Definition of MetUM Vectorial Diagnostics on a Rotated Grid

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Contents

Vectorial STASH diagnostics

There are several pairs of diagnostics in the MetUM which are the x- and y-components of a vector. A few are shown here (see appendix for a more extensive list):

- `(0, 2) U COMPNT OF WIND AFTER TIMESTEP`
- `(0, 3) V COMPNT OF WIND AFTER TIMESTEP`

- `(3, 209) 10 METRE WIND U-COMP`
- `(3, 210) 10 METRE WIND V-COMP`

- `(3, 225) 10 METRE WIND U-COMP B GRID`
- `(3, 226) 10 METRE WIND V-COMP B GRID`

- `(3, 460) X-COMP SURFACE BL STRESS`
- `(3, 461) Y-COMP SURFACE BL STRESS`

- `(3, 560) X-COMP OF BL WIND STRESS ON P GRID`
- `(3, 561) Y-COMP OF BL WIND STRESS ON P GRID`

- `(15, 2) U WIND ON MODEL LEVELS B GRID`
- `(15, 3) V WIND ON MODEL LEVELS B GRID`

- `(15, 201) U WIND ON PRESSURE LEVELS B GRID`
- `(15, 202) V WIND ON PRESSURE LEVELS B GRID`

- `(15, 212) 50 METRE WIND U-COMPONENT B GRID`
- `(15, 213) 50 METRE WIND V-COMPONENT B GRID`

- `(15, 243) U WIND ON PRESSURE LEVELS`
- `(15, 244) V WIND ON PRESSURE LEVELS`

- `(15, 245) 50 METRE WIND U-COMPONENT`
- `(15, 246) 50 METRE WIND V-COMPONENT`

- `(30, 1) U COMPNT OF WIND RHO GRID`
- `(30, 2) V COMPNT OF WIND RHO GRID`

- `(30, 201) U COMPNT OF WIND ON P LEV/UV GRID`
- `(30, 202) V COMPNT OF WIND ON P LEV/UV GRID`

Definition of components

On a normal grid, where the `grid_latitude` and `grid_longitude` coordinates are true latitude and longitude, these are always the eastward (x or u) and northward (y or v) components. However, if we run the model on a rotated grid, we need to be careful about whether the components are relative to `grid_latitude` and `grid_longitude` or true latitude and longitude.

Unfortunately, there seems to be nothing in the diagnostic metadata to tell us, so we have to consult the `STASHmaster_A` file. In the trunk of the MetUM, this can be found in `rose-meta/um-atmos/HEAD/etc/stash/STASHmaster`.

Each STASH item has 5 lines of information:

```
#|Model |Sectn | Item |Name |
#|Space |Point | Time | Grid |LevelT|LevelF|LevelL|PseudT|PseudF|PseudL|LevCom|
#| Option Codes | Version Mask | Halo |
#|DataT |DumpP | PC1 PC2 PC3 PC4 PC5 PC6 PC7 PC8 PC9 PCA |
#|Rotate| PPF | USER | LBVC | BLEV | TLEV |RBLEVV| CFLL | CFFF |
```

The crucial piece of information is "`Rotate`" at the start of line 5:

- `Rotate=0`: Defined relative to **model's own grid**
- `Rotate=1`: Defined relative to **true latitude and longitude**

For example:

```
1| 1 | 0 | 2 |U COMPNT OF WIND AFTER TIMESTEP |
2| 2 | 0 | 1 | 18 | 1 | 1 | 2 | 0 | 0 | 0 | 0 |
3| 000000000000000000000000000000 | 00000000000000000001 | 1 |
4| 1 | 2 | -3 -3 -3 -3 -12 20 -3 -99 -99 -99 |
5| 0 | 56 | 0 | 65 | 0 | 0 | 0 | 0 | 5 |
#
1| 1 | 15 | 201 |U WIND ON PRESSURE LEVELS B GRID |
2| 0 | 0 | 1 | 11 | 3 | 1 | 2 | 0 | 0 | 0 | 1 |
3| 000000000000000000000000000000 | 00000000000000000001 | 3 |
4| 1 | 2 | -3 -3 -3 -3 -12 19 -3 -99 -99 -99 |
5| 1 | 56 | 0 | 8 | 0 | 0 | 0 | 0 | 5 |
```

Here, we see that STASH item `(0, 2)` is the grid-relative x-component of the wind, but `(15, 201)` is the true eastward wind.

In fact, it turns out there are only three diagnostics (as of version 12.0 of the MetUM) with `Rotate=1`:

- `(15, 201) U WIND ON PRESSURE LEVELS B GRID`
- `(15, 202) V WIND ON PRESSURE LEVELS B GRID`
- `(15, 229) POTENTIAL VORTICITY ON PRESSURE LEVS`

Everything else is defined relative to the model grid.

Plotting

This section assumes we are using Python, Matplotlib and Cartopy for plotting, and Iris for reading in the model ouput. Via `iris.plot`, Iris provides wrappers to Matplotlib which automatically obtain the necessary grid information from an Iris `Cube`. Here is a simple example:

```
import matplotlib.pyplot as plt
import iris
import iris.plot as iplt
import cartopy.crs as ccrs

u = iris.load_cube('/path/to/file.nc', 'u')
v = iris.load_cube('/path/to/file.nc', 'v')

ax = plt.subplot(111, projection=ccrs.PlateCarree())
iplt.quiver(u, v)
plt.show()
```

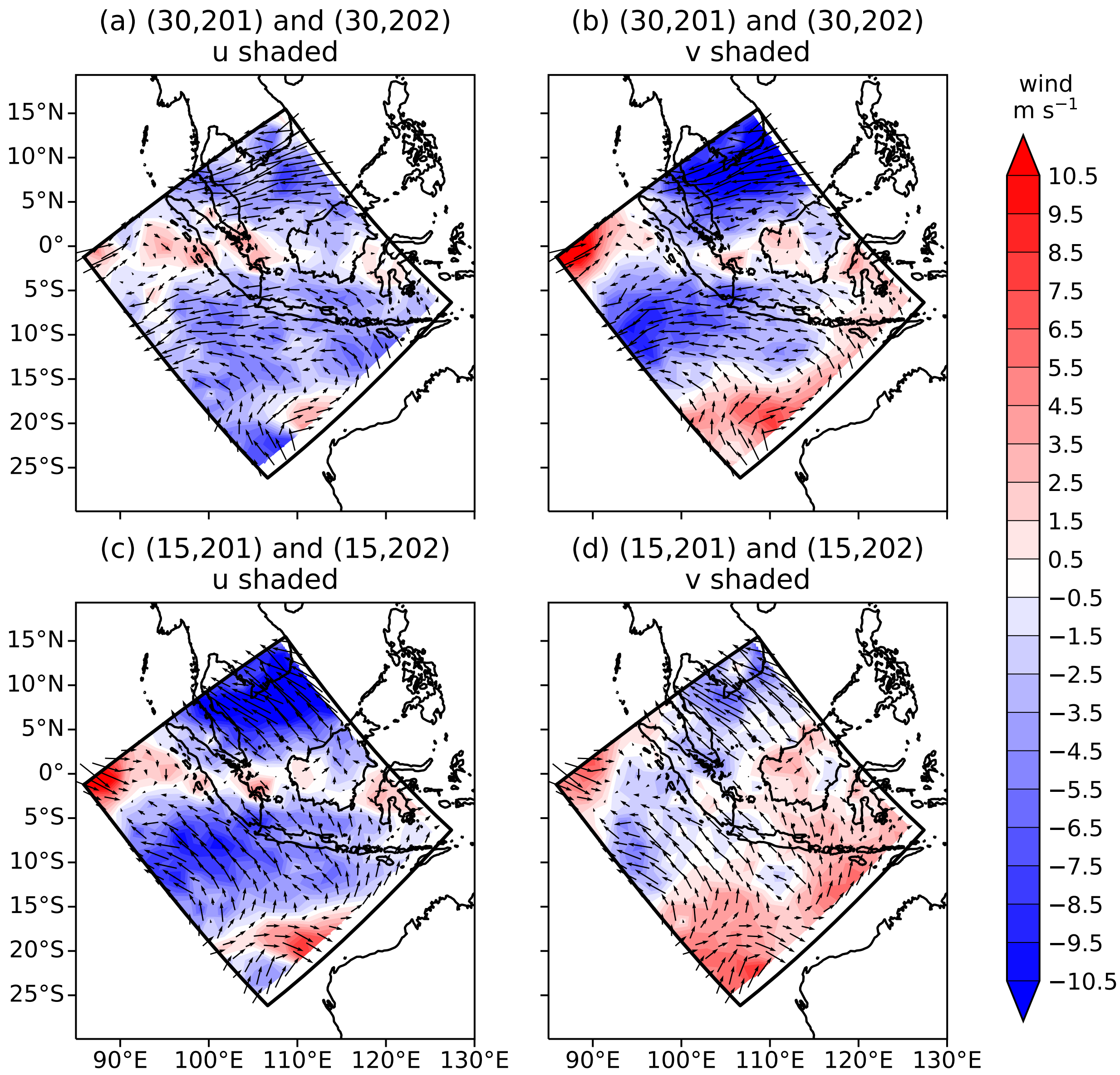

Figure 1: Wind diagnostics for a forecast on a rotated grid, plotted with a Plate Carrée projection. (a,b) Diagnostic with `Rotate=0`, **correctly** plotted; (c,d) equivalent diagnostic with `Rotate=1`, **incorrectly** plotted. The u component is shaded in (a) and (c), and the v component is shaded in (b) and (d).

Figure 1 is an example of `(30, 201)` and `(30, 202)` (pressure level winds with `Rotate=0`, defined relative to the model grid), and `(15, 201)` and `(15, 202)` (pressure level winds with `Rotate=1`, defined relative to true latitude and longitude), taken from the same time and level in the same model run. By comparison with ERA5 (not shown) it is confirmed that the vectors in (a) and (b) appear correctly, but the vectors in (c) and (d) are plotted incorrectly. In both cases, the shading of u and v correctly corresponds to the vectors as plotted, relative to the rotated grid (i.e., you need to tilt your head $\sim 45°$ to the right for the shading to make sense).

The data will have `grid_latitude` and `grid_longitude` dimension coordinates. There may also be 2D `latitude` and `longitude` auxiliary coordinates, which are the true latitude and longitude values, although these are ignored by `iris.plot`:

```
>>> print(u_30_201)
x_wind / (m s-1)                    (grid_latitude: 701; grid_longitude: 800)
    Dimension coordinates:
        grid_latitude                             x                     -
        grid_longitude                            -                     x
    Auxiliary coordinates:
        latitude                                  x                     x
        longitude                                 x                     x
```

Instead, `iris.plot` takes the `coord_system` from the dimension coordinates:

```
>>> u_30_201.coord('grid_latitude').coord_system
RotatedGeogCS(37.5, 177.5)
>>> str(u_30_201.coord('grid_latitude').coord_system.as_cartopy_crs())
'+proj=ob_tran +datum=WGS84 +ellps=WGS84 +o_proj=latlon +o_lon_p=0.0 +o_lat_p=37.5 +lon_0=357.5
+to_meter=111319.4907932736 +no_defs +type=crs'
```

This information is passed to Cartopy so that the shape and location of the grid is drawn correctly. However, the vector components need to be rotated as well and, as we have seen, this is handled correctly for `Rotate=0` but not `Rotate=1`. It is counter-intuitive that the `Rotate=1` diagnostics should be plotted incorrectly, because they are the ones defined relative to true latitude and longitude. Presumably this is because Iris and Cartopy have no way of knowing this, so the data are assumed to be defined relative to their own grid.

Hence, for `Rotate=1` we would need to rotate the winds before plotting. In principle this can be done using `cartopy.crs.CRS.transform_vectors()` (but getting it to work is fiddly!). The simpler solution is to avoid `(15, 201)` and `(15, 202)` altogether.

More vectorial diagnostics

This is a more complete list than was given earlier, but still may not be exhaustive.

- `(0, 176) X-COMP SURF & BL WIND STR: CPL N/M2`
- `(0, 177) Y-COMP SURF & BL WIND STRL CPL N/M2`
- `(0, 5) OROGRAPHIC GRADIENT X COMPONENT`
- `(0, 6) OROGRAPHIC GRADIENT Y COMPONENT`
- `(0, 176) X-COMP SURF & BL WIND STR: CPL N/M2`
- `(0, 177) Y-COMP SURF & BL WIND STRL CPL N/M2`
- `(0, 202) U COMPNT PERTURBATION- DUMMY (ret)`
- `(0, 203) V COMPNT PERTURBATION- DUMMY (ret)`
- `(0, 256) ADVECTED U CMPT OF WIND AFTER TS`
- `(0, 257) ADVECTED V CMPT OF WIND AFTER TS`
- `(0, 515) WAVE WIND U-COMP: CPL`
- `(0, 516) WAVE WIND V-COMP: CPL`
- `(3, 2) U COMPNT OF WIND AFTER B.LAYER(retd)`
- `(3, 3) V COMPNT OF WIND AFTER B.LYR (retd)`
- `(3, 185) U WIND INCR: bdy layer`
- `(3, 186) V WIND INCR: bdy layer`
- `(3, 195) U WIND INCR: Leonard term`
- `(3, 196) V WIND INCR: Leonard term`
- `(3, 219) X-COMP OF SURF & BL WIND STRESS N/M2`
- `(3, 220) Y-COMP OF SURF & BL WIND STRESS N/M2`
- `(3, 365) 10 METRE NEUTRAL WIND U-COMP B GRID`
- `(3, 366) 10 METRE NEUTRAL WIND V-COMP B GRID`
- `(3, 368) 10 METRE NEUTRAL WIND U-COMP`
- `(3, 369) 10 METRE NEUTRAL WIND V-COMP`
- `(3, 370) X-COMP OF SURF PSEUDOSTRESS M2.S-2`
- `(3, 371) Y-COMP OF SURF PSEUDOSTRESS M2.S-2`
- `(3, 391) X-COMP OF LAND SURF WIND STRESS N/M2`
- `(3, 392) X-COMP OF MEAN SEA SURF STRESS N/M2`
- `(3, 393) Y-COMP OF LAND SURF WIND STRESS N/M2`
- `(3, 394) Y-COMP OF MEAN SEA SURF STRESS N/M2`
- `(3, 474) X-COMP OF DIST OROG STRESS ON P GRID`
- `(3, 475) Y-COMP OF DIST OROG STRESS ON P GRID`
- `(3, 553) LEONARD TERM VERTICAL FLUX U WIND`
- `(3, 554) LEONARD TERM VERTICAL FLUX V WIND`
- `(5, 185) U WIND INCR: convection`
- `(5, 186) V WIND INCR: convection`
- `(5, 235) U compnt of wind after convection`
- `(5, 236) V compnt of wind after convection`
- `(6, 2) U COMPNT OF WIND AFTER G.WAVE DRAG`
- `(6, 3) V COMPNT OF WIND AFTER G.WAVE DRAG`

- (6, 185) U WIND INCR: gwd scheme
- (6, 186) V WIND INCR: gwd scheme
- (6, 201) X COMPONENT OF GRAVITY WAVE STRESS
- (6, 202) Y COMPONENT OF GRAVITY WAVE STRESS
- (6, 223) X COMPONENT OF GW SATURATION STRESS
- (6, 224) Y COMPONENT OF GW SATURATION STRESS
- (6, 227) X COMPONENT OF BLOCKED FLOW STRESS
- (6, 228) Y COMPONENT OF BLOCKED FLOW STRESS
- (6, 231) U-ACCEL FROM BLOCKED FLOW
- (6, 232) V-ACCEL FROM BLOCKED FLOW
- (6, 235, X-COMPONENT OF SURFACE SSO STRESS
- (6, 236, Y-COMPONENT OF SURFACE SSO STRESS
- (6, 241) X COMPT OF GRAV. WAVE STRESS P LEVS
- (6, 247) U-ACCEL FROM SATURATED STRESS P LEVS
- (12, 185) U WIND INCR: advection
- (12, 186) V WIND INCR: advection
- (20, 20) MAX WIND U-COMPONENT
- (20, 21) MAX WIND V-COMPONENT
- (30, 312) ELIASSEN-PALM FLUX (MERID. COMPNT)
- (35, 1) U COMPNT OF WIND AFTER SKEB2
- (35, 2) V COMPNT OF WIND AFTER SKEB2
- (35, 3) U COMPNT OF WIND INCR SKEB2
- (35, 4) V COMPNT OF WIND INCR SKEB2
- (35, 5) ROT U COMPNT OF WIND INCR SKEB2
- (35, 6) ROT V COMPNT OF WIND INCR SKEB2
- (35, 7) DIV U COMPNT OF WIND INCR SKEB2
- (35, 8) DIV V COMPNT OF WIND INCR SKEB2
- (39, 6) ANALYSIS U WIND ON MODEL LEVELS
- (39, 7) U COMPNT OF WIND AFTER NUDGING
- (39, 8) U WIND INCREMENT DUE TO NUDGING
- (39, 9) U WIND INCREMENT DUE TO OTHER
- (39, 10) U WIND RELAXATION PARAMETER
- (39, 11) ANALYSIS V WIND ON MODEL LEVELS
- (39, 12) V COMPNT OF WIND AFTER NUDGING
- (39, 13) V WIND INCREMENT DUE TO NUDGING
- (39, 14) V WIND INCREMENT DUE TO OTHER
- (39, 15) V WIND RELAXATION PARAMETER
- (53, 185) U wind Inc: Idealised (m/s/step)
- (53, 186) V wind Inc: Idealised (m/s/step)
- (53, 204) U wind reference profile (m/s)
- (53, 205) V wind reference profile (m/s)