# Architectures for Rainfall Property Estimation From Polarimetric Radar


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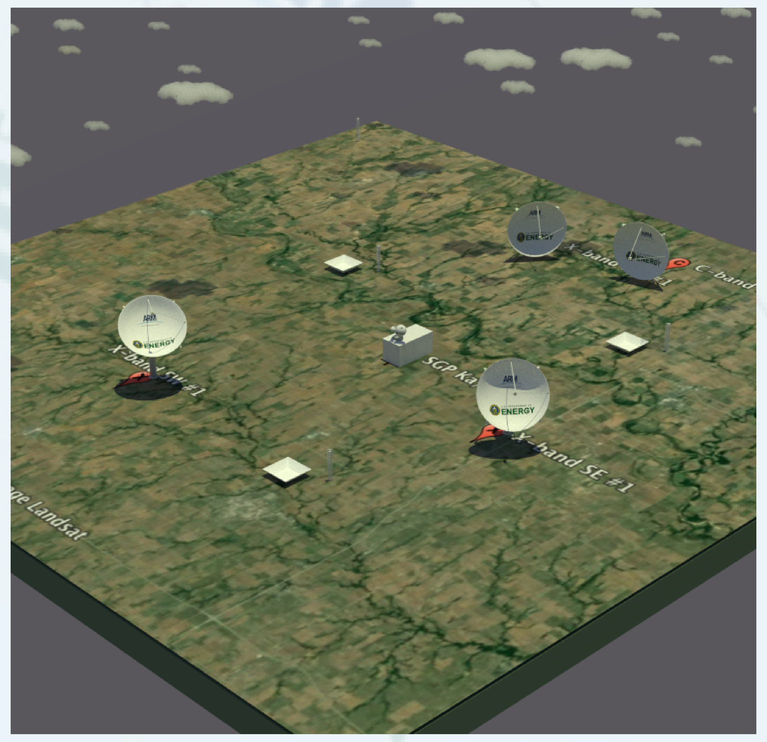
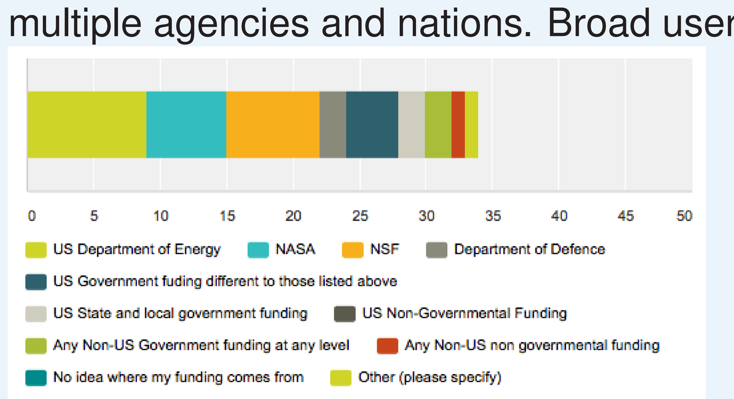
## Introducton

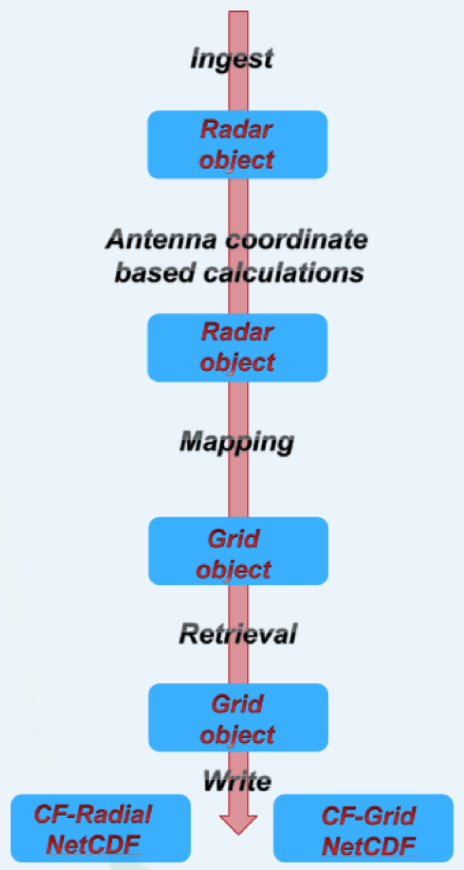


- Numerical simulations of decadal climate are done at resolutions far courser than the natural scale of precipitation. To even have a chance of understanding future precipitation extremes we must reconcile the relation between the statistics of broad-scale precipitation and high resolution observations.
- 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.
- They 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.



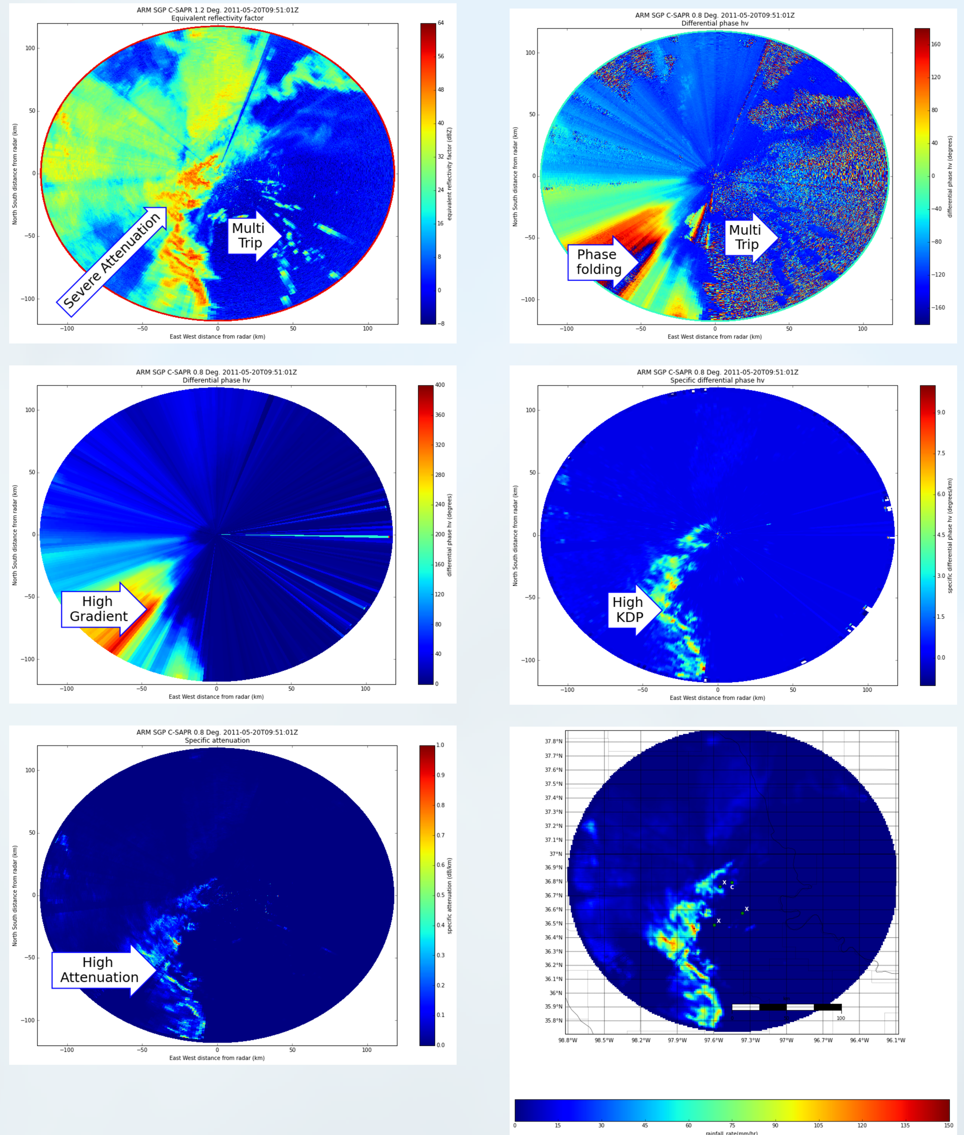

## Links

The Python ARM Radar Toolkit

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

## Raw data to Quantitative Precipitation Estimates

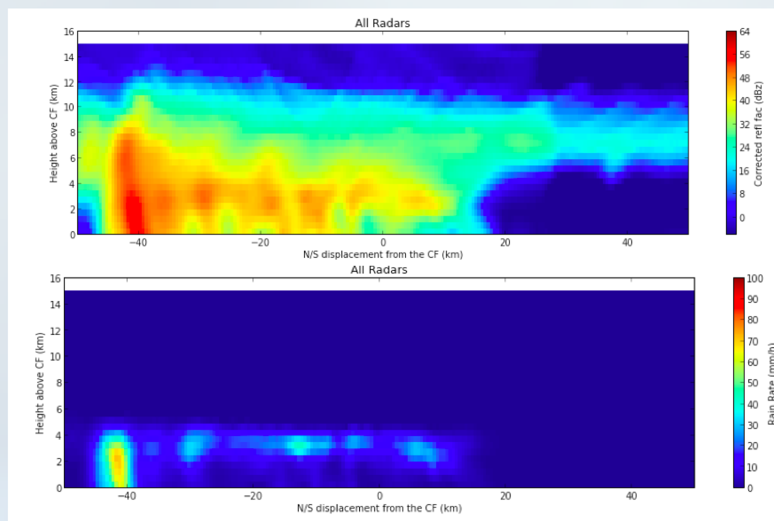
- Raw collected radar data in engineering units is unsuitable for comparison with model data.
- Shorter wavelength radar have a higher attenuation cross section. However Signal to noise in phase information much higher and calibration insensitive.
- Measured phase is a mix of propagation phase, phase shift on backscatter and artifacts: $\phi_{dp}^{signal}(r) = \phi_{dp}^{prop}(r) + \delta(r) + E(r)$.
- 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 $K_{dp} = \phi_{dp}^{prop} * f_{20} = \sum_{M=0}^{19} \phi_{dp}(r-M) f(M)$ 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 a 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 variables (not radial velocity or $\phi_{dp}$), gates can be drawn from mulitple 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((xnw_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:

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

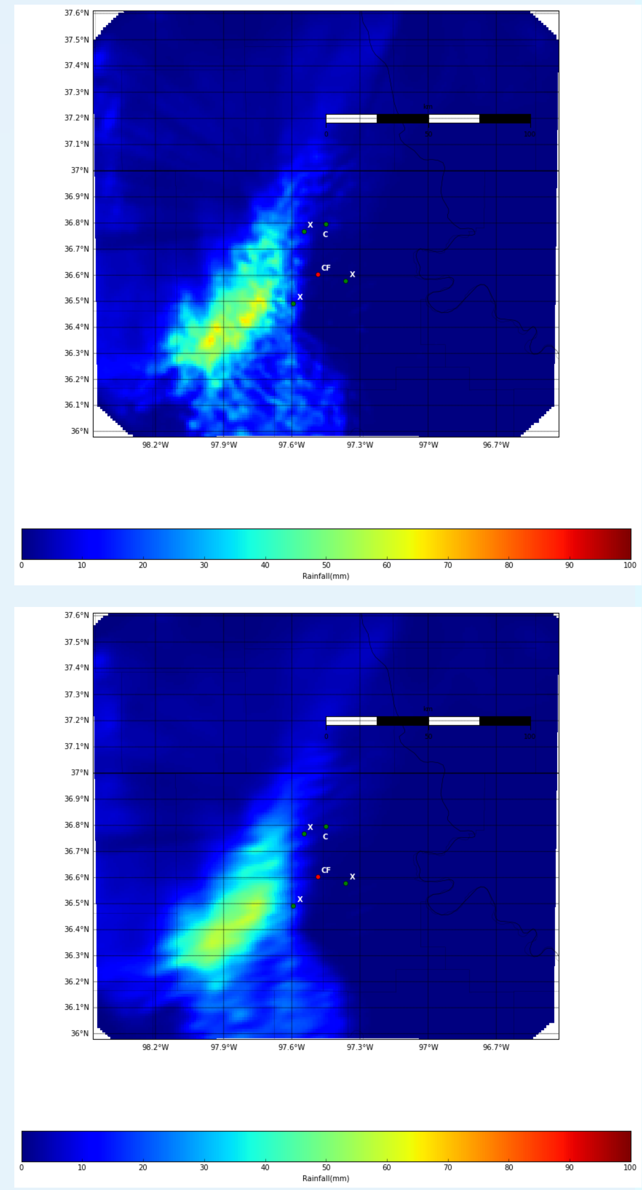
- Setting $t_1 = 0$

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

- 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:

$$\mathbf{G}_{t1} = \mathcal{F}\{R_{t1}\}, \mathbf{G}_{t2} = \mathcal{F}\{R_{t2}\}$$
$$C = \frac{\mathbf{G}_{t1} \circ \mathbf{G}_{t2}^*}{|\mathbf{G}_{t1} \circ \mathbf{G}_{t2}^*|}$$
$$r = \mathcal{F}^{-1}\{C\}$$
$$\Delta x, \Delta y = \mathrm{argmax}\{r\}$$

- where $\mathcal{F}$ is the Fourier transform, $^*$ is the complex conjugate and $\circ$ is the element wise multiplication.

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