
else:
    raise ValueError("coordsys value does not apply in this example")

gridXCoord = xctfield.grid.get_coords(x)
gridYCoord = xctfield.grid.get_coords(y)
xctfield.data[...] = 10.0 + numpy.cos(gridXCoord * deg2rad) ** 2 + numpy.cos(2␣
↪* gridYCoord * deg2rad)


dstfield.data[...] = 1e20

# create an object to regrid data from the source to the destination field
mask_values=None
if domask:
```

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```
    mask_values=numpy.array([0])

regrid = esmpy.Regrid(srcfield, dstfield,
                      regrid_method=esmpy.RegridMethod.NEAREST_DTOS,
                      unmapped_action=esmpy.UnmappedAction.ERROR,
                      src_mask_values=mask_values)

# do the regridding from source to destination field
dstfield = regrid(srcfield, dstfield, zero_region=esmpy.Region.SELECT)

# compute the mean relative error
from operator import mul
num_nodes = numpy.prod(xctfield.data.shape[:])
relerr = 0
meanrelerr = 0

dstfield = numpy.ravel(dstfield.data)
xctfield = numpy.ravel(xctfield.data)

if num_nodes != 0:
    ind = numpy.where((dstfield != 1e20) & (xctfield != 0))[0]
    relerr = numpy.sum(numpy.abs(dstfield[ind] - xctfield[ind]) / numpy.
↪abs(xctfield[ind]))
    meanrelerr = relerr / num_nodes

# handle the parallel case
if esmpy.pet_count() > 1:
    relerr = helpers.reduce_val(relerr, op=constants.Reduce.SUM)
    num_nodes = helpers.reduce_val(num_nodes, op=constants.Reduce.SUM)

# output the results from one processor only
if esmpy.local_pet() == 0:
    meanrelerr = relerr / num_nodes
    print ("ESMPy LocStream Grid Regridding Example")
    print ("  interpolation mean relative error = {0}".format(meanrelerr))

    assert (meanrelerr < 9e-5)
```

4.3.6 Using MPI.Spawn() from a Serial Python Driver

```
# This example demonstrates how to call ESMPy regridding as a parallel
# subprocess spawned using mpi4py from a serial Python driver.
#
# NOTE: MPI.COMM_WORLD.Spawn does not seem to work for mpi4py installations
#       installations built with mpich, however openmpi does work (July 2016).
#
# The data files can be retrieved from the ESMF data repository by␣
↪uncommenting the
# following block of code:
#
```

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```
# import os
# DD = os.path.join(os.getcwd(), "examples/data")
# if not os.path.isdir(DD):
#     os.makedirs(DD)
# from esmpy.util.cache_data import cache_data_file
# cache_data_file(os.path.join(DD, "ll1deg_grid.nc"))
# cache_data_file(os.path.join(DD, "mpas_uniform_10242_dual_counterclockwise.nc
↪"))

import numpy
from mpi4py import MPI
import sys, os

from esmpy.util.cache_data import DATA_DIR
from esmpy.util.exceptions import DataMissing

def regrid():
    try:
        import esmpy
    except:
        raise ImportError("ESMF is not available on this machine")

    grid1 = os.path.join(DATA_DIR, "ll1deg_grid.nc")
    if not os.path.exists(grid1):
        raise DataMissing("Data not available, try 'make download'.")

    grid2 = os.path.join(DATA_DIR, "mpas_uniform_10242_dual_counterclockwise.nc
↪")
    if not os.path.exists(grid2):
        raise DataMissing("Data not available, try 'make download'.")

    # Create a uniform global latlon grid from a SCRIP formatted file
    grid = esmpy.Grid(filename=grid1, filetype=esmpy.FileFormat.SCRIP)
    # NOTE: corners are needed for conservative regridding
    # grid = esmpy.Grid(filename=grid1, filetype=esmpy.FileFormat.SCRIP,
    #                   add_corner_stagger=True)

    # create a field on the center stagger locations of the source grid
    srcfield = esmpy.Field(grid, name='srcfield',
                           staggerloc=esmpy.StaggerLoc.CENTER)

    # create an ESMF formatted unstructured mesh with clockwise cells removed
    mesh = esmpy.Mesh(filename=grid2, filetype=esmpy.FileFormat.ESMFMESH)

    # create a field on the nodes of the destination mesh
    dstfield = esmpy.Field(mesh, name='dstfield', meshloc=esmpy.MeshLoc.NODE)
    xctfield = esmpy.Field(mesh, name='xctfield', meshloc=esmpy.MeshLoc.NODE)
    # NOTE: Field must be built on elements of Mesh for conservative regridding
    # dstfield = esmpy.Field(mesh, name='dstfield', meshloc=esmpy.MeshLoc.
↪ELEMENT)
    # xctfield = esmpy.Field(mesh, name='xctfield', meshloc=esmpy.MeshLoc.
↪ELEMENT)
```

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```
    # initialize the fields
    [lon, lat] = [0, 1]
    deg2rad = 3.14159 / 180

    gridXCoord = srcfield.grid.get_coords(lon, esmpy.StaggerLoc.CENTER)
    gridYCoord = srcfield.grid.get_coords(lat, esmpy.StaggerLoc.CENTER)
    srcfield.data[...] = 10.0 + (gridXCoord * deg2rad) ** 2 + (
                                                                gridYCoord *␣
↪deg2rad) ** 2

    gridXCoord = xctfield.grid.get_coords(lon, esmpy.StaggerLoc.CENTER)
    gridYCoord = xctfield.grid.get_coords(lat, esmpy.StaggerLoc.CENTER)
    xctfield.data[...] = 10.0 + (gridXCoord * deg2rad) ** 2 + (
                                                                gridYCoord *␣
↪deg2rad) ** 2

    dstfield.data[...] = 1e20

    # create an object to regrid data from the source to the destination field
    regrid = esmpy.Regrid(srcfield, dstfield,
                          regrid_method=esmpy.RegridMethod.BILINEAR,
                          unmapped_action=esmpy.UnmappedAction.ERROR)

    # do the regridding from source to destination field
    dstfield = regrid(srcfield, dstfield)

    return dstfield, xctfield

def compute_error(dstfield, xctfield):
    # compute the mean relative error
    from operator import mul
    num_nodes = reduce(mul, xctfield.shape)
    relerr = 0
    meanrelerr = 0
    if num_nodes != 0:
        ind = numpy.where((dstfield != 1e20) & (xctfield != 0))[0]
        relerr = numpy.sum(
            numpy.abs(dstfield[ind] - xctfield[ind]) / numpy.abs(
                xctfield[ind]))
        meanrelerr = relerr / num_nodes

    meanrelerr = relerr / num_nodes
    print "ESMPy regridding as a spawned MPI process:"
    print "  interpolation mean relative error = {0}".format(meanrelerr)


######################################### MAIN ############################

start_worker = 'worker'
usage = 'Program should be started without arguments'
pet_count = 4
```

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```
# Parent
if len(sys.argv) == 1:

    # Spawn workers
    comm = MPI.COMM_WORLD.Spawn(
        sys.executable,
        args=[sys.argv[0], start_worker],
        maxprocs=pet_count)

    # gather output fields from workers
    dstfield = None
    dstfield = comm.gather(dstfield, root=MPI.ROOT)
    dstfield = numpy.concatenate([dstfield[i] for i in range(pet_count)])

    xctfield = None
    xctfield = comm.gather(xctfield, root=MPI.ROOT)
    xctfield = numpy.concatenate([xctfield[i] for i in range(pet_count)])

    # plot results
    compute_error(dstfield, xctfield)

    # Shutdown
    comm.Disconnect()

# Worker
elif sys.argv[1] == start_worker:

    # Connect to parent
    try:
        comm = MPI.Comm.Get_parent()
        rank = comm.Get_rank()
    except:
        raise ValueError('Could not connect to parent - ' + usage)

    try:
        # call ESMPy regridding
        dstfield, xctfield = regrid()

        # send output to parent
        comm.gather(sendobj=dstfield.data, root=0)
        comm.gather(sendobj=xctfield.data, root=0)
    except:
        comm.Disconnect()

    # Shutdown
    comm.Disconnect()

# Catch
else:
    raise ValueError(usage)
```

CHAPTER

FIVE

API

5.1 Classes

ESMPy uses a *Field* object to represent data variables built on an underlying spatial discretization, which is represented by a *Grid*, *Mesh* or *LocStream*. Regridding between *Fields* is accomplished with the *Regrid* class. All of these classes are explained in more detail in the sections provided by the links in the following table.

Class	Description
Manager	A manager class to initialize and finalize ESMF
Field	A data field built on a *Grid*, *Mesh*, or *LocStream*
Grid	A class to represent a logically rectangular grid
Mesh	A class to represent an unstructured grid
LocStream	A class to represent observational data as a collection of disconnected points
Regrid	The regridding utility
RegridFromFile	The from file regridding utility

5.2 Named Constants

ESMPy follows the ESMF convention of using "named constants" to represent the available options for parameters that expect a variety of specific inputs. The following table lists the available named constants and provides links to pages that further explain the available values.

Named constants	Description
CoordSys	Specify the coordinate system of a *Grid*
ExtrapMethod	Specify the extrapolation method
FileFormat	Specify the format of a data file
FileMode	Specify the mode of a data file
GridItem	Specify a mask or area item on a *Grid*
LineType	Specify the type of line that connects two points on a sphere
LogKind	Specify how much logging should be done
MeshElemType	Specify the type of the *Mesh* elements
MeshLoc	Specify a nodal or elemental *Mesh*
NormType	Specify the type of normalization to use for conservative regridding weights
PoleKind	Specify the type of connection that appears at the poles of the *Grid*
PoleMethod	Specify which type of artificial pole to construct on the source *Grid* for regridding
Region	Specify various regions in the data layout of
RegridMethod	Specify which interpolation method to use regridding
StaggerLoc	Specify the position for data in a *Grid* cell
TypeKind	Specify the type and kind of data
UnmappedAction	Specify which action to take with respect to unmapped destination points

5.3 Manager

The *Manager* is used by ESMPy to simplify a number of low-level calls used by the underlying ESMF framework to allocate resources, enable logging, and control garbage collection.

5.3.1 Resource Allocation

The ESMF Virtual Machine (VM) is created at the beginning of each ESMPy execution, and contains information about the topology and characteristics of the underlying computer. The VM allocates computational resources in the form of **Persistent Execution Threads**, or **PETs**. These are equivalent to operating system threads with a lifetime of at least that of the ESMPy execution. In the simplest, and most common case, a PET is equivalent to an MPI process. The number of PETs and the current PET can be queried from the *Manager*:

```
mg = esmpy.Manager()
pet_count = mg.pet_count()
local_pet = mg.local_pet()
```

Refer to the VM Class of the ESMF Reference Manual for more information.

5.3.2 Logging

The *Manager* is also used to enable logging:

```
mg = esmpy.Manager(debug=True)
local_pet = mg.local_pet
```

The output will be logged in files named PET<local_pet>.ESMF_LogFile.

5.3.3 Memory management

The underlying ESMF framework needs to be initialized and finalized once and only once per execution. This is handled internally by the *Manager* and **does not** require any explicit user intervention. However, the ESMF garbage collection feature is not triggered until the finalization routine is invoked, which may not happen until the *Manager* goes out of scope at the end of the program execution.

If memory deallocation of ESMPy objects is required *prior* to the end of the program, the class level `destroy` routines should be invoked:

```
mg = esmpy.Manager()

mg.destroy()
```

This is commonly required when reusing a *Regrid* object to interpolate data between many *Field* pairs.

5.3.4 MOAB Mesh backend

The Manager can be used to enable the MOAB mesh backend to the Mesh.

```
mg.set_moab(moab_on=True)
```

The MOAB mesh is an alternative to the native ESMF mesh, and does not yet have full support.

5.4 Spatial Discretization Objects

There are three different objects used for spatial coordinate representation: *Grid*, *Mesh*, and *LocStream*. *Grids* are used to represent logically rectangular grids, *Meshes* are used for unstructured collections of polygons, and *LocStreams* are used for unstructured collections of individual points. These objects are nearly identical counterparts to the objects of the same name in ESMF, with some simplifications for ease of use in the Python environment.

5.4.1 Grid

The *Grid* is used to represent the geometry and discretization of logically rectangular physical grids. The *Grid* can also hold information that can used in calculations involving the *Grid*, like a mask or the cell areas. Refer to the Grid Class of the ESMF Reference Manual for more information.

Staggering

Staggering is a finite difference technique in which the values of different physical quantities are placed at different locations within a grid cell.

The ESMF *Grid* class supports a variety of stagger locations, including cell centers, corners, and edge centers. The default stagger location in ESMF is the cell center, and cell counts in *Grid* are based on this assumption. Combinations of the 2D ESMF stagger locations are sufficient to specify any of the Arakawa staggers. ESMF also supports staggering in 3D and higher dimensions. There are shortcuts for standard staggers, and interfaces through which users can create custom staggers.

As a default the ESMF *Grid* class provides symmetric staggering, so that cell centers are enclosed by cell perimeter (e.g. corner) stagger locations. This means the coordinate arrays for stagger locations other than the center will have an additional element of padding in order to enclose the cell center locations. However, to achieve other types of

staggering, the user may alter or eliminate this padding by using the appropriate options when adding coordinates to a *Grid*.

Grid staggers are indicated using *StaggerLoc*.

```
grid = esmpy.Grid(np.array([3,4]), staggerloc=esmpy.StaggerLoc.CENTER)
```

Spherical Coordinates

In the case that the *Grid* is on a sphere (coord_sys = *esmpy.api.constants.CoordSys.SPH_DEG* or *esmpy.api.constants.CoordSys.SPH_RAD*) then the coordinates given in the *Grid* are interpreted as latitude and longitude values. The coordinates can either be in degrees or radians as indicated by the `coord_sys` flag set during *Grid* creation. As is true with many global models, this application currently assumes the latitude and longitude refer to positions on a perfect sphere.

The *Grid* coordinate system is represented using *CoordSys*.

```
grid = esmpy.Grid(np.array([3,4]), staggerloc=esmpy.StaggerLoc.CENTER,
                  coord_sys=esmpy.CoordSys.SPH_DEG)
```

Periodicity

A periodic connection can be specified when building *Grids* in spherical coordinates. The `num_peri_dims` parameter indicates the total number of periodic dimensions and `periodic_dim` is used to identify which dimensions should be considered periodic. There must always be at least one non-periodic dimension. For example, to create a global latitude-longitude *Grid* there would be one periodic dimension, dimension 0 (longitude).

```
grid = esmpy.Grid(np.array([3,4]), staggerloc=esmpy.StaggerLoc.CENTER,
                  coord_sys=esmpy.CoordSys.SPH_DEG,
                  num_peri_dims=1, periodic_dim=0)
```

Pole Generation

The *Grid* can generate an artificial pole by using the `pole_dim` parameter. This can be helpful for regridding operations to smooth out the interpolated values in the polar region. For the example of creating a global latitude-longitude *Grid*, the pole dimension would be 1 (latitude).

```
grid = esmpy.Grid(np.array([3,4]), staggerloc=esmpy.StaggerLoc.CENTER,
                  coord_sys=esmpy.CoordSys.SPH_DEG,
                  num_peri_dims=1, periodic_dim=0, pole_dim=1)
```

Masking

Masking is the process used to mark parts of a *Grid* to be ignored during an operation. Marking *Grid* cells as masked can affect the *Field* values that are represented by those cells. Masking is specified by assigning an integer value to a *Grid* cell. This allows many different masks to be defined on the same *Grid*, any combination of which may be also activated on the *Field* by specifying the corresponding integer values. The activation of *Field* masks with respect to the underlying *Grid* mask is handled by *Regrid*, and a more general discussion of masking is covered in the *masking* section.

```
In [1]: import numpy as np
   ...: import esmpy
   ...: grid = esmpy.Grid(np.array([3,4]), staggerloc=esmpy.StaggerLoc.CENTER,
   ...:                                    coord_sys=esmpy.CoordSys.SPH_DEG,
   ...:                                    num_peri_dims=1, periodic_dim=0, pole_dim=1)
   ...:
   ...: mask = grid.add_item(esmpy.GridItem.MASK, staggerloc=esmpy.StaggerLoc.CENTER)
   ...: mask
   ...:
Out[1]:
array([[1, 1, 1, 1],
       [1, 1, 1, 1],
       [1, 1, 1, 1]], dtype=int32)
```

Cell Areas

Grid cell areas can be calculated by ESMPy. Space must first be allocated for this calculation by adding an *AREA* item to the *Grid*. Then a *Field* must be created, and the *get_area()* function called.

Note: The *Grid* area calculation assumes the *Grid* is a unit sphere.

Grid cell areas may also be set to user-defined values after the *AREA* item has been allocated and retrieved using *get_item()*.

```
In [1]: grid = esmpy.Grid(np.array([3,4]), staggerloc=[esmpy.StaggerLoc.CENTER, esmpy.
↪StaggerLoc.CORNER],
   ...:                   coord_sys=esmpy.CoordSys.SPH_DEG,
   ...:                   num_peri_dims=1, periodic_dim=0, pole_dim=1)
   ...:
   ...:
   ...: gridLon = grid.get_coords(0)
   ...: gridLat = grid.get_coords(1)
   ...: gridLonCorner = grid.get_coords(0, staggerloc=esmpy.StaggerLoc.CORNER)
   ...: gridLatCorner = grid.get_coords(1, staggerloc=esmpy.StaggerLoc.CORNER)
   ...:
   ...: lon = np.linspace(-120,120,3)
   ...: lat = np.linspace(-67.5, 67.5,4)
   ...: lon_corner = np.arange(-180,180,120)
   ...: lat_corner = np.linspace(-90, 90, 5)
   ...:
   ...: lonm, latm = np.meshgrid(lon, lat, indexing='ij')
   ...: lonm_corner, latm_corner = np.meshgrid(lon_corner, lat_corner, indexing='ij')
   ...:
   ...: gridLon[:] = lonm
   ...: gridLat[:] = latm
   ...: gridLonCorner[:] = lonm_corner
   ...: gridLatCorner[:] = latm_corner
   ...:
   ...: field = esmpy.Field(grid)
   ...: field.get_area()
   ...: field.data
```

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```
   ...:
Out[1]:
array([[ 0.32224085,  1.02707409,  1.02707409,  0.32224085],
       [ 0.32224085,  1.02707409,  1.02707409,  0.32224085],
       [ 0.32224085,  1.02707409,  1.02707409,  0.32224085]])
```

5.4.2 Mesh

A *Mesh* is an object for representing unstructured grids. Refer to the Mesh Class of the ESMF Reference Manual for more information.

A *Mesh* is constructed of *nodes* and *elements*. A node, also known as a vertex or corner, is a part of a *Mesh* which represents a single point. An element, also known as a cell, is a part of a *Mesh* which represents a small region of space. Elements are described in terms of a connected set of nodes which represent locations along their boundaries.

Field data may be located on either the nodes or elements of a *Mesh*. *Fields* created on a *Mesh* can also be used as either the source or destination or both of a regridding operation.

The dimension of a *Mesh* in ESMF is specified with two parameters: the *parametric* dimension and the *spatial* dimension.

The parametric dimension of a *Mesh* is the dimension of the topology of the *Mesh*. This can be thought of as the dimension of the elements which make up the *Mesh*. For example, a *Mesh* composed of triangles would have a parametric dimension of 2, and a *Mesh* composed of tetrahedra would have a parametric dimension of 3.

The spatial dimension of a *Mesh* is the dimension of the space in which the *Mesh* is embedded. In other words, it is the number of coordinate dimensions needed to describe the location of the nodes making up the *Mesh*.

For example, a *Mesh* constructed of squares on a plane would have a parametric dimension of 2 and a spatial dimension of 2. If that same *Mesh* were used to represent the 2D surface of a sphere, then the *Mesh* would still have a parametric dimension of 2, but now its spatial dimension would be 3.

Only *Meshes* whose number of coordinate dimensions (spatial dimension) is 2 or 3 are supported. The dimension of the elements in a *Mesh* (parametric dimension) must be less than or equal to the spatial dimension, but also must be either 2 or 3. This means that a *Mesh* may be either 2D elements in 2D space, 3D elements in 3D space, or a manifold constructed of 2D elements embedded in 3D space.

For a parametric dimension of 2, the native supported element types are triangles and quadrilaterals. In addition to these, ESMF supports 2D polygons with any number of sides. Internally these are represented as sets of triangles, but to the user should behave like any other element. For a parametric dimension of 3, the supported element types are tetrahedrons and hexahedrons. The *Mesh* supports any combination of element types within a particular dimension, but types from different dimensions may not be mixed. For example, a *Mesh* cannot be constructed of both quadrilaterals and tetrahedra.

Mesh Creation

To create a *Mesh* we need to set some properties of the *Mesh* as a whole, some properties of each node in the *Mesh* and then some properties of each element which connects the nodes.

For the *Mesh* as a whole we set its parametric dimension and spatial dimension. A *Mesh's* parametric dimension can be thought of as the dimension of the elements which make up the *Mesh*. A *Mesh's* spatial dimension, on the other hand, is the number of coordinate dimensions needed to describe the location of the nodes making up the *Mesh*.

The structure of the per node and element information used to create a *Mesh* is influenced by the *Mesh* distribution strategy. The *Mesh* class is distributed by elements. This means that a node must be present on any PET that contains an element associated with that node, but not on any other PET (a node can't be on a PET without an element "home").

Since a node may be used by two or more elements located on different PETs, a node may be duplicated on multiple PETs. When a node is duplicated in this manner, one and only one of the PETs that contain the node must "own" the node. The user sets this ownership when they define the nodes during *Mesh* creation. When a *Field* is created on a *Mesh* (i.e. on the *Mesh* nodes), on each PET the *Field* is only created on the nodes which are owned by that PET. This means that the size of the *Field* memory on the PET can be smaller than the number of nodes used to create the *Mesh* on that PET.

Three properties need to be defined for each *Mesh* node: the global id of the node (`node_ids`), node coordinates (`node_coords`), and which PET owns the node (`node_owners`). The node id is a unique (across all PETs) integer attached to the particular node. It is used to indicate which nodes are the same when connecting together pieces of the *Mesh* on different PETs. The node coordinates indicate the location of a node in space and are used in the *Regrid* functionality when interpolating. The node owner indicates which PET is in charge of the node. This is used when creating a *Field* on the *Mesh* to indicate which PET should contain a *Field* location for the data.

Three properties need to be defined for each *Mesh* element: the global id of the element (`element_ids`), the topology type of the element (`element_types`), and which nodes are connected together to form the element (`element_conn`). The element id is a unique (across all PETs) integer attached to the particular element. The element type describes the topology of the element (e.g. a triangle vs. a quadrilateral). The range of choices for the topology of the elements in a *Mesh* are restricted by the *Mesh's* parametric dimension (e.g. a *Mesh* can't contain a 2D element like a triangle, when its parametric dimension is 3D), but it can contain any combination of elements appropriate to its dimension. In particular, in 2D ESMF supports two native element types triangle and quadrilateral, but also provides support for polygons with any number of sides. These polygons are represented internally as sets of triangles, but to the user should behave like other elements. To specify a polygon with more than four sides, the element type should be set to the number of corners of the polygon (e.g. element type=6 for a hexagon). The element connectivity indicates which nodes are to be connected together to form the element. The number of nodes connected together for each element is implied by the elements topology type (`element_types`). It is IMPORTANT to note, that the entries in this list are NOT the global ids of the nodes, but are indices into the PET local lists of node info used in the *Mesh* creation. In other words, the element connectivity isn't specified in terms of the global list of nodes, but instead is specified in terms of the locally described node info. One other important point about connectivities is that the order of the nodes in the connectivity list of an element is important. In general, when specifying an element with parametric dimension 2, the nodes should be given in counterclockwise order around the element.

The three step *Mesh* creation process starts with a call to the *Mesh* constructor. It is then followed by the *add_nodes()* call to specify nodes, and then the *add_elements()* call to specify elements.

```
#  2.5        8         10 --------11
#           /     \   /             |
#  2.1   7          9               12
#        |          |      5        /
#        |    4     |             /
#        |          |           /
#  1.0   4 ------- 5 ------- 6
#        |          |  \    3  |
#        |    1     |     \     |
#        |          |  2    \   |
# -0.1   1 ------- 2 ------- 3
#
#      -0.1        1.0       2.1   2.5
#
#          Node Ids at corners
#          Element Ids in centers

# Two parametric dimensions, and two spatial dimensions
mesh = esmpy.Mesh(parametric_dim=2, spatial_dim=2, coord_sys=coord_sys)
```

(continues on next page)

(continued from previous page)

```
num_node = 12
num_elem = 5
nodeId = np.array([1,2,3,4,5,6,7,8,9,10,11,12])
nodeCoord = np.array([-0.1,-0.1,  #node id 1
                      1.0,-0.1,  #node id 2
                      2.1,-0.1,  #node id 3
                      0.1, 1.0,  #node id 4
                      1.0, 1.0,  #node id 5
                      2.1, 1.0,  #node id 6
                      0.1, 2.1,  #node id 7
                      0.5, 2.5,  #node id 8
                      1.0, 2.1,  #node id 9
                      1.5, 2.5,  #node id 10
                      2.5, 2.5,  #node id 11
                      2.5, 2.1]) #node id 12


nodeOwner = np.zeros(num_node)

elemId = np.array([1,2,3,4,5])
elemType=np.array([esmpy.MeshElemType.QUAD,
                   esmpy.MeshElemType.TRI,
                   esmpy.MeshElemType.TRI, 5, 6])

elemConn=np.array([0,1,4,3,         # elem id 1
                   1,2,4,           # elem id 2
                   2,5,4,           # elem id 3
                   3,4,8,7,6,       # elem id 4
                   4,5,11,10,9,8])  # elem id 5

mesh.add_nodes(num_node,nodeId,nodeCoord,nodeOwner)

mesh.add_elements(num_elem,elemId,elemType,elemConn)
```

Masking

There are two types of masking available in *Mesh*: node masking and element masking. These both work in a similar manner, but vary slightly in the details of setting the mask information during *Mesh* creation.

For node masking, the mask information is set using the `node_mask` parameter. When a *Regrid* object is created the mask values arguments `src_mask_values` and `dst_mask_values` can then be used to indicate which particular values set in the `node_mask` array indicate that the node should be masked. For example, if `dst_mask_values` has been set to 1, then any node in the destination *Mesh* whose corresponding `node_mask` value is 1 will be masked out (a node with any other value than 1 will not be masked).

For element masking, the mask information is set using the `element_mask` parameter when adding elements to the *Mesh*. In a similar manner to node masking, the mask values parameters to *Regrid*, `src_mask_values` and `dst_mask_values` can then be used to indicate which particular values set in the `element_mask` array indicate that the element should be masked. For example, if `dst_mask_values` has been set to 1, then any element in the destination *Mesh* whose corresponding `element_mask` value is 1 will be masked out (an element with any other value than 1 will not be masked).

Areas

Mesh cell areas can be specified using the `element_areas` parameter to *add_elements()*.

If cell areas are not specified by the user they can be calculated by ESMPy using *get_area()*.

5.4.3 LocStream

A *LocStream* can be used to represent the locations of a set of data points. For example, in the data assimilation world, *LocStreams* can be used to represent a set of observations. The values of the data points are stored within a *Field* created using the *LocStream*. Refer to the LocStream Class of the ESMF Reference Manual for more information.

The locations are generally described using Cartesian (x, y, z), or (lat, lon, radius) coordinates. The coordinates are stored using constructs called *keys*. A key is essentially a list of point descriptors, one for each data point. They may hold other information besides the coordinates - a mask, for example. They may also hold a second set of coordinates. Keys are referenced by name. Each key must contain the same number of elements as there are data points in the *LocStream*. While there is no assumption in the ordering of the points, the order chosen must be maintained in each of the keys.

A *LocStream* can be very large. Data assimilation systems might use *LocStreams* with up to 10^8 observations, so efficiency is critical. *LocStreams* can be created from file.

A *LocStream* is similar to a *Mesh* in that both are collections of irregularly positioned points. However, the two structures differ because a *Mesh* also has connectivity: each data point represents either a center or corner of a cell. There is no requirement that the points in a *LocStream* have connectivity, in fact there is no requirement that any two points have any particular spatial relationship at all.

```
locstream = esmpy.LocStream(16, coord_sys=coord_sys)

deg_rad = pi
if coord_sys == esmpy.CoordSys.SPH_DEG:
    deg_rad = 180

locstream["ESMF:Lon"] = [0.0, 0.5*deg_rad, 1.5*deg_rad, 2*deg_rad, 0.0, 0.5*deg_rad, 1.
↪5*deg_rad, 2*deg_rad, 0.0, 0.5*deg_rad, 1.5*deg_rad, 2*deg_rad, 0.0, 0.5*deg_rad, 1.
↪5*deg_rad, 2*deg_rad]
locstream["ESMF:Lat"] = [deg_rad/-2.0, deg_rad/-2.0, deg_rad/-2.0, deg_rad/-2.0, -0.
↪25*deg_rad, -0.25*deg_rad, -0.25*deg_rad, -0.25*deg_rad, 0.25*deg_rad, 0.25*deg_rad, 0.
↪25*deg_rad, 0.25*deg_rad, deg_rad/2.0, deg_rad/2.0, deg_rad/2.0, deg_rad/2.0]
if domask:
    locstream["ESMF:Mask"] = np.array([1, 0, 0, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1],␣
↪dtype=np.int32)
```

5.5 Create a Grid or Mesh from File

5.5.1 File Formats

ESMPy can create *Grid* or *Mesh* objects from NetCDF files in a variety of formats. A *Mesh* can be created from files in *SCRIP*, *ESMFMESH*, and *UGRID* formats. *Grid* files can be in *SCRIP* and *GRIDSPEC* format.

SCRIP

This file format is used by the *SCRIP* [1], package, grid files that work with that package should also work here. *SCRIP* format files are capable of storing either 2D logically rectangular grids or 2D unstructured grids. More information can be found in the ESMF Reference Manual.

ESMFMESH

ESMF has a custom unstructured grid file format for describing *Meshes*. This format is more compatible than the *SCRIP* format with the methods used to create a *Mesh* object, so less conversion needs to be done to create a *Mesh*. The *ESMFMESH* format is thus more efficient than *SCRIP* when used with ESMPy. More information can be found in the ESMF Reference Manual.

GRIDSPEC

GRIDSPEC is an extension to the Climate and Forecast (CF) metadata conventions for the representation of gridded data for Earth System Models. ESMPy supports NetCDF files that follow the CF *GRIDSPEC* convention to support logically rectangular lat/lon grids. More information can be found in the ESMF Reference Manual.

UGRID

UGRID is an extension to the CF metadata conventions for the unstructured grid data model. ESMPy support NetCDF files that follow the CF *UGRID* convention for unstructured grids. More information can be found in the ESMF Reference Manual.

5.5.2 Meshes from File

When creating a *Mesh* from a *SCRIP* format file, there are a number of options to control the output *Mesh*. The data is located at the center of the grid cell in a *SCRIP* grid. Therefore, when the *Mesh* will be part of a conservative regridding operation, the `convert_to_dual` flag must be set to True to properly generate coordinates at the the cell corners.

A *Mesh* may also be created with boolean flags to specify whether or not to add an area property to the *Mesh* `add_user_area`, or to add a mask `add_mask` held by the NetCDF variable indicated in the optional argument, `varname`. These argument are only valid for *UGRID* formatted files. The mask generated for a *Mesh* created from file will have 0 for the masked values and 1 for the unmasked values.

5.5.3 Grids from File

A number of optional boolean arguments are also supported to create a structured *Grid* from a file. These include `is_sphere` to indicate whether the grid is spherical or regional, `add_corner_stagger` to add the corner stagger information to the *Grid* for conservative regridding, and `add_user_area` to specify whether to read in the cell area from the NetCDF file or to calculate them.

For *GRIDSPEC* formated files there is the `add_mask` optional argument to add a mask held by the NetCDF variable indicated in optional argument, `varname`, and the `coord_names` argument to specify the longitude and latitude variable names in a *GRIDSPEC* file containing multiple sets of coordinates.

For *SCRIP* formated files the integer array `grid_imask` is used to mask out grid cells which should not participate in the regridding.

The mask generated for a *Grid* created from file (any format) will have 0 for the masked values and 1 for the unmasked values.

5.6 Regridding

The following table describe the regridding methods and options that are available in ESMPy, the flag that is required to use it and a short description. More information can be found on these options in the ESMF Reference Manual.

Class	Description
BILINEAR	Linear regridding in two dimensions
PATCH	Higher-order least squares method
NEAREST_STOD	Nearest source point used for each destination
NEAREST_DTOS	Nearest destination point used for each source
CONSERVE	First-order conservative
CONSERVE_2ND	Second-order conservative
NormType	Normalization options for integral conservation
LineType	Line types for spherical and Cartesian space
UnmappedAction	Unmapped destination point handling options
CoordSys	Spherical grids and pole handling

5.6.1 Great Circle Cells

For Grids and Meshes on a sphere some combinations of interpolation options (e.g. first and second-order conservative methods) use cells whose edges are great circles. This section describes some behavior that the user may not expect from these cells and some potential solutions. A great circle edge isn't necessarily the same as a straight line in latitude longitude space. For small edges, this difference will be small, but for long edges it could be significant. This means if the user expects cell edges as straight lines in latitude longitude space, they should avoid using one large cell with long edges to compute an average over a region (e.g. over an ocean basin).

Also, the user should also avoid using cells that contain one edge that runs half way or more around the earth, because the regrid weight calculation assumes the edge follows the shorter great circle path. There isn't a unique great circle edge defined between points on the exact opposite side of the earth from one another (antipodal points). However, the user can work around both of these problem by breaking the long edge into two smaller edges by inserting an extra node, or by breaking the large target grid cells into two or more smaller grid cells. This allows the application to resolve the ambiguity in edge direction.

5.7 Masking

Masking is the process whereby parts of a *Grid*, *Mesh* or *LocStream* can be marked to be ignored during an operation, such as when they are used in regridding. Masking can be used on a *Field* created from a regridding source to indicate that certain portions should not be used to generate regridded data. This is useful, for example, if a portion of the source contains unusable values. Masking can also be used on a *Field* created from a regridding destination to indicate that a certain portion should not receive regridded data. This is useful, for example, when part of the destination isn't being used (e.g. the land portion of an ocean grid).

The user may mask out points in the source *Field* or destination *Field* or both. To do masking the user sets mask information in the *Grid*, *Mesh*, or *LocStream* upon which the *Fields* passed into the *Regrid* call are built. The `src_mask_values` and `dst_mask_values` arguments to that call can then be used to specify which values in that mask information indicate that a location should be masked out. For example, if `dst_mask_values` is set to [1,2], then any location that has a value of 1 or 2 in the mask information of the *Grid*, *Mesh* or *LocStream* upon which the destination *Field* is built will be masked out.

Masking behavior differs slightly between regridding methods. For non-conservative regridding methods (e.g. bilinear or high-order patch), masking is done on points. For these methods, masking a destination point means that the point

will not participate in regridding. For these methods, masking a source point means that the entire source cell using that point is masked out. In other words, if any corner point making up a source cell is masked then the cell is masked. For conservative regridding methods masking is done on cells. Masking a destination cell means that the cell won't participate in regridding. Similarly, masking a source cell means that the cell won't participate in regridding. For any type of interpolation method (conservative or non-conservative) the masking is set on the location upon which the *Fields* passed into the regridding call are built. For example, if *Fields* built on *StaggerLoc.CENTER* are passed into *Regrid* then the masking should also be set on *StaggerLoc.CENTER*.

The mask generated for a *Grid*, *Mesh* or *LocStream* created from file will have 0 for the masked values and 1 for the unmasked values.

Note: The *Region.SELECT* flag to the

`zero_region` parameter of *Regrid* can be used to maintain *Fields* values on locations that do not participate in the regridding operation. This is useful when setting an uninitialized value to help identify masked locations within the *Fields* data.

5.8 Numpy Slicing and Indexing

Numpy arrays are used to represent *Grid*, *Mesh* and *LocStream* coordinates and *Field* data, among other things. Standard numpy conventions for array indexing and slicing can be expected. There are some exceptions when it comes to fancy indexing, index arrays, and multi-dimensional slicing. Significant effort has been put into raising exceptions where inappropriate indexing or slicing operations are attempted.

It is very important to remember that all indexing and slicing operations apply **ONLY** to the ESMPy level objects, and these operations do not propagate down to the lower-level Fortran- and C-based representations of the ESMF objects. One example of where this could come up is when passing a *Field* slice into regridding. The entire original *Field* will still be run through the ESMF regridding engine, and only the appropriate portion of the *Field* slice will be updated with the regridded values.

5.8.1 Dimension Ordering

Warning: The underlying ESMF library is built with a mix of Fortran and C/C++ and follows Fortran conventions with respect to array indexing and dimension ordering. Some effort has been made to make ESMPy feel more natural to the Python user where possible. This means that ESMPy uses 0-based indexing, which is translated to the 1-based indexing used by the ESMPy backend. However, the dimension ordering still follows Fortran conventions. Namely, longitude comes before latitude, which also comes before temporal dimensions when in use.

```
In [1]: import numpy as np
   ...: import esmpy
   ...:
   ...: grid = esmpy.Grid(np.array([3,4]), staggerloc=esmpy.StaggerLoc.CENTER)
   ...:
   ...: gridLon = grid.get_coords(0)
   ...: gridLat = grid.get_coords(1)
   ...:
   ...: lon = np.linspace(-120,120,3)
   ...: lat = np.linspace(-67.5, 67.5,4)
   ...:
   ...: lonm, latm = np.meshgrid(lon, lat, indexing='ij')
   ...:
```

```
   ...: gridLon[:] = lonm
   ...: gridLat[:] = latm
   ...:

In [2]: grid.coords[esmpy.StaggerLoc.CENTER][0].shape
Out[2]: (3, 4)

In [3]: lon.shape
Out[3]: (3,)

In [4]: lat.shape
Out[4]: (4,)

In [5]: grid.coords[esmpy.StaggerLoc.CENTER][0]
Out[5]:
array([[-120., -120., -120., -120.],
       [   0.,    0.,    0.,    0.],
       [ 120.,  120.,  120.,  120.]])

In [6]: grid.coords[esmpy.StaggerLoc.CENTER][1]
Out[6]:
array([[-67.5, -22.5,  22.5,  67.5],
       [-67.5, -22.5,  22.5,  67.5],
       [-67.5, -22.5,  22.5,  67.5]])

In [7]: field = esmpy.Field(grid, ndbounds=[10]) # create a Field with a time␣
↪dimension

In [8]: field.data.shape
Out[8]: (3, 4, 10)
```

5.9 Parallel Execution

ESMPy is a thin wrapper on top of ESMF, which was designed for high performance and scalable computing. The ESMF virtual machine is used to manage the available resources of the execution environment in a layer that is transparent to the ESMPy user. This allows the full power of the high performance computing environment to be utilized by the ESMPy user with little use of specialized parallel programming techniques.

ESMPy objects will be distributed across the available computing resources with no additional parameters required. The *Grid*, *Mesh*, *LocStream*, and *Field* classes will all be transparently "parallelized" with no need for user calls to a message passing interface. Likewise, the *Regrid* class will compute and apply the interpolation weights using all available computing resources with no need for user intervention.

However, it is useful to remember that resulting *Field* values will only be accessible on certain PETs. The mpi4py package may be necessary for post processing tasks that require access to global *Field* values.

5.9.1 mpirun vs. MPI.Spawn

There are a few different options for using ESMPy in a parallel environment. Using mpirun to specify the desired number of computing cores is probably the easiest way to start a parallel ESMPy job. Another option is to call the MPI.Spawn() function from the mpi4py Python package from within a serial Python script or interpreter. It has been observed that MPI.Spawn() may not work properly when mpi4py is built with an underlying mpich library, openmpi has seen better success. A third option is to call mpirun using a system call from within a serial Python script or interpreter, however this method is not highly recommended.

The following two examples demonstrate how to execute an ESMPy script in parallel. Any of the scripts found in the examples directory of the ESMPy source code can be run in parallel using mpirun as well as in serial mode.

mpirun

```
mpirun -n 4 python hello_world.py
```

MPI.Spawn

```
import sys
from mpi4py import MPI

# Parent
if len(sys.argv) == 1:

    # Spawn workers
    comm = MPI.COMM_WORLD.Spawn(
        sys.executable,
        args=[sys.argv[0], 'worker'],
        maxprocs=4)

    # Shutdown
    comm.Disconnect()

# Worker
elif sys.argv[1] == 'worker':

    # Connect to parent
    try:
        comm = MPI.Comm.Get_parent()
        rank = comm.Get_rank()
    except:
        raise ValueError('Could not connect to parent - ' + usage)

    # worker code goes here, regridding etc..
    print "Hello World from PET #"+str(rank)

    # Shutdown
    comm.Disconnect()

# Catch
else:
    raise ValueError('Program should be started without arguments')
```

A more detailed example of using MPI.Spawn() can be found in the Tutorials section of the documentation.

CHAPTER

SIX

APPENDICES

6.1 Class APIs

6.1.1 Manager

class esmpy.api.esmpymanager.**Manager**(*debug=False*)

This singleton class is designed to ensure that ESMF is properly initialized and finalized. ESMF is initialized at *Manager* creation, and the __del__ method is registered with atexit to ensure ESMF is always finalized prior to exiting Python. If the object is copied, the copy will always be an alias to the original *Manager* object. The *Manager* will be created when the first ESMPy object is created if it is not created explicitly by the user.

Explicit creation of a *Manager* object allows for setting a flag which results in the output of debug information from the ESMF logging capability during the application runtime. The output log files are named PET<PET number>.ESMF_LogFile.

The PET rank (local_pet) and total number of PETs (pet_count) can also be retrieved from the *Manager* using the following calls:

```
esmpy.local_pet()
esmpy.pet_count()
```

`local_pet` and `pet_count` are also properties of the *Manager*.

Calls ESMP_Initialize and registers __del__ with atexit when called the first time. Subsequent calls only return whether or not ESMF is initialized. Registering __del__ with atexit ensures the ESMP_Finalize will always be called prior to exiting Python. Calling __init__ explicitly results in a no-op.

The *Manager* can be used to enable the MOAB mesh backend to the `Mesh`. This is done by calling `set_moab()` with `moab_on=True`.

The *Manager* has a *test_exhaustive* member variable that can be enabled to run combinatorial expansions of `Grid` and `Field` creation parameters.

Parameters
debug (*bool*) – outputs logging information to ESMF logfiles. If `None`, defaults to False.

property local_pet

Return type
int

Returns
The id of the current Persistent Execution Thread (PET i.e. processing core).

property moab

Return type
bool

Returns
A boolean value to indicate if the MOAB mesh backend is in use.

property pet_count

Return type
int

Returns
The number of Persistent Execution Threads (PETs i.e. processing cores) available in this execution.

barrier()

Collective VM communication call that blocks calling PET until all PETs of the VM have issued the call.

set_moab(*moab_on=True*)

Set the Mesh backend to use MOAB or the Native ESMF mesh.

6.1.2 Field

class esmpy.api.field.**Field**(*grid*, *name=None*, *typekind=None*, *staggerloc=None*, *meshloc=None*, *ndbounds=None*)

The *Field* class is a Python wrapper object for the ESMF Field. The individual values of all data arrays are referenced to those of the underlying Fortran ESMF object.

A *Field* represents a physical field, such as temperature. The *Field* class contains distributed and discretized field data, a reference to its associated grid, and metadata. The *Field* class stores the grid staggering for that physical field. This is the relationship of how the data array of a field maps onto a grid (e.g. one item per cell located at the cell center, one item per cell located at the NW corner, one item per cell vertex, etc.). This means that different *Fields* which are on the same underlying *Grid* but have different staggerings can share the same *Grid* object without needing to replicate it multiple times.

Refer to the Field Class of the ESMF Reference Manual for more information.

The following parameters are used to create a *Field* from a *Grid*, *Mesh* or *LocStream*.

REQUIRED:

:param *Grid*/Mesh/*LocStream* grid: A *Grid*,
Mesh or *LocStream* with coordinates allocated on at least one stagger location.

OPTIONAL:

Parameters

- **name** (*str*) – An optional user friendly name for the *Field*.
- **typekind** (TypeKind) – Type of the *Field* data. If None, defaults to *R8*.
- **staggerloc** (StaggerLoc) – The stagger location of the *Field* data, only specify this argument when using a *Grid*. If None, defaults to *CENTER* in 2D and *CENTER_VCENTER* in 3D.
- **meshloc** (MeshLoc) – The mesh location of the *Field* data, only specify this argument when using a *Mesh* if None, defaults to *NODE*.

- **ndbounds** (*tuple*) – The number of entries in an extra *Field* dimension. This is represented as a single value, a list or a tuple containing the number of entries for each desired extra dimension of the *Field*. The time dimension must be last, following Fortran indexing conventions.

property data

Return type
TypeKind

Returns
The data of the *Field*

property grid

Return type
Grid, *Mesh*, or *LocStream*

Returns
The discretization object upon which the *Field* is built.

property lower_bounds

Return type
ndarray

Returns
The lower bounds of the *Field*.

property name

Return type
str

Returns
the name of the *Field*.

property ndbounds

Return type
list

Returns
The bounds of the extra dimensions in the *Field*.

property rank

Return type
int

Returns
The rank of the *Field*.

property staggerloc

Return type
StaggerLoc or *MeshLoc*

Returns
The location upon which the *Field* is built.

property type

Return type
TypeKind

Returns
The type of the data in the *Field*.

property upper_bounds

Return type
ndarray

Returns
The upper bounds of the *Field*.

property xd

Return type
int

Returns
The number of extra (ungridded) dimensions of the *Field*.

copy()
Copy a *Field* in an ESMF-safe manner.

Returns
A *Field* shallow copy.

destroy()
Release the memory associated with a *Field*.

get_area()
Initialize an existing *Field* with the areas of the cells of the underlying *Grid* or *Mesh*.

read(*filename*, *variable*, *timeslice=None*)
Read data into an existing *Field* from a CF-compliant NetCDF file.

Note
This interface is not supported when ESMF is built with `ESMF_COMM=mpiuni`.

Note
This interface does not currently support reading ungridded dimensions.

REQUIRED:

Parameters

- **filename** (*str*) – The name of the NetCDF file.
- **variable** (*str*) – The name of the data variable to read from file.

OPTIONAL:

Parameters
timeslice (*int*) – The number of timeslices to read.

6.1.3 Grid

class esmpy.api.grid.**Grid**(*max_index=None*, *num_peri_dims=0*, *periodic_dim=None*, *pole_dim=None*, *coord_sys=None*, *coord_typekind=None*, *staggerloc=None*, *pole_kind=None*, *filename=None*, *filetype=None*, *reg_decomp=None*, *decompflag=None*, *is_sphere=None*, *add_corner_stagger=None*, *add_user_area=None*, *add_mask=None*, *varname=None*, *coord_names=None*, *tilesize=None*, *regDecompPTile=None*, *name=None*)

The *Grid* class is a Python wrapper object for the ESMF Grid. The individual values of all coordinate and mask arrays are referenced to those of the underlying Fortran ESMF object.

The *Grid* class is used to describe the geometry and discretization of logically rectangular physical grids. It also contains the description of the underlying topology and decomposition of the physical grid across the available computational resources. The most frequent use of the *Grid* class is to describe physical grids in user code so that sufficient information is available to perform regridding operations.

Refer to the Grid Class of the ESMF Reference Manual for more information.

A *Grid* can be created in two different ways, as a *Grid* in memory, or from SCRIP formatted or CF compliant GRIDSPEC file. The arguments for each type of *Grid* creation are outlined below.

Created in-memory:

REQUIRED:

Parameters

max_index (*list*) – An integer list of length 2 or 3, with the number of grid cells in each dimension.

OPTIONAL:

Parameters

- **num_peri_dims** (*int*) – The number of periodic dimensions, either `0` or `1`. If `None`, defaults to `0`.
- **periodic_dim** (*int*) – The periodic dimension: `0`, `1` or `2`. If `None`, defaults to `0`.
- **pole_dim** (*int*) – The pole dimension `0` or `1`. If `None`, defaults to `1`.
- **coord_sys** (CoordSys) – Coordinate system for the *Grid*. If `None`, defaults to *SPH_DEG*.
- **coord_typekind** (TypeKind) – Type of the *Grid* coordinates. If `None`, defaults to *R8*.

Created either from file or in-memory:

Parameters

- **staggerloc** (StaggerLoc) – The stagger location of the coordinate values. If `None`, defaults to *CENTER* in 2D and *CENTER_VCENTER* in 3D.
- **pole_kind** (PoleKind) – Two item list which specifies the type of connection which occurs at the pole. The first value specifies the connection that occurs at the minimum end of the pole dimension. The second value specifies the connection that occurs at the maximum end of the pole dimension. If `None`, defaults to *MONOPOLE*.

Created from file:

REQUIRED:

Parameters

- **filename** (*str*) – The name of the NetCDF grid file.

- **filetype** (FileFormat) – The grid *FileFormat*.

OPTIONAL:

Parameters

- **is_sphere** (*bool*) – Set to `True` for a spherical grid, or `False` for regional. Defaults to `True`.
- **add_corner_stagger** (*bool*) – Set to `True` to use the information in the grid file to add the corner stagger to the grid. The coordinates for the corner stagger are required for conservative regridding. If not specified, defaults to `False`.
- **add_user_area** (*bool*) – Set to `True` to read in the cell area from the grid file; otherwise, ESMF will calculate it. Defaults to `False`.
- **add_mask** (*bool*) – Set to `True` to generate the mask using the `missing_value` attribute defined in `varname`. This argument is only supported with filetype *GRIDSPEC*. Defaults to `False`.
- **varname** (*str*) – If add_mask is `True`, provide a variable name stored in the grid file and the mask will be generated using the missing value of the data value of this variable. The first two dimensions of the variable has to be the longitude and the latitude dimension and the mask is derived from the first 2D values of this variable even if this data is a 3D, or 4D array. This argument is only supported with filetype *GRIDSPEC*. Defaults to `None`.
- **coord_names** (*list*) – A two-element array containing the longitude and latitude variable names in a GRIDSPEC file if there are multiple coordinates defined in the file. This argument is only supported with filetype *GRIDSPEC*. Defaults to `None`.

Cubed sphere:

REQUIRED:

Parameters

tilesize (*int*) – The number of elements on each side of the tile of the cubed sphere grid.

OPTIONAL:

Parameters

- **regDecompPTile** (*list*) – List of DE counts for each dimension. The second index steps through the tiles. The total deCount is determined as the sum over the products of regDecompPTile elements for each tile. By default every tile is decomposed in the same way. If the total PET count is less than 6, one tile will be assigned to one DE and the DEs will be assigned to PETs sequentially, therefore, some PETs may have more than one DE. If the total PET count is greater than 6, the total number of DEs will be a multiple of 6 and less than or equal to the total PET count. For instance, if the total PET count is 16, the total DE count will be 12 with each tile decomposed into 1x2 blocks. The 12 DEs are mapped to the first 12 PETs and the remaining 4 PETs have no DEs locally.
- **name** (*str*) – The name of the *Grid*.

`property area`

Return type

A list of numpy arrays with an entry for every stagger location of the *Grid*.

Returns

The *Grid* cell areas represented as numpy arrays of floats of size given by `upper_bounds - lower_bounds`.

property areatype

Return type
TypeKind

Returns
The ESMF typekind of the *Grid* cell areas.

property coords

Return type
2D list of numpy arrays of size given by `upper_bounds - lower_bounds`, where the first index represents the stagger locations of the *Grid* and the second index represent the coordinate dimensions of the *Grid*.

Returns
The coordinates of the *Grid*.

property coord_sys

Return type
CoordSys

Returns
The coordinate system of the *Grid*.

property has_corners

Return type
bool

Returns
A boolean value to tell if the *Grid* has corners allocated.

property lower_bounds

Return type
A list of numpy arrays with an entry for every stagger location of the *Grid*.

Returns
The lower bounds of the *Grid* represented as numpy arrays of ints of size given by `upper_bounds - lower_bounds`.

property mask

Return type
A list of numpy arrays with an entry for every stagger location of the *Grid*.

Returns
The mask of the *Grid* represented as numpy arrays of ints of size given by ` *upper_bounds - lower_bounds* `.

property max_index

Return type
A numpy array with as many values as the *Grid* rank.

Returns
The number of *Grid* cells in each dimension of the grid.

property num_peri_dims

Return type
int

Returns
The total number of periodic dimensions in the *Grid*.

property periodic_dim

Return type
int

Returns
The periodic dimension of the *Grid* (e.g. `0` for `x` or `longitude`, `1` for `y` or `latitude`, etc.).

property pole_dim

Return type
int

Returns
The pole dimension of the *Grid* (e.g. `0` for `x` or `longitude`, `1` for `y` or `latitude`, etc.).

property rank

Return type
int

Returns
The rank of the *Grid*.

property size

Return type
A list of numpy arrays with an entry for every stagger location of the *Grid*.

Returns
The size of the *Grid* represented as numpy arrays of ints of size given by `upper_bounds - lower_bounds`.

property staggerloc

Return type
list of bools

Returns
The stagger locations that have been allocated for the *Grid*.

property type

Return type
TypeKind

Returns
The ESMF typekind of the *Grid* coordinates.

property upper_bounds

Return type
A list of numpy arrays with an entry for every stagger location of the *Grid*.

Returns
The upper bounds of the *Grid* represented as numpy arrays of ints of size given by `upper_bounds - lower_bounds`.

add_coords(*staggerloc=None*, *coord_dim=None*, *from_file=False*)

Add coordinates to the *Grid* at the specified stagger location.

Parameters

- **staggerloc** (StaggerLoc) – The stagger location of the coordinate values. If `None`, defaults to *CENTER* in 2D and *CENTER_VCENTER* in 3D.
- **coord_dim** (*int*) – The dimension number of the coordinates to return e.g. `[x, y, z] = (0, 1, 2)`, or `[lon, lat] = (0, 1)` (coordinates will not be returned if coord_dim is not specified and staggerlocs is a list with more than one element).
- **from_file** (*bool*) – Boolean for internal use to determine whether the *Grid* has already been created from file.

Returns
A numpy array of coordinate values if staggerloc and coord_dim are specified, otherwise return None.

add_item(*item*, *staggerloc=None*, *from_file=False*)

Allocate space for a *Grid* item (mask or areas) at a specified stagger location.

REQUIRED:

Parameters
item (GridItem) – The *GridItem* to allocate.

OPTIONAL:

Parameters

- **staggerloc** (StaggerLoc) – The stagger location of the item values. If `None`, defaults to *CENTER* in 2D and *CENTER_VCENTER* in 3D.
- **from_file** (*bool*) – Boolean for internal use to determine whether the *Grid* has already been created from file.

Returns
A numpy array of the mask or area values if a single staggerloc is given, otherwise return None.

copy()

Copy a *Grid* in an ESMF-safe manner.

Returns
A *Grid* shallow copy.

destroy()

Release the memory associated with a *Grid*.

get_coords(*coord_dim*, *staggerloc=None*)

Return a numpy array of coordinates at a specified stagger location. The returned array is NOT a copy, it is directly aliased to the underlying memory allocated by esmpy.

REQUIRED:

Parameters
coord_dim (*int*) – The dimension number of the coordinates to return e.g. `[x, y, z] =`

`(0, 1, 2)`, or `[lon, lat] = (0, 1)` (coordinates will not be returned if `coord_dim` is not specified and `staggerlocs` is a list with more than one element).

OPTIONAL:

Parameters
staggerloc (StaggerLoc) – The stagger location of the coordinate values. If `None`, defaults to *CENTER* in 2D and *CENTER_VCENTER* in 3D.

Returns
A numpy array of coordinate values at the specified staggerloc.

get_item(*item*, *staggerloc=None*)

Return a numpy array of item values at a specified stagger location. The returned array is NOT a copy, it is directly aliased to the underlying memory allocated by esmpy.

REQUIRED:

Parameters
item (GridItem) – The *GridItem* to return.

OPTIONAL:

Parameters
staggerloc (StaggerLoc) – The stagger location of the item values. If `None`, defaults to *CENTER* in 2D and *CENTER_VCENTER* in 3D.

Returns
A numpy array of mask or area values at the specified staggerloc.

6.1.4 Mesh

class esmpy.api.mesh.**Mesh**(*parametric_dim=None*, *spatial_dim=None*, *coord_sys=None*, *filename=None*, *filetype=None*, *convert_to_dual=None*, *add_user_area=None*, *meshname=''*, *mask_flag=None*, *varname=''*)

The *Mesh* class is a Python wrapper object for the ESMF Mesh. The individual values of all coordinate and mask arrays are referenced to those of the underlying Fortran ESMF object.

The ESMF library provides a class for representing unstructured grids called the *Mesh*. *Fields* can be created on a *Mesh* to hold data. *Fields* created on a *Mesh* can also be used as either the source or destination or both of a regrididng operation which allows data to be moved between unstructured grids. A *Mesh* is constructed of nodes and elements. A node, also known as a vertex or corner, is a part of a *Mesh* which represents a single point. Coordinate information is set in a node. An element, also known as a cell, is a part of a mesh which represents a small region of space. Elements are described in terms of a connected set of nodes which represent locations along their boundaries. *Field* data may be located on either the nodes or elements of a *Mesh*.

Refer to the Mesh Class of the ESMF Reference Manual for more information.

An unstructured *Mesh* can be created in two different ways, as a *Mesh* in memory, or from a SCRIP formatted or CF compliant UGRID file. The arguments for each type of *Mesh* creation are outlined below.

Created in-memory:

The in-memory *Mesh* can be created manually in 3 steps:

1. create the *Mesh* (specifying `parametric_dim` and `spatial_dim`),
2. add nodes,
3. add elements.

REQUIRED:

Parameters

- **parametric_dim** (*int*) – the dimension of the topology of the *Mesh* (e.g. a *Mesh* composed of squares would have a parametric dimension of 2 and a *Mesh* composed of cubes would have a parametric dimension of 3).
- **spatial_dim** (*int*) – the number of coordinate dimensions needed to describe the locations of the nodes making up the *Mesh*. For a manifold the spatial dimension can be larger than the parametric dimension (e.g. the 2D surface of a sphere in 3D space), but it cannot be smaller.

OPTIONAL:

Parameters

coord_sys (CoordSys) – Coordinate system for the *Mesh*. If None, defaults to *SPH_DEG*.

Created from file:

Note that *Meshes* created from file do not use the parametric_dim and spatial_dim parameters.

REQUIRED:

Parameters

- **filename** (*str*) – the name of NetCDF file containing the *Mesh*.
- **filetype** (FileFormat) – the input *FileFormat* of the *Mesh*.

OPTIONAL:

Parameters

- **convert_to_dual** (*bool*) – a boolean value to specify if the dual *Mesh* should be calculated. Defaults to False. This argument is only supported with *SCRIP*.
- **add_user_area** (*bool*) – a boolean value to specify if an area property should be added to the mesh. This argument is only supported for *SCRIP* or *ESMFMESH*. If None, defaults to False.
- **meshname** (*str*) – the name of the *Mesh* metadata variable in a UGRID file. This argument is only supported with *UGRID*. If None, defaults to the empty string.
- **mask_flag** (MeshLoc) – an enumerated integer that, if specified, tells whether a mask in a UGRID file should be defined on the Mesh. This argument is only supported with *UGRID*. If None, defaults to no masking.
- **varname** (*str*) – a variable name for the mask in a UGRID file if mask_flag is specified. This argument is only supported for *UGRID*. If None, defaults to the empty string.

property area

Return type
A two element list of numpy arrays to hold values for the nodes and elements of the *Mesh*.

Returns
The *Mesh* area represented as a numpy array of floats of the same number of entries as *Mesh* elements.

property coords

Return type
A two element list of numpy arrays to hold values for the nodes and elements of the *Mesh*.

Returns
The coordinates represented as a numpy array of floats with a value for each node and/or element of the *Mesh* `Mesh`.

property coord_sys

Return type
CoordSys

Returns
The coordinate system of the *Mesh*.

property mask

Return type
A two element list of numpy arrays to hold values for the nodes and elements of the *Mesh*.

Returns
The masked values on the nodes and elements of the *Mesh*.

property rank

Return type
int

Returns
The rank of the Mesh, (i.e. always 1).

property size

Return type
A two element list of integers.

Returns
The number of nodes and elements in the *Mesh* on the current processor.

property size_owned

Return type
A two element list of integers.

Returns
The number of owned nodes and elements in the *Mesh* on the current processor.

add_elements(*element_count*, *element_ids*, *element_types*, *element_conn*, *element_mask=None*, *element_area=None*, *element_coords=None*)

Add elements to a *Mesh*, this must be done after adding nodes.

REQUIRED:

Parameters

- **element_count** (*int*) – the number of elements to add to the *Mesh*.
- **element_ids** (*ndarray*) – a numpy array of of shape `(element_count, 1)` to specify the element ids.
- **element_types** (*ndarray*) – a numpy array of `MeshElemType`s of shape ``(element_count, 1)`` to specify the element types.
- **element_conn** (*ndarray*) – a numpy array of shape `sum(element_types[:], 1)` to specify the connectivity of the *Mesh*. The connectivity array is constructed by concatenating the tuples that correspond to the element_ids. The connectivity tuples are constructed by listing the node_ids of each element in **COUNTERCLOCKWISE** order.

OPTIONAL:

Parameters

- **element_mask** (*ndarray*) – a numpy array of shape `(element_count, 1)` containing integer values to specify masked elements. The specific values that are masked are specified in the *Regrid* constructor.
- **element_area** (*ndarray*) – a numpy array of shape `(element_count, 1)` to specify the areas of the elements.
- **element_coords** (*ndarray*) – a numpy array of shape `(element_count, 1)` to specify the coordinates of the elements.

add_nodes(*node_count*, *node_ids*, *node_coords*, *node_owners*)

Add nodes to a *Mesh*, this must be done before adding elements.

Parameters

- **node_count** (*int*) – the number of nodes to add to the *Mesh*.
- **node_ids** (*ndarray*) – a numpy array of shape (node_count, 1) to specify the node_ids.
- **node_coords** (*ndarray*) – a numpy array of shape (spatial_dim*node_count, 1) to specify the coordinates of the *Mesh*. The array should be constructed by concatenating the coordinate tuples into a numpy array that correspond to node_ids.
- **node_owners** (*ndarray*) – a numpy array of shape (node_count, 1) to specify the rank of the processor that owns each node.

copy()

Copy a *Mesh* in an ESMF-safe manner.

Returns

A *Mesh* shallow copy.

destroy()

Release the memory associated with a *Mesh*.

free_memory()

Free memory associated with the creation of a *Mesh* which is no longer needed for ongoing operations.

get_coords(*coord_dim*, *meshloc=<MeshLoc.NODE: 0>*)

Return a numpy array of coordinates at a specified *Mesh* location (coordinates can only be returned for the *Mesh NODE* at this time). The returned array is NOT a copy, it is directly aliased to the underlying memory allocated by esmpy.

REQUIRED:

Parameters

coord_dim (*int*) – the dimension number of the coordinates to return: e.g. `[x, y, z] = (0, 1, 2)`, or `[lat, lon] = (0, 1)`

OPTIONAL:

Parameters

meshloc (MeshLoc) – the *MeshLoc* of the coordinates. If `None`, defaults to *NODE*.

Returns

A numpy array of coordinate values at the specified *MeshLoc*.

6.1.5 LocStream

class esmpy.api.locstream.**LocStream**(*location_count*, *coord_sys=None*, *name=None*, *esmf=True*)

The *LocStream* class is a Python wrapper object for the ESMF LocStream. *LocStream* is a derived type of a Python dictionary.

The individual values of all key arrays are referenced to those of the underlying Fortran ESMF object.

A *LocStream* is used to represent the locations of a set of data points. The values of the data points are stored within a *Field* created using the *LocStream*.

In the data assimilation world, location streams can be thought of as a set of observations. Their locations are generally described using Cartesian `(x, y, z)`, or `(lat, lon, height)` coordinates. There is no assumption of any regularity in the positions of the points. To make the concept more general, the locations for each data point are represented using a construct called keys. Keys can include other descriptors besides location, including a second set of coordinates.

Refer to the LocStrea Class of the ESMF Reference Manual for more information.

LocStream follows standard dictionary syntax. For example:

```
>>> locstream["ESMF:X"] = [1, 2, 3]
>>> x = locstream["ESMF:X"]
>>> locstream["ESMF:Y"] = [1, 2, 3]
>>> y = locstream["ESMF:Y"]
>>> locstream["ESMF:Mask"] = [0, 1, 0]
>>> mask = locstream["ESMF:Mask"]
```

Note: Setting keys of lists of mixed types can result in errors due to type mismatches from the ESMF library.

Note: Mask must be of type *I4*, and coordinates must by of type *R8*.

For ESMF to be able to recognize coordinates specified in a *LocStream* key they need to be named with the appropriate identifiers. The particular identifiers depend on the coordinate system (i.e. `coord_sys` argument) used to create the *LocStream*.

The valid values are:

Parameters

- **location_count** (*int*) – The number of points in this stream.
- **coord_sys** (CoordSys) – Coordinate system for the location stream. If `None`, defaults to *SPH_DEG*.
- **name** (*str*) – Optional name for the location stream.
- **esmf** (*bool*) – Internal parameter controlling shallow copying by esmpy.

property lower_bounds

Return type
int

Returns
The lower bounds of the *LocStream*.

property name

Return type
str

Returns
The name of the *LocStream*.

property rank

Return type
int

Returns
The rank of the *LocStream*.

property size

Return type
int

Returns
The size of the *LocStream*.

property upper_bounds

Return type
int

Returns
The upper bounds of the *LocStream*.

copy()

Copy a *LocStream* in an ESMF-safe manner.

Returns
A *LocStream* shallow copy.

destroy()

Release the memory associated with a *LocStream*.

6.1.6 Regrid

class esmpy.api.regrid.**Regrid**(*srcfield=None*, *dstfield=None*, *filename=None*, *rh_filename=None*, *src_mask_values=None*, *dst_mask_values=None*, *regrid_method=None*, *pole_method=None*, *regrid_pole_npoints=None*, *line_type=None*, *norm_type=None*, *extrap_method=None*, *extrap_num_src_pnts=None*, *extrap_dist_exponent=None*, *extrap_num_levels=None*, *unmapped_action=None*, *ignore_degenerate=None*, *create_rh=None*, *filemode=None*, *src_file=None*, *dst_file=None*, *src_file_type=None*, *dst_file_type=None*, *factors=False*, *large_file=None*, *src_frac_field=None*, *dst_frac_field=None*)

The *Regrid* object represents a regridding operator between two *Fields*. The creation of this object is analogous to ESMF_FieldRegridStore(), and calling this object corresponds to ESMF_FieldRegrid(). ESMF_FieldRegridRelease() is called when the *Regrid* object goes out of scope (this only happens when the *Manager* goes out of scope, there is a destroy() call for explicit deallocation of the *Regrid*).

Refer to the ESMF_FieldRegrid methods in the ESMF Reference Manual for more information.

The following arguments are used to create a handle to a Regridding operation between two *Fields*.

REQUIRED:

Parameters

- **srcfield** (Field) – source *Field* associated with an underlying *Grid*, *Mesh* or *LocStream*.
- **dstfield** (Field) – destination *Field* associated with an underlying *Grid*, *Mesh* or *LocStream*. The data in this *Field* may be overwritten by this call.

OPTIONAL:

Parameters

- **filename** (*string*) – path to the output netCDF weight file.
- **rh_filename** (*string*) – path to the output RouteHandle file.
- **src_mask_values** (*ndarray*) – a numpy array of values that should be considered masked value on the source *Field*.
- **dst_mask_values** (*ndarray*) – a numpy array of values that should be considered masked value on the destination *Field*.
- **regrid_method** (RegridMethod) – specifies which *RegridMethod* to use. If None, defaults to *BILINEAR*.
- **pole_method** (PoleMethod) – specifies which type of artificial pole to construct on the source *Grid* for regridding. If None, defaults to: *NONE* for regridmethod == *CONSERVE*, or *ALLAVG* for regridmethod != *CONSERVE*.
- **regrid_pole_npoints** (*int*) – specifies how many points to average over if polemethod == *ALLAVG*.
- **line_type** (LineType) – select the path of the line that connects two points on the surface of a sphere. This in turn controls the path along which distances are calculated and the shape of the edges that make up a cell. If None, defaults to: *GREAT_CIRCLE* for regridmethod == *CONSERVE*, or *CART* for regridmethod != *CONSERVE*.
- **norm_type** (NormType) – control which type of normalization to do when generating conservative regridding weights. If None, defaults to *DSTAREA*.
- **extrap_method** (ExtrapMethod) – Specify which extrapolation method to use on unmapped destination points after regridding.
- **extrap_num_src_pnts** (*int*) – The number of source points to use for the extrapolation methods that use more than one source point (e.g. *NEAREST_IDAVG*). If not specified, defaults to 8.
- **extrap_dist_exponent** (*float*) – The exponent to raise the distance to when calculating weights for the *NEAREST_IDAVG* extrapolation method. A higher value reduces the influence of more distant points. If not specified, defaults to 2.0.
- **extrap_num_levels** (*int*) – The number of levels to output for the extrapolation methods that fill levels (e.g. CREEP). When a method is used that requires this, then an error will be returned if it is not specified.
- **unmapped_action** (UnmappedAction) – specifies which action to take if a destination point is found which does not map to any source point. If None, defaults to *ERROR*.
- **ignore_degenerate** (*bool*) – Ignore degenerate cells when checking the input *Grids* or *Meshes* for errors. If this is set to True, then the regridding proceeds, but degenerate cells

will be skipped. If set to False, a degenerate cell produces an error. This currently only applies to *CONSERVE*, other regrid methods currently always skip degenerate cells. If None, defaults to False.

- **src_frac_field** (*ndarray*) – return a numpy array of values containing weights corresponding to the amount of each *Field* value which contributes to the total mass of the *Field*.
- **dst_frac_field** (*ndarray*) – return a numpy array of values containing weights corresponding to the amount of each *Field* value which contributes to the total mass of the *Field*.
- **factors** (*bool*) – If True, return the factor and factor index list when calling into ESMF's regrid store method. These lists are converted to NumPy arrays and attached to the regrid object. The factor arrays are retrievable via get_factors() or get_weights_dict(). See the respective documentation on those methods for additional information. For more information on how ESMF treats factor retrieval see the ESMF_FieldRegridStore interface in the ESMF Reference Manual.
- **large_file** (*bool*) – If True, create the weight file in NetCDF using the 64-bit offset format to allow variables larger than 2GB. Note the 64-bit offset format is not supported in the NetCDF version earlier than 3.6.0. An error message will be generated if this flag is specified while the application is linked with a NetCDF library earlier than 3.6.0. Defaults to False.

__call__(*srcfield*, *dstfield*, *zero_region=None*)

Call a regridding operation from srcfield to dstfield.

REQUIRED:

Parameters

- **srcfield** (Field) – the *Field* of source data to regrid.
- **dstfield** (Field) – the *Field* to hold the regridded data.

OPTIONAL:

Parameters

zero_region (Region) – specify which region of the field indices will be zeroed out before adding the values resulting from the interpolation. If None, defaults to *TOTAL*.

Returns

dstfield

copy()

Copy a *Regrid* in an ESMF-safe manner.

Returns

A *Regrid* shallow copy.

destroy()

Release the memory associated with a *Regrid*.

get_factors(*deep_copy=False*)

Return factor and factor index arrays. These arrays will only be available if the Regrid object was initialized with factors=True. See the ESMF_FieldRegridStore interface in the ESMF Reference Manual for additional information on these arrays (see below for indexing in Python though).

```
>>> factors, factors_index = get_factors(...)
```

The first tuple element `factors` will have shape `(m,)` where `m` is the number of factors or weights. It will be `dtype(float64)`. The second tupe element `factors_index` will have shape `(m, 2)` where `m` is the number of factors or weights. The source/col indices are selected by `factors_index[:, 0]`. The destination/row indices are selected by `factors_index[:, 1]`. It will be `dtype(int32)`.

Note: If `deep_copy=True`, array memory is C contiguous according to NumPy array flags (`<array>.flags`).

Warning: Remember to call `destroy()` to deallocate memory associated with a regrid operation. This will be called by the Python garbage collector. However, if numerous regridding operations are called in a tight loop, a memory leak will occur without a call to `destroy`.

Parameters
deep_copy (*bool*) – If `True`, make deep copies of the returned arrays. If `False` (the default), the returned arrays will reference the underlying `ESMF` memory.

Returns
tuple of NumPy array objects

`get_weights_dict`(*deep_copy=False*)

Return a dictionary mapping that is more user-friendly for weight/factor retrieval. Please read the documentation for `get_factors()` before using this function.

Key	Value
`weights`	Weight value array
`row_dst`	Destination/row indices
`col_src`	Source/col indices

Note: If `deep_copy=True`, array memory is C contiguous according to NumPy array flags (`<array>.flags`).

Parameters
deep_copy (*bool*) – If `True`, make deep copies of the returned arrays. If `False` (the default), the returned arrays will reference the underlying `ESMF` memory.

Returns
dict

6.1.7 RegridFromFile

`class esmpy.api.regrid.RegridFromFile`(*srcfield*, *dstfield*, *filename=None*, *rh_filename=None*)

The *RegridFromFile* object represents a regridding operator between two *Fields* that is read from a file. The creation of this object is analogous to= ESMF_FieldSMMStore(), and calling this object corresponds to ESMF_FieldRegrid(). ESMF_FieldRegridRelease() is called when the *RegridFromFile* object goes out of scope (this only happens when the *Manager* goes out of scope, there is a destroy() call for explicit deallocation of the *RegridFromFile*).

For more information about the ESMF Regridding functionality, please see the ESMF_FieldRegrid methods in the ESMF Reference Manual.

The following arguments are used to create a handle to a regridding operation between two *Fields*.

REQUIRED:

Parameters

- **srcfield** (Field) – source *Field* associated with an underlying *Grid*, *Mesh* or *LocStream*.
- **dstfield** (Field) – destination *Field* associated with an underlying *Grid*, *Mesh* or *LocStream*. The data in this *Field* may be overwritten by this call.
- **filename** (*string*) – the name of the file from which to retrieve the weights.
- **rh_filename** (*string*) – the name of the file from which to retrieve the routehandle information.

__call__(*srcfield*, *dstfield*, *zero_region=None*)

Call a regridding operation from srcfield to dstfield.

REQUIRED:

Parameters

- **srcfield** (Field) – the *Field* of source data to regrid.
- **dstfield** (Field) – the *Field* to hold the regridded data.

OPTIONAL:

Parameters

zero_region (Region) – specify which region of the field indices will be zeroed out before adding the values resulting from the interpolation. If None, defaults to *TOTAL*.

Returns

dstfield

copy()

Copy a *Regrid* in an ESMF-safe manner.

Returns

A *Regrid* shallow copy.

destroy()

Release the memory associated with the *RegridFromFile* object.

6.2 Named Constants

6.2.1 CoordSys

class esmpy.api.constants.**CoordSys**(*value*, *names=None*, *module=None*, *type=None*, *start=1*)

This flag indicates the coordinate system of a *Grid*. This value is useful both to indicate to other users the type of the coordinates, but also to control how the coordinates are interpreted in regridding methods (e.g. *Regrid*).

CART = <CoordSys.CART: 0>

Cartesian coordinate system. In this system, the Cartesian coordinates are mapped to the *Grid* coordinate dimensions in the following order: x, y, z. (e.g. using coord_dim=1 in *get_coords()* references the y dimension)

SPH_DEG = <CoordSys.SPH_DEG: 1>

Spherical coordinates in degrees. In this system, the spherical coordinates are mapped to the *Grid* coordinate dimensions in the following order: longitude, latitude, radius. (E.g. using coord_dim=1 in `get_coords()` references the latitude dimension).

SPH_RAD = <CoordSys.SPH_RAD: 2>

Spherical coordinates in radians. In this system, the spherical coordinates are mapped to the *Grid* coordinate dimensions in the following order: longitude, latitude, radius. (E.g. using coord_dim=1 in *get_coords()* references the latitude dimension).

6.2.2 ExtrapMethod

class esmpy.api.constants.**ExtrapMethod**(*value*, *names=None*, *module=None*, *type=None*, *start=1*)

Specify which extrapolation method to use on unmapped destination points after regridding.

NONE = <ExtrapMethod.NONE: 0>

Indicates that no extrapolation should be done.

NEAREST_STOD = <ExtrapMethod.NEAREST_STOD: 1>

Nearest source to destination. Here each destination point is mapped to the closest source point. A given source point may go to multiple destination points, but no destination point will receive input from more than one source point.

NEAREST_IDAVG = <ExtrapMethod.NEAREST_IDAVG: 2>

Inverse distance weighted average. Here the value of a destination point is the weighted average of the closest N source points. The weight is the reciprocal of the distance of the source point from the destination point raised to a power P. All the weights contributing to one destination point are normalized so that they sum to 1.0. The user can choose N and P when using this method, but defaults are also provided.

CREEP_FILL = <ExtrapMethod.CREEP_FILL: 3>

Creep fill extrapolation. Here unmapped destination points are filled by repeatedly moving data from mapped locations to neighboring unmapped locations. The data filled into a new location is the average of its already filled neighbors' values. This process is repeated for a user specified number of levels (e.g. in Regrid() this is specified via the extrap_num_levels parameter). This extrapolation method is not supported with conservative regrid methods.

6.2.3 FileFormat

class esmpy.api.constants.**FileFormat**(*value*, *names=None*, *module=None*, *type=None*, *start=1*)

The *Grid* and *Mesh* objects may be created from specifications in a NetCDF data file. This flag indicates the format of the data file.

VTK = <FileFormat.VTK: 1>

Use the VTK file format.

SCRIP = <FileFormat.SCRIP: 2>

Use the *SCRIP* file format.

ESMFMESH = <FileFormat.ESMFMESH: 3>

Use the *ESMFMESH* unstructured grid file format.

ESMFGRID = <FileFormat.ESMFGRID: 4>

Use the ESMF structured grid file format.

UGRID = <FileFormat.UGRID: 5>

Use the *UGRID* unstructured grid file format.

GRIDSPEC = <FileFormat.GRIDSPEC: 6>

Use the *UGRID single tile grid file format based on CF V1.6 conventions (a.k.a GRIDSPEC)*.

6.2.4 FileMode

class esmpy.api.constants.**FileMode**(*value*, *names=None*, *module=None*, *type=None*, *start=1*)

Specify which mode to use when writing a weight file.

BASIC = <FileMode.BASIC: 0>

Indicates that only the factorList and factorIndexList should be written.

WITHAUX = <FileMode.WITHAUX: 1>

Indicates that grid center coordinates and cell areas should also be written.

6.2.5 GridItem

class esmpy.api.constants.**GridItem**(*value*, *names=None*, *module=None*, *type=None*, *start=1*)

The *Grid* can contain other kinds of data besides coordinates. This data is referred to as *Grid* "items". Some items may be used for calculations involving the *Grid*.

MASK = <GridItem.MASK: 0>

A grid item to represent a mask.

AREA = <GridItem.AREA: 1>

A grid item to represent an area field for conservative regridding.

6.2.6 LineType

class esmpy.api.constants.**LineType**(*value*, *names=None*, *module=None*, *type=None*, *start=1*)

This argument controls the path of the line which connects two points on the surface of the sphere. This in turn controls the path along which distances are calculated and the shape of the edges that make up a cell. Both of these quantities can influence how interpolation weights are calculated. As would be expected, this argument is only applicable with grids which lie on the surface of a sphere.

CART = <LineType.CART: 0>

Cartesian line. When this option is specified distances are calculated in a straight line through the 3D Cartesian space in which the sphere is embedded. Cells are approximated by 3D planes bounded by 3D Cartesian lines between their corner vertices. When calculating regrid weights, this line type is currently the default for the following all regrid methods except for conservative.

GREAT_CIRCLE = <LineType.GREAT_CIRCLE: 1>

Great circle line. When this option is specified distances are calculated along a great circle path (the shortest distance between two points on a sphere surface). Cells are bounded by great circle paths between their corner vertices. When calculating regrid weights, this line type is currently the default for the conservative regrid method.

6.2.7 LogKind

class esmpy.api.constants.**LogKind**(*value*, *names=None*, *module=None*, *type=None*, *start=1*)

This flag is used to specify how much logging should be done.

MULTI = <LogKind.MULTI: 2>

Use multiple log files – one per PET.

NONE = <LogKind.NONE: 3>

Do not issue messages to a log file.

6.2.8 MeshElemType

class esmpy.api.constants.**MeshElemType**(*value*, *names=None*, *module=None*, *type=None*, *start=1*)

A *Mesh* can be constructed from a combination of different elements. The type of elements that can be used in a *Mesh* depends on the parametric dimension of the *Mesh*, which is set during *Mesh* creation. The following are the valid *Mesh* element types for each valid *Mesh* parametric dimension (2D or 3D).

TRI = <MeshElemType.TRI: 3>

2D triangular elements with 3 sides.

QUAD = <MeshElemType.QUAD: 4>

2D quadrilateral elements with 4 sides.

TETRA = <MeshElemType.TETRA: 10>

3D tetrahedral elements with 4 faces.

HEX = <MeshElemType.HEX: 12>

3D hexahedral elements with 6 faces.

6.2.9 MeshLoc

class esmpy.api.constants.**MeshLoc**(*value*, *names=None*, *module=None*, *type=None*, *start=1*)

The *Mesh* location used to hold *Field* data.

NODE = <MeshLoc.NODE: 0>

The nodes of the *Mesh*.

ELEMENT = <MeshLoc.ELEMENT: 1>

The elements of the *Mesh*.

6.2.10 NormType

class esmpy.api.constants.**NormType**(*value*, *names=None*, *module=None*, *type=None*, *start=1*)

When doing conservative regridding, this option allows the user to select the type of normalization used when producing the weights.

DSTAREA = <NormType.DSTAREA: 0>

Destination area normalization. Here the weights are calculated by dividing the area of overlap of the source and destination cells by the area of the entire destination cell. In other words, the weight is the fraction of the entire destination cell which overlaps with the given source cell.

FRACAREA = <NormType.FRACAREA: 1>

Fraction area normalization. Here in addition to the weight calculation done for destination area normalization the weights are also divided by the fraction that the destination cell overlaps with the entire source grid. In other words, the weight is the fraction of just the part of the destination cell that overlaps with the entire source mesh.

6.2.11 PoleKind

class esmpy.api.constants.**PoleKind**(*value*, *names=None*, *module=None*, *type=None*, *start=1*)

This type describes the type of connection that occurs at the pole of a *Grid*.

NONE = <PoleKind.NONE: 0>

No connection at pole.

MONOPOLE = <PoleKind.MONOPOLE: 1>

This edge is connected to itself. Given that the edge is n elements long, then element i is connected to element i+n/2.

BIPOLE = <PoleKind.BIPOLE: 2>

This edge is connected to itself. Given that the edge is n elements long, element i is connected to element n-i-1.

6.2.12 PoleMethod

class esmpy.api.constants.**PoleMethod**(*value*, *names=None*, *module=None*, *type=None*, *start=1*)

Indicates which type of artificial pole to construct on the source *Grid* for regridding.

NONE = <PoleMethod.NONE: 0>

No pole. Destination points which lie above the top or below the bottom row of the source *Grid* won't be mapped.

ALLAVG = <PoleMethod.ALLAVG: 1>

Construct an artificial pole placed in the center of the top (or bottom) row of nodes, but projected onto the sphere formed by the rest of the grid. The value at this pole is the average of all the source values surrounding the pole.

NPNTAVG = <PoleMethod.NPNTAVG: 2>

Construct an artificial pole placed in the center of the top (or bottom) row of nodes, but projected onto the sphere formed by the rest of the grid. The value at this pole is the average of the N source nodes next to the pole and surrounding the destination point (i.e. the value may differ for each destination point). Here N is set by using the regridPoleNPnts parameter and ranges from 1 to the number of nodes around the pole. This option is useful for interpolating values which may be zeroed out by averaging around the entire pole (e.g. vector components).

TEETH = <PoleMethod.TEETH: 3>

No new pole point is constructed, instead the holes at the poles are filled by constructing triangles across the top and bottom row of the source *Grid*. This can be useful because no averaging occurs, however, because the top and bottom of the sphere are now flat, for a big enough mismatch between the size of the destination and source pole holes, some destination points may still not be able to be mapped to the source *Grid*.

6.2.13 Region

class esmpy.api.constants.**Region**(*value*, *names=None*, *module=None*, *type=None*, *start=1*)

Specify various regions in the data layout of a *Field* object.

TOTAL = <Region.TOTAL: 0>

An operation applies to every element in the selected domain.

SELECT = <Region.SELECT: 1>

An operation applies to a select portion of the domain. One use of this is to specify that the portions of a *Field* that are not mapped in a regridding operation should retain their original value (as opposed to being initialized to 0).

EMPTY = <Region.EMPTY: 2>

An operation does not apply any element in the domain.

6.2.14 RegridMethod

class esmpy.api.constants.**RegridMethod**(*value*, *names=None*, *module=None*, *type=None*, *start=1*)

Specify which interpolation method to use during regridding.

BILINEAR = <RegridMethod.BILINEAR: 0>

Bilinear interpolation. Destination value is a linear combination of the source values in the cell which contains the destination point. The weights for the linear combination are based on the distance of destination point from each source value.

PATCH = <RegridMethod.PATCH: 1>

Higher-order patch recovery interpolation. Destination value is a weighted average of 2D polynomial patches constructed from cells surrounding the source cell which contains the destination point. This method typically results in better approximations to values and derivatives than bilinear. However, because of its larger stencil, it also results in a much larger interpolation matrix (and thus routeHandle) than the bilinear.

CONSERVE = <RegridMethod.CONSERVE: 2>

First-order conservative interpolation. The main purpose of this method is to preserve the integral of the field across the interpolation from source to destination. In this method the value across each source cell is treated as a constant, so it will typically have a larger interpolation error than the bilinear or patch methods. The value of a destination cell is calculated as the weighted sum of the values of the source cells that it overlaps. The weights are determined by the amount the source cell overlaps the destination cell. This method requires corner coordinate values to be provided in the *Grid*. It currently only works for `Fields <esmpy.api.field.Field>`s created on the :class:`~esmpy.api.grid.Grid` center stagger or the *Mesh* element location.

NEAREST_STOD = <RegridMethod.NEAREST_STOD: 3>

In this version of nearest neighbor interpolation each destination point is mapped to the closest source point. A given source point may go to multiple destination points, but no destination point will receive input from more than one source point.

NEAREST_DTOS = <RegridMethod.NEAREST_DTOS: 4>

In this version of nearest neighbor interpolation each source point is mapped to the closest destination point. A given destination point may receive input from multiple source points, but no source point will go to more than one destination point.

CONSERVE_2ND = <RegridMethod.CONSERVE_2ND: 5>

Second-order conservative interpolation. This method's main purpose is to preserve the integral of the field across the interpolation from source to destination. The difference between the first and second-order conservative methods is that the second-order takes the source gradient into account, so it yields a smoother destination field that typically better matches the source field. This difference between the first and second-order methods is particularly apparent when going from a coarse source grid to a finer destination grid. Another difference is that the second-order method does not guarantee that after regridding the range of values in the destination field is within the range of values in the source field. For example, if the mininum value in the source field is 0.0, then it's possible that after regridding with the second-order method, the destination field will contain values less than 0.0. This method requires corner coordinate values to be provided in the *Grid*. It currently only works for `Fields <esmpy.api.field.Field>`s created on the :class:`~esmpy.api.grid.Grid` center stagger or the *Mesh* element location.

6.2.15 StaggerLoc

class esmpy.api.constants.**StaggerLoc**(*value*, *names=None*, *module=None*, *type=None*, *start=1*)

In the *Grid* class, data can be located at different positions in a *Grid* cell. When setting or retrieving coordinate data the stagger location is specified to tell the *Grid* method from where in the cell to get the data.

CENTER = <StaggerLoc.CENTER: 0>

2D: Cell centered stagger location.

EDGE1 = <StaggerLoc.EDGE1: 1>

2D: First dimension edge stagger location.

EDGE2 = <StaggerLoc.EDGE2: 2>

2D: Second dimension edge stagger location.

CORNER = <StaggerLoc.CORNER: 3>

2D: Cell corner stagger location.

CENTER_VCENTER = <StaggerLoc.CENTER: 0>

3D: Vertically centered stagger location.

EDGE1_VCENTER = <StaggerLoc.EDGE1: 1>

3D: Vertically centered first dimension edge stagger location.

EDGE2_VCENTER = <StaggerLoc.EDGE2: 2>

3D: Vertically centered second dimension edge stagger location.

CORNER_VCENTER = <StaggerLoc.CORNER: 3>

3D: Vertically centered corner stagger location.

CENTER_VFACE = <StaggerLoc.CENTER_VFACE: 4>

3D: Centered stagger location of the top and bottom cell faces.

EDGE1_VFACE = <StaggerLoc.EDGE1_VFACE: 5>

3D: First dimension edge stagger location of the top and bottom cell faces.

EDGE2_VFACE = <StaggerLoc.EDGE2_VFACE: 6>

3D: Second dimension edge stagger location of the top and bottom cell faces.

CORNER_VFACE = <StaggerLoc.CORNER_VFACE: 7>

3D: Corner stagger location of the top and bottom cell faces.

6.2.16 TypeKind

class esmpy.api.constants.**TypeKind**(*value*, *names=None*, *module=None*, *type=None*, *start=1*)

This is used to indicate the type and kind of ESMPy types to the underlying ESMF library routines.

I4 = <TypeKind.I4: 3>

A four byte integer, equivalent to numpy.int32.

I8 = <TypeKind.I8: 4>

An eight byte integer, equivalent to numpy.int64.

R4 = <TypeKind.R4: 5>

A four byte real, equivalent to numpy.float32.

R8 = <TypeKind.R8: 6>

An eight byte real, equivalent to numpy.float64.

6.2.17 UnmappedAction

class esmpy.api.constants.**UnmappedAction**(*value*, *names=None*, *module=None*, *type=None*, *start=1*)

This is used to indicate what action to take with respect to unmapped destination points and the entries of the sparse matrix that correspond to these points.

ERROR = <UnmappedAction.ERROR: 0>

Unmapped points result in an error code return.

IGNORE = <UnmappedAction.IGNORE: 1>

Unmapped points are ignored.

6.3 References

- genindex
- modindex
- search

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PYTHON MODULE INDEX

e
esmpy, 3

INDEX

Symbols

__call__() (*esmpy.api.regrid.Regrid method*), 67
__call__() (*esmpy.api.regrid.RegridFromFile method*), 69

A

add_coords() (*esmpy.api.grid.Grid method*), 59
add_elements() (*esmpy.api.mesh.Mesh method*), 62
add_item() (*esmpy.api.grid.Grid method*), 59
add_nodes() (*esmpy.api.mesh.Mesh method*), 63
ALLAVG (*esmpy.api.constants.PoleMethod attribute*), 73
AREA (*esmpy.api.constants.GridItem attribute*), 71
area (*esmpy.api.grid.Grid property*), 56
area (*esmpy.api.mesh.Mesh property*), 61
areatype (*esmpy.api.grid.Grid property*), 56

B

barrier() (*esmpy.api.esmpymanager.Manager method*), 52
BASIC (*esmpy.api.constants.FileMode attribute*), 71
BILINEAR (*esmpy.api.constants.RegridMethod attribute*), 74
BIPOLE (*esmpy.api.constants.PoleKind attribute*), 73

C

CART (*esmpy.api.constants.CoordSys attribute*), 69
CART (*esmpy.api.constants.LineType attribute*), 71
CENTER (*esmpy.api.constants.StaggerLoc attribute*), 75
CENTER_VCENTER (*esmpy.api.constants.StaggerLoc attribute*), 75
CENTER_VFACE (*esmpy.api.constants.StaggerLoc attribute*), 75
CONSERVE (*esmpy.api.constants.RegridMethod attribute*), 74
CONSERVE_2ND (*esmpy.api.constants.RegridMethod attribute*), 74
coord_sys (*esmpy.api.grid.Grid property*), 57
coord_sys (*esmpy.api.mesh.Mesh property*), 62
coords (*esmpy.api.grid.Grid property*), 57
coords (*esmpy.api.mesh.Mesh property*), 61
CoordSys (*class in esmpy.api.constants*), 69
copy() (*esmpy.api.field.Field method*), 54
copy() (*esmpy.api.grid.Grid method*), 59
copy() (*esmpy.api.locstream.LocStream method*), 65
copy() (*esmpy.api.mesh.Mesh method*), 63
copy() (*esmpy.api.regrid.Regrid method*), 67
copy() (*esmpy.api.regrid.RegridFromFile method*), 69
CORNER (*esmpy.api.constants.StaggerLoc attribute*), 75
CORNER_VCENTER (*esmpy.api.constants.StaggerLoc attribute*), 75
CORNER_VFACE (*esmpy.api.constants.StaggerLoc attribute*), 75
CREEP_FILL (*esmpy.api.constants.ExtrapMethod attribute*), 70

D

data (*esmpy.api.field.Field property*), 53
destroy() (*esmpy.api.field.Field method*), 54
destroy() (*esmpy.api.grid.Grid method*), 59
destroy() (*esmpy.api.locstream.LocStream method*), 65
destroy() (*esmpy.api.mesh.Mesh method*), 63
destroy() (*esmpy.api.regrid.Regrid method*), 67
destroy() (*esmpy.api.regrid.RegridFromFile method*), 69
DSTAREA (*esmpy.api.constants.NormType attribute*), 72

E

EDGE1 (*esmpy.api.constants.StaggerLoc attribute*), 75
EDGE1_VCENTER (*esmpy.api.constants.StaggerLoc attribute*), 75
EDGE1_VFACE (*esmpy.api.constants.StaggerLoc attribute*), 75
EDGE2 (*esmpy.api.constants.StaggerLoc attribute*), 75
EDGE2_VCENTER (*esmpy.api.constants.StaggerLoc attribute*), 75
EDGE2_VFACE (*esmpy.api.constants.StaggerLoc attribute*), 75
ELEMENT (*esmpy.api.constants.MeshLoc attribute*), 72
EMPTY (*esmpy.api.constants.Region attribute*), 74
ERROR (*esmpy.api.constants.UnmappedAction attribute*), 76
ESMFGRID (*esmpy.api.constants.FileFormat attribute*), 70
ESMFMESH (*esmpy.api.constants.FileFormat attribute*), 70
esmpy

module, 3
ExtrapMethod (*class in esmpy.api.constants*), 70

F

Field (*class in esmpy.api.field*), 52
FileFormat (*class in esmpy.api.constants*), 70
FileMode (*class in esmpy.api.constants*), 71
FRACAREA (*esmpy.api.constants.NormType attribute*), 72
free_memory() (*esmpy.api.mesh.Mesh method*), 63

G

get_area() (*esmpy.api.field.Field method*), 54
get_coords() (*esmpy.api.grid.Grid method*), 59
get_coords() (*esmpy.api.mesh.Mesh method*), 63
get_factors() (*esmpy.api.regrid.Regrid method*), 67
get_item() (*esmpy.api.grid.Grid method*), 60
get_weights_dict() (*esmpy.api.regrid.Regrid method*), 68
GREAT_CIRCLE (*esmpy.api.constants.LineType attribute*), 71
Grid (*class in esmpy.api.grid*), 55
grid (*esmpy.api.field.Field property*), 53
GridItem (*class in esmpy.api.constants*), 71
GRIDSPEC (*esmpy.api.constants.FileFormat attribute*), 71

H

has_corners (*esmpy.api.grid.Grid property*), 57
HEX (*esmpy.api.constants.MeshElemType attribute*), 72

I

I4 (*esmpy.api.constants.TypeKind attribute*), 76
I8 (*esmpy.api.constants.TypeKind attribute*), 76
IGNORE (*esmpy.api.constants.UnmappedAction attribute*), 76

L

LineType (*class in esmpy.api.constants*), 71
local_pet (*esmpy.api.esmpymanager.Manager property*), 51
LocStream (*class in esmpy.api.locstream*), 64
LogKind (*class in esmpy.api.constants*), 72
lower_bounds (*esmpy.api.field.Field property*), 53
lower_bounds (*esmpy.api.grid.Grid property*), 57
lower_bounds (*esmpy.api.locstream.LocStream property*), 64

M

Manager (*class in esmpy.api.esmpymanager*), 51
MASK (*esmpy.api.constants.GridItem attribute*), 71
mask (*esmpy.api.grid.Grid property*), 57
mask (*esmpy.api.mesh.Mesh property*), 62
max_index (*esmpy.api.grid.Grid property*), 57
Mesh (*class in esmpy.api.mesh*), 60
MeshElemType (*class in esmpy.api.constants*), 72
MeshLoc (*class in esmpy.api.constants*), 72
moab (*esmpy.api.esmpymanager.Manager property*), 51
module
    esmpy, 3
MONOPOLE (*esmpy.api.constants.PoleKind attribute*), 73
MULTI (*esmpy.api.constants.LogKind attribute*), 72

N

name (*esmpy.api.field.Field property*), 53
name (*esmpy.api.locstream.LocStream property*), 64
ndbounds (*esmpy.api.field.Field property*), 53
NEAREST_DTOS (*esmpy.api.constants.RegridMethod attribute*), 74
NEAREST_IDAVG (*esmpy.api.constants.ExtrapMethod attribute*), 70
NEAREST_STOD (*esmpy.api.constants.ExtrapMethod attribute*), 70
NEAREST_STOD (*esmpy.api.constants.RegridMethod attribute*), 74
NODE (*esmpy.api.constants.MeshLoc attribute*), 72
NONE (*esmpy.api.constants.ExtrapMethod attribute*), 70
NONE (*esmpy.api.constants.LogKind attribute*), 72
NONE (*esmpy.api.constants.PoleKind attribute*), 73
NONE (*esmpy.api.constants.PoleMethod attribute*), 73
NormType (*class in esmpy.api.constants*), 72
NPNTAVG (*esmpy.api.constants.PoleMethod attribute*), 73
num_peri_dims (*esmpy.api.grid.Grid property*), 57

P

PATCH (*esmpy.api.constants.RegridMethod attribute*), 74
periodic_dim (*esmpy.api.grid.Grid property*), 58
pet_count (*esmpy.api.esmpymanager.Manager property*), 52
pole_dim (*esmpy.api.grid.Grid property*), 58
PoleKind (*class in esmpy.api.constants*), 73
PoleMethod (*class in esmpy.api.constants*), 73

Q

QUAD (*esmpy.api.constants.MeshElemType attribute*), 72

R

R4 (*esmpy.api.constants.TypeKind attribute*), 76
R8 (*esmpy.api.constants.TypeKind attribute*), 76
rank (*esmpy.api.field.Field property*), 53
rank (*esmpy.api.grid.Grid property*), 58
rank (*esmpy.api.locstream.LocStream property*), 65
rank (*esmpy.api.mesh.Mesh property*), 62
read() (*esmpy.api.field.Field method*), 54
Region (*class in esmpy.api.constants*), 74
Regrid (*class in esmpy.api.regrid*), 65
RegridFromFile (*class in esmpy.api.regrid*), 68
RegridMethod (*class in esmpy.api.constants*), 74

S

SCRIP (*esmpy.api.constants.FileFormat attribute*), 70
SELECT (*esmpy.api.constants.Region attribute*), 74
set_moab() (*esmpy.api.esmpymanager.Manager method*), 52
size (*esmpy.api.grid.Grid property*), 58
size (*esmpy.api.locstream.LocStream property*), 65
size (*esmpy.api.mesh.Mesh property*), 62
size_owned (*esmpy.api.mesh.Mesh property*), 62
SPH_DEG (*esmpy.api.constants.CoordSys attribute*), 69
SPH_RAD (*esmpy.api.constants.CoordSys attribute*), 70
StaggerLoc (*class in esmpy.api.constants*), 75
staggerloc (*esmpy.api.field.Field property*), 53
staggerloc (*esmpy.api.grid.Grid property*), 58

T

TEETH (*esmpy.api.constants.PoleMethod attribute*), 73
TETRA (*esmpy.api.constants.MeshElemType attribute*), 72
TOTAL (*esmpy.api.constants.Region attribute*), 74
TRI (*esmpy.api.constants.MeshElemType attribute*), 72
type (*esmpy.api.field.Field property*), 53
type (*esmpy.api.grid.Grid property*), 58
TypeKind (*class in esmpy.api.constants*), 76

U

UGRID (*esmpy.api.constants.FileFormat attribute*), 70
UnmappedAction (*class in esmpy.api.constants*), 76
upper_bounds (*esmpy.api.field.Field property*), 54
upper_bounds (*esmpy.api.grid.Grid property*), 58
upper_bounds (*esmpy.api.locstream.LocStream property*), 65

V

VTK (*esmpy.api.constants.FileFormat attribute*), 70

W

WITHAUX (*esmpy.api.constants.FileMode attribute*), 71

X

xd (*esmpy.api.field.Field property*), 54