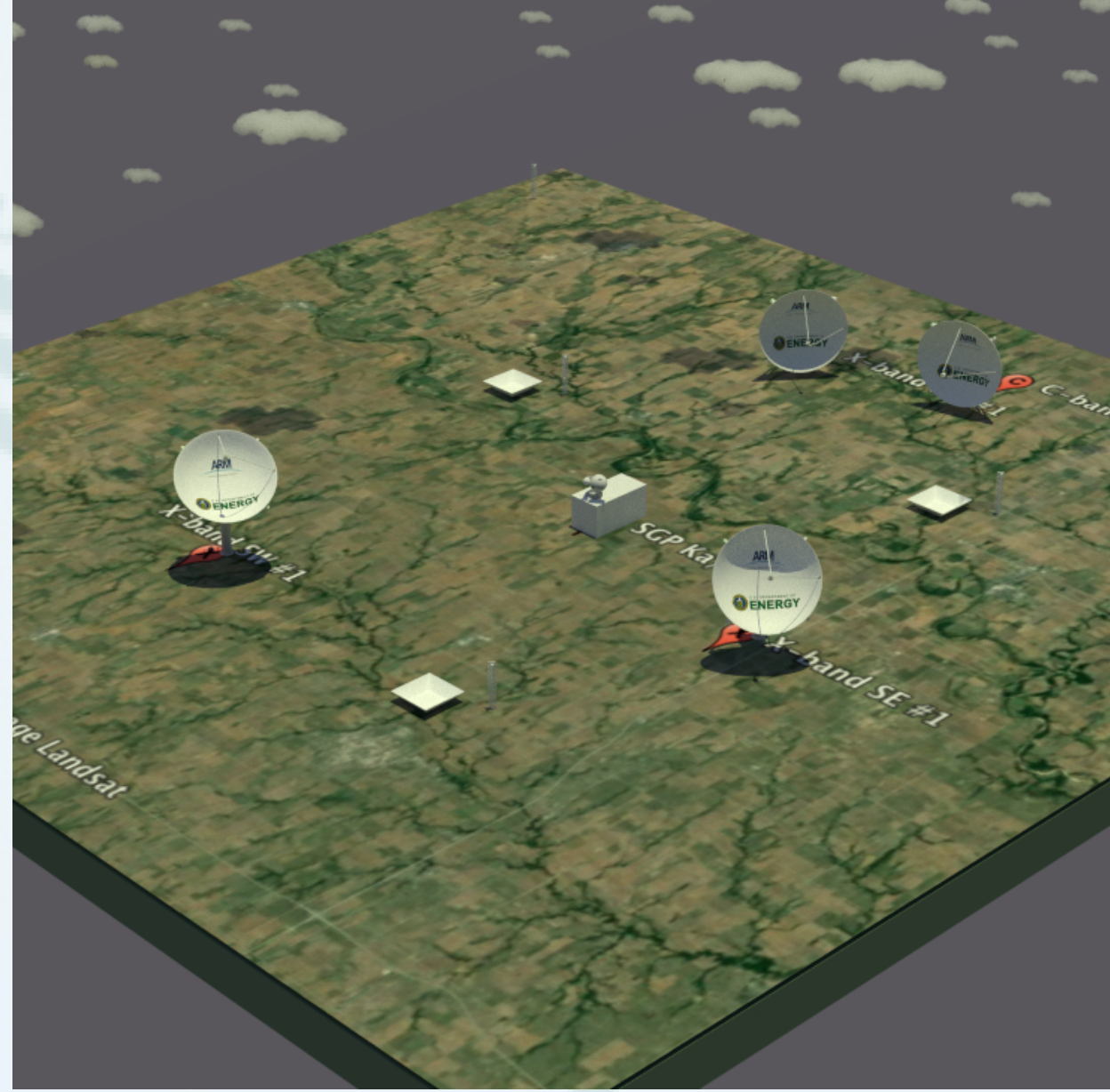


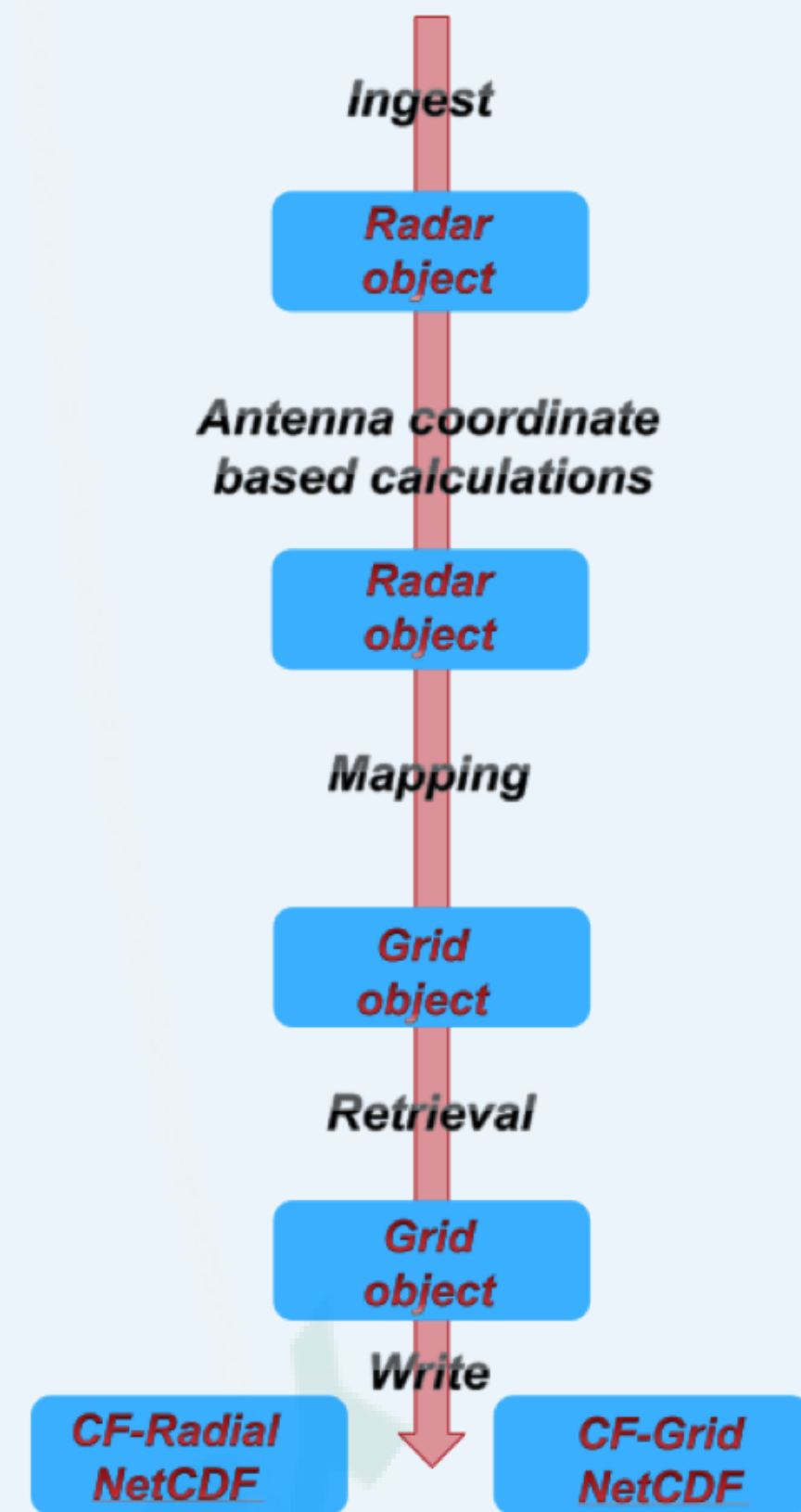
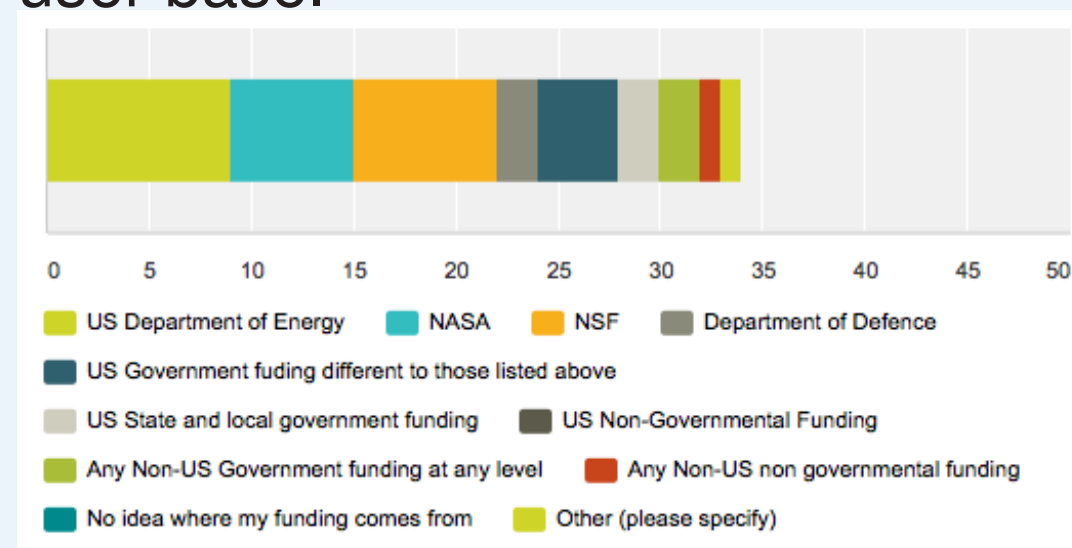
## INTRODUCTION

- Numerical simulations of decadal climate are done at resolutions far coarser than the natural scale of precipitation. To even have a chance of understanding future precipitation extremes we must reconcile the relation between the statistics of broad-scale precipitation and high resolution observations.
- To this end The Department of Energy's ARM Climate Research Facility operates a network of 5 and 3 cm scanning radar systems.
- Fixed sites are at the Azores, Barrow on the North Slope of Alaska and a multi-scale heterogeneous network on the Southern Great Plains of Oklahoma.



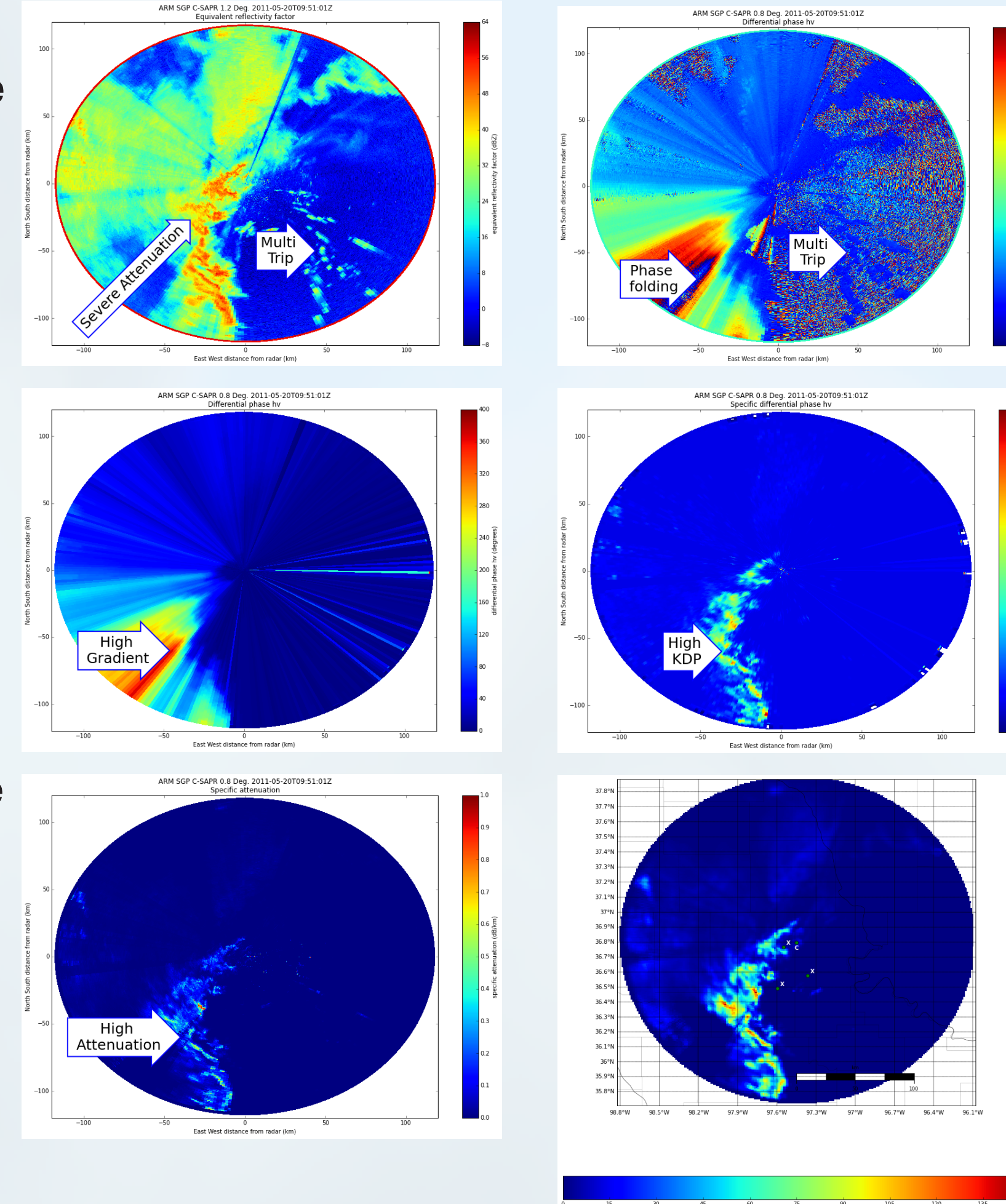
## ACHIEVING INSIGHT WITH THE COMMUNITY: THE PYTHON ARM RADAR TOOLKIT

- Weather radars are not a new invention, first academic mention in Bent et al. (1943).
- Massive advances in computing and radar software has not kept up.
- The Python ARM Radar Toolkit, Py-ART is a data model driven architecture for interactively and offline processing of active remote sensing data. Open source and, using GitHub, community based.
- Part of a larger growing international community of codes, see Heistermann et al. (2014)
- Twenty four forks, eight active contributors from multiple agencies and nations. Broad user base.



## RAW DATA TO QUANTITATIVE PRECIPITATION ESTIMATES

- Raw collected radar data in engineering units is unsuitable for comparison with model data.
- Shorter wavelength radar have a higher attenuation cross section. However Signal to noise in phase information much higher and calibration insensitive.
- Measured phase is a mix of propagation phase, phase shift on backscatter and artifacts:  $\phi_{dp}^{total}(r) = \phi_{dp}^{prop}(r) + \delta(r) + E(r)$ .
- When calculating Specific Differential Phase,  $K_{dp}$  only the propagation component should be considered,  $K_{dp} = \frac{d\phi_{dp}^{prop}(r)}{dr}$ .
- Method of Giangrande et al. (2013) used to extract  $\phi_{dp}^{prop}$  and a 20 point sobel filter  $K_{dp} = \phi_{dp}^{prop} * f_{20} = \sum_{M=-15}^{15} \phi_{dp}(r-M)f(M)$  where  $f(M)$  is a linear ramp through zero.

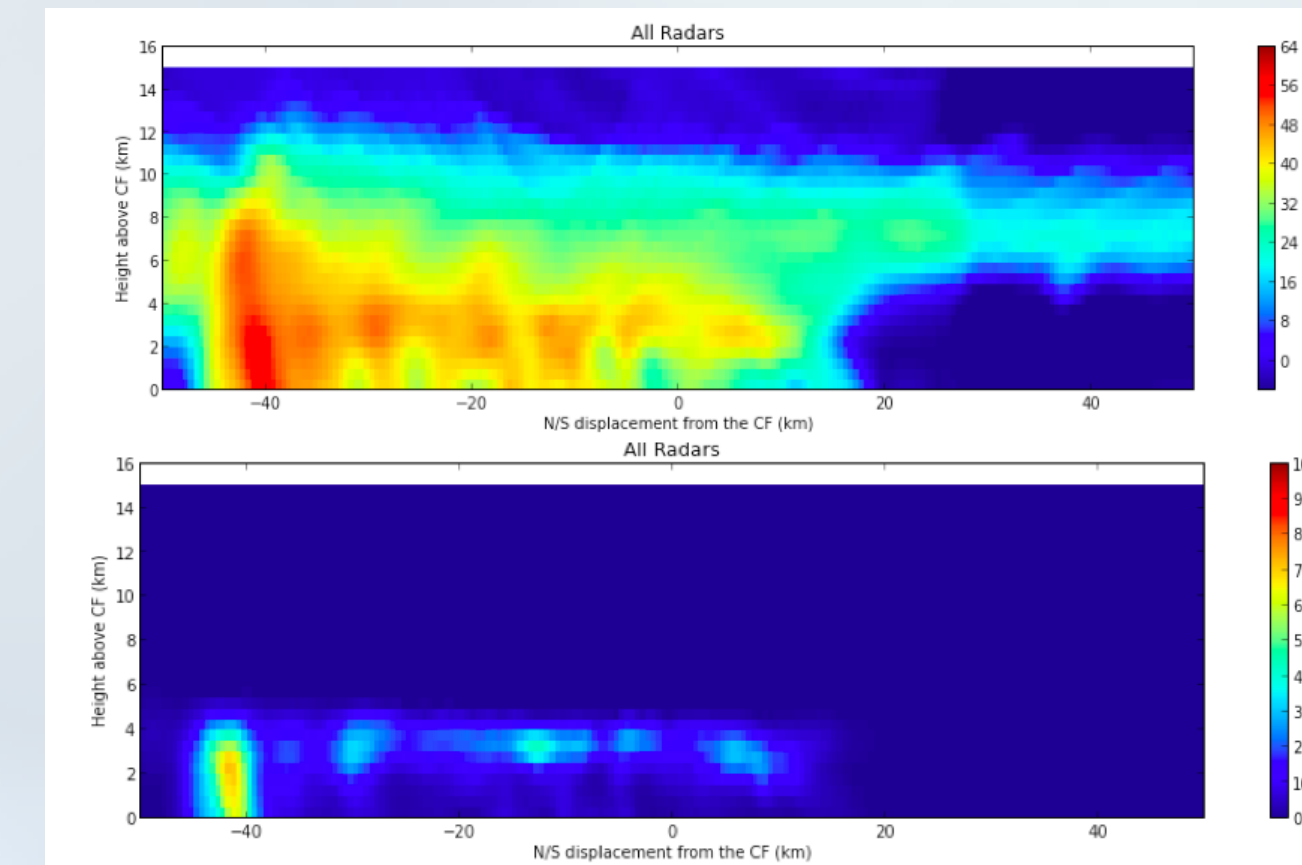


- Specific attenuation is calculated using  $K_{dp}$  and  $Z_e$  using a method after Gu et al. (2011) and is used as an estimator for rainfall using a method after Ryzhkov et al. (2014).
- In Giangrande et al. (2014) it was shown that specific attenuation at short wavelengths performed as well as retrievals at S-band wavelengths.

## MAPPING: OBJECTIVE ANALYSIS

- Radar data is on  $\theta$  and  $\phi$  coordinates, there is a need to estimate on different coordinates systems (Cartesian, Sigma, pressure).
- Py-ART tags each gate with an estimate of its central coordinate and inserts these into a cloud.
- For propagation insensitive variables (not radial velocity or  $\phi_{dp}$ ), gates can be drawn from multiple radars to be estimated onto a single grid.
- In Py-ART the act of gridding takes in a  $n$ -tuple of radar objects and returns a grid object which can be saved to a CF-Radial complaint file.

```
mesh_mapped_x = pyart.map.grid_from_radars((xmw_radar, xsw_radar, xse_radar),
grid_shape=(35, 401, 401),
grid_limits=((0, 17000), (-50000, 40000), (-60000, 40000)),
grid_origin = (36.57861, -97.363611),
fields=['corrected_reflectivity', 'rain_rate_A', 'reflectivity'],
refl_field='corrected_reflectivity',
max_refl=100.)
```



## ADVECTIVE INTERPOLATION

- Simply accumulating precipitation retrievals by integrating can create a "chain of pearls effect" due to the lack of spatial coherency between successive radar scans.
- This can create false information and skew any interpretation of the scale of rainfall.
- The solution is to calculate the image advection and then generate sub-temporal-scale images and average:

$$G(t + \Delta t, z, y, x) = (1 - \frac{t + \Delta t - t_1}{t_2 - t_1})G_1(t_1, z, y + v\Delta t, x + u\Delta t) + \frac{t + \Delta t - t_1}{t_2 - t_1}G_2(t_2, z, y - v\Delta t, x - u\Delta t)$$

- Setting  $t_1 = 0$

$$G(t + \Delta t, z, y, x) = (1 - \frac{t + \Delta t}{t_2})G_1(t_1, z, y + v\Delta t, x + u\Delta t) + \frac{t + \Delta t}{t_2}G_2(t_2, z, y - v\Delta t, x - u\Delta t)$$

- In a nice novel twist (we Py-ART developers love applying math to radar) the advection can be determined from the cross correlation phase between the two images,  $r = \mathcal{F}^{-1}\{C\}$ .
- Borrowing liberally from Wikipedia:

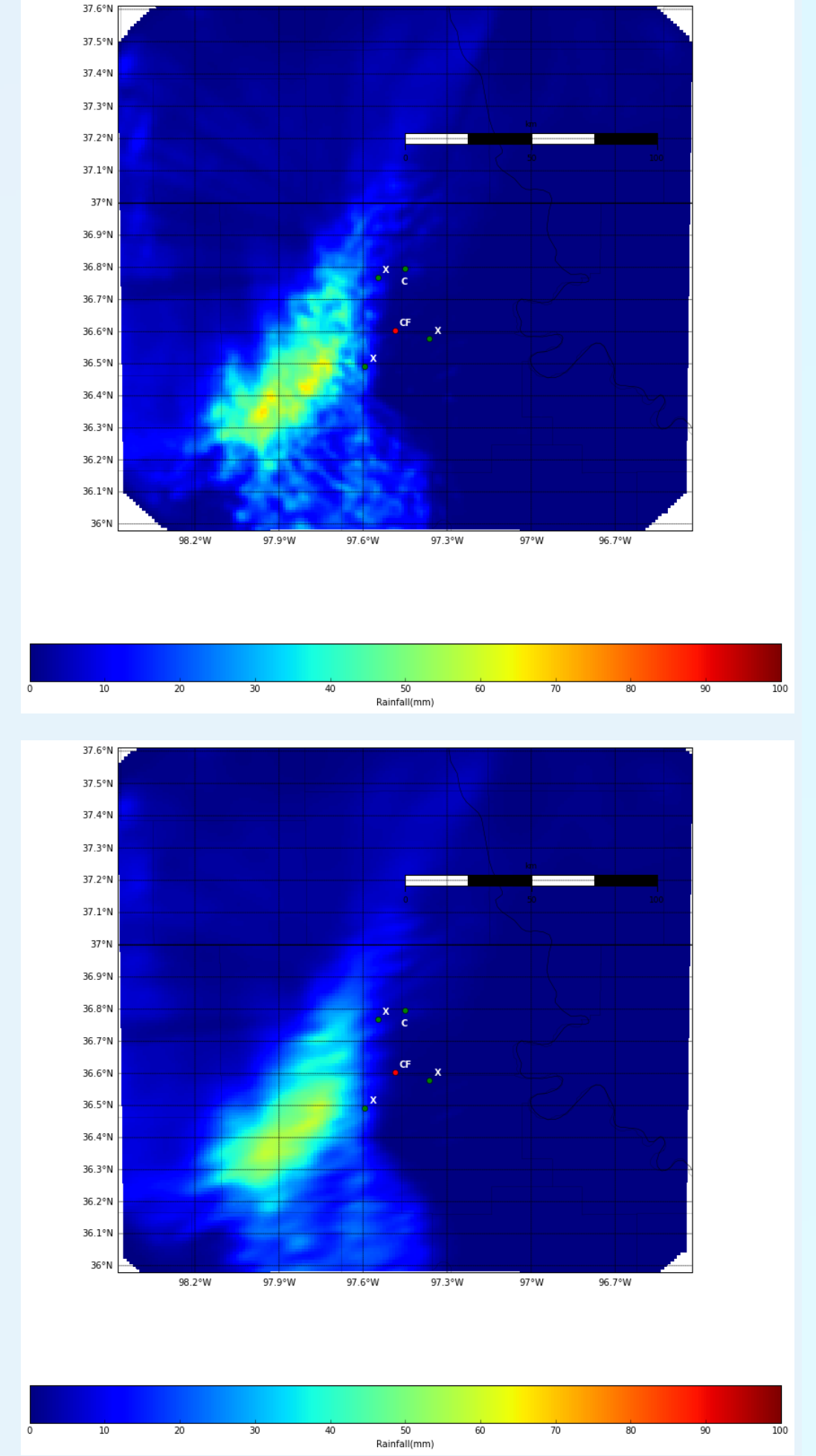
$$G_{t1} = \mathcal{F}\{R_{t1}\}, G_{t2} = \mathcal{F}\{R_{t2}\}$$

$$C = \frac{G_{t1} \circ G_{t2}^*}{|G_{t1} \circ G_{t2}^*|}$$

$$r = \mathcal{F}^{-1}\{C\}$$

$$\Delta x, \Delta y = \operatorname{argmax}\{r\}$$

- where  $\mathcal{F}$  is the Fourier transform,  $*$  is the complex conjugate and  $\circ$  represents element wise multiplication.
- Summing sub-sample advective interpolation steps results in an accumulation that is less affected by lack of temporal resolution.



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## LINKS

The Python ARM Radar Toolkit:



This is an open source poster, for notebooks, code and tex:

