FITACF 3.0

Pasha Ponomarenko and Keith Kotyk

Institute for Space and Atmospheric Studies

University of Saskatchewan, Saskatoon, Canada

Outline

- Background and problem formulation
- Main tasks and their implementation
- Preliminary testing
- Conclusions and future work

Linear Least Square fitting

- Fitting is done by minimising a weighted sum of squared residuals between the measured parameter φ and its model f (e.g. *Numerical Recipes*, Ch. 15.2),

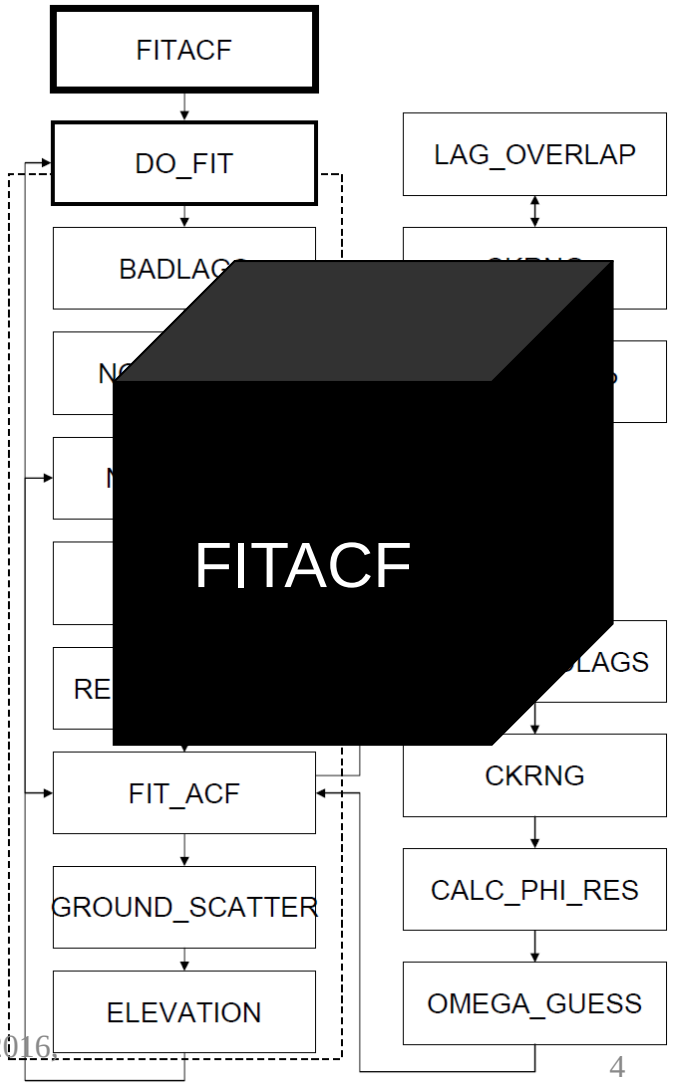
$$\chi^2 = \sum_{i=1}^{n_{lag}} \frac{\left(\varphi_i - f_i\right)^2}{\sigma_{\varphi i}^2}$$

  - n_{lag} is the number of lags (degrees of freedom, DoF)
  - $\sigma_{\varphi i}$ is variance at the i^{th} lag

  Statistical variations in both signal and cross-range interference (CRI) contribute to the overall variance.

Issues with original FITACF

- Confusing organisation of the package:
  - Lack of transparency (“black box”)
  - Strong interdependence between different routines
- Questionable implementation of some analysis procedures:
  - Too large spectral width values
  - Meaningless velocity errors
  - Empirical data selection procedures



Two major revisions

2004-2005

- **Main issue**: too large spectral width values
- **Main findings**:
  - Incorrect treatment of statistical fluctuations
  - Too liberal threshold for cross-range interference
  - Some other issues (*more_badlags*, noise ACF, etc)
- **Result:** FITACF2.0 – most width-related issues were fixed, but the package's structure remained untouched

2012-2013:

- **Main issue**: meaningless velocity error values
- **Main findings**:
  - Coding errors in error calculations
  - **Non-optimal implementation of the Least Squares fitting:**
    - **Incorrect weighting coefficients for both phase and power**
    - **Use of CRI level for lag rejection rather than for weighting fitted data**
  - In order to implement the above changes, it is necessary to re-structure the package
- **Result**: FTACF3.0 (See below!)

A bit of chronology on FITACF3.0

- 29 May 2013 – “SuperDARN velocity errors” (tutorial at SuperDARN Meeting, Moose Jaw)
- 31 May 2013 – Data Analysis Working Group initiated
- September 2013 – software overhaul formulated based on the tutorial at SD’13

- August 2014 – started re-factoring FITACF2.5 with AJ but he moved to Silicon Valley
- All stagnated until Keith Kotyk has become our Software Engineer in mid-May 2015 and made FITACF3.0 possible

FITACF3.0 tasks: Data selection

- ACF rejection:
  1. Single SNR threshold (< 0 dB) – same as before
  2. Minimum number of fitted lags (< 3) – same.
- Lag rejection:
  1. Transmitter-pulse overlap (power and phase)
  2. Low-power tail (power only)
  3. **No rejection based on CRI!!!**
  4. **No rejection based on shape (no *more_badlags.c*)!!!**

FITACF3.0 tasks: Least-square fitting

- Subroutines for least-square fitting (same as before):
  - Linear function with offset (Lorentzian log-power and XCF phase)
  - Parabolic function with offset (Gaussian log-power)
  - Linear function with no offset (ACF phase)
- **Separate (optimal) weights** for power and phase with **CRI effects** included (*Bendat and Piersol*, 1986)
- Calculating errors using **textbook formulas** rather than custom-made expressions
- **No power fitting for XCF** – these data are never used and their quality is inferior to that of ACF power fits. If necessary, one still can get them using older FITCAF versions.

Software engineer prospective: FITACF 1.x-2.x drawbacks

High degree of coupling in software. Function calls are highly dependent on each other meaning it's hard to change pieces.

Lack of internal data encapsulation. There is no real structure to internal data with functions being passed 10+ arguments

Misleading or uninformative naming schemes of functions and variables make it incredibly difficult to understand the software and locate functions.

FITACF 3.0 Implementation: Preliminary preparations

- **Re-factoring the "old" FITACF**
  - Learning about its functionality
  - Producing a reference package

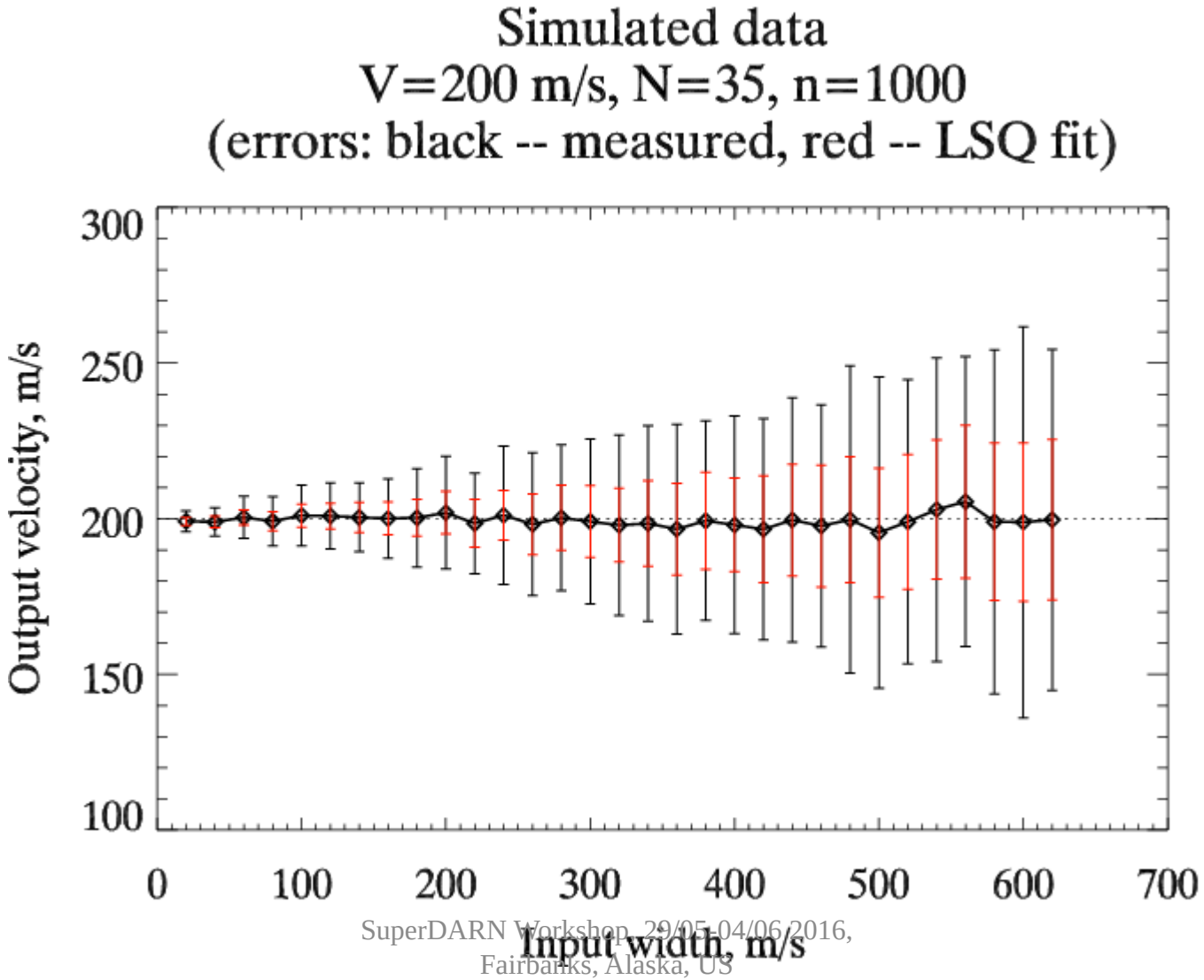
Result: better structured and commented FITACF 2.6 that produces the same results as the latest version, FITACF 2.5

FITACF 3.0 Main Points

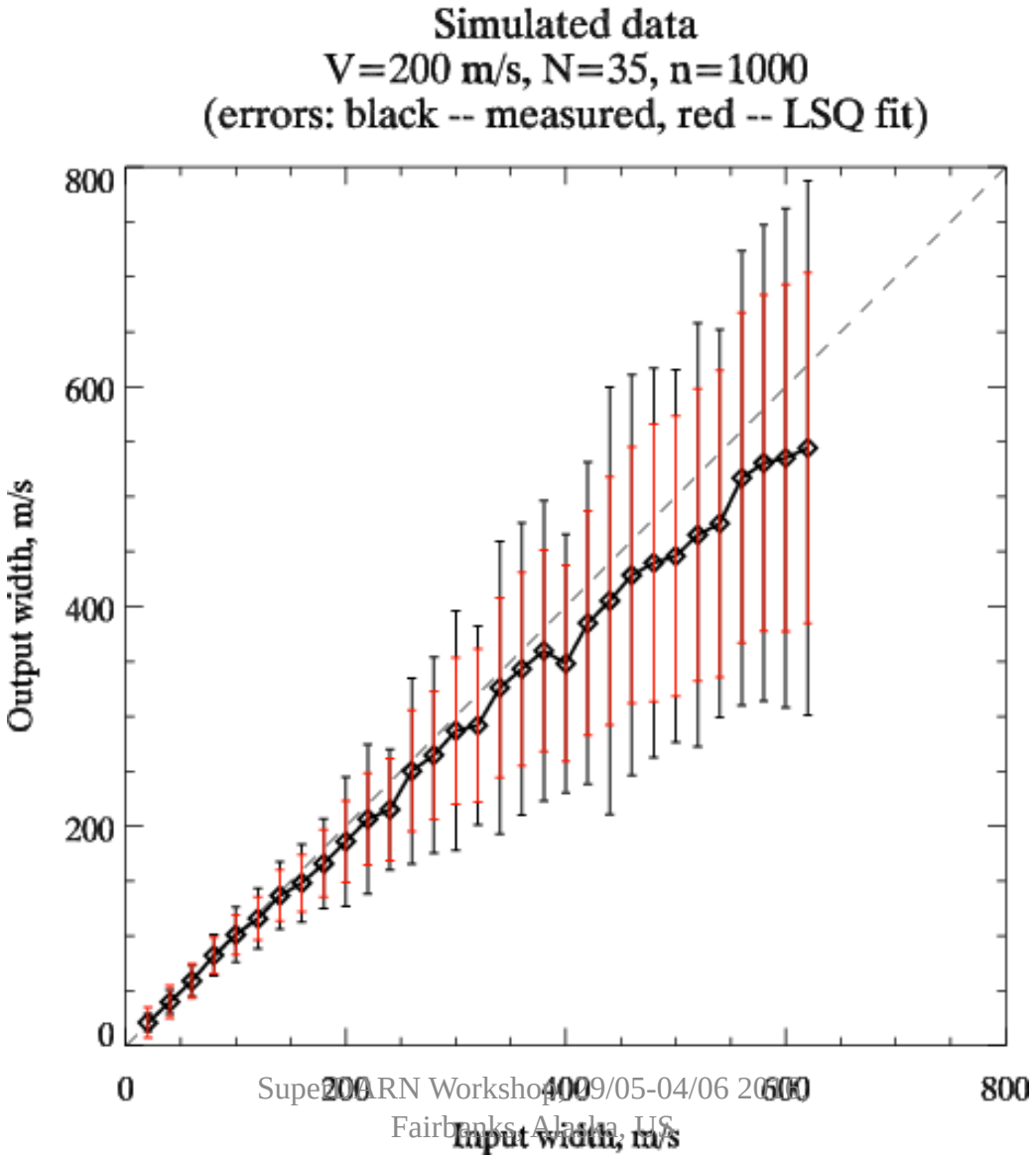
- More modularity. Easier to add, modify, or remove features
- Everything operates on a self contained data structure
- File names give clearer idea of what functions are contained within

Testing: Simulated data

Velocity *vs* spectral width

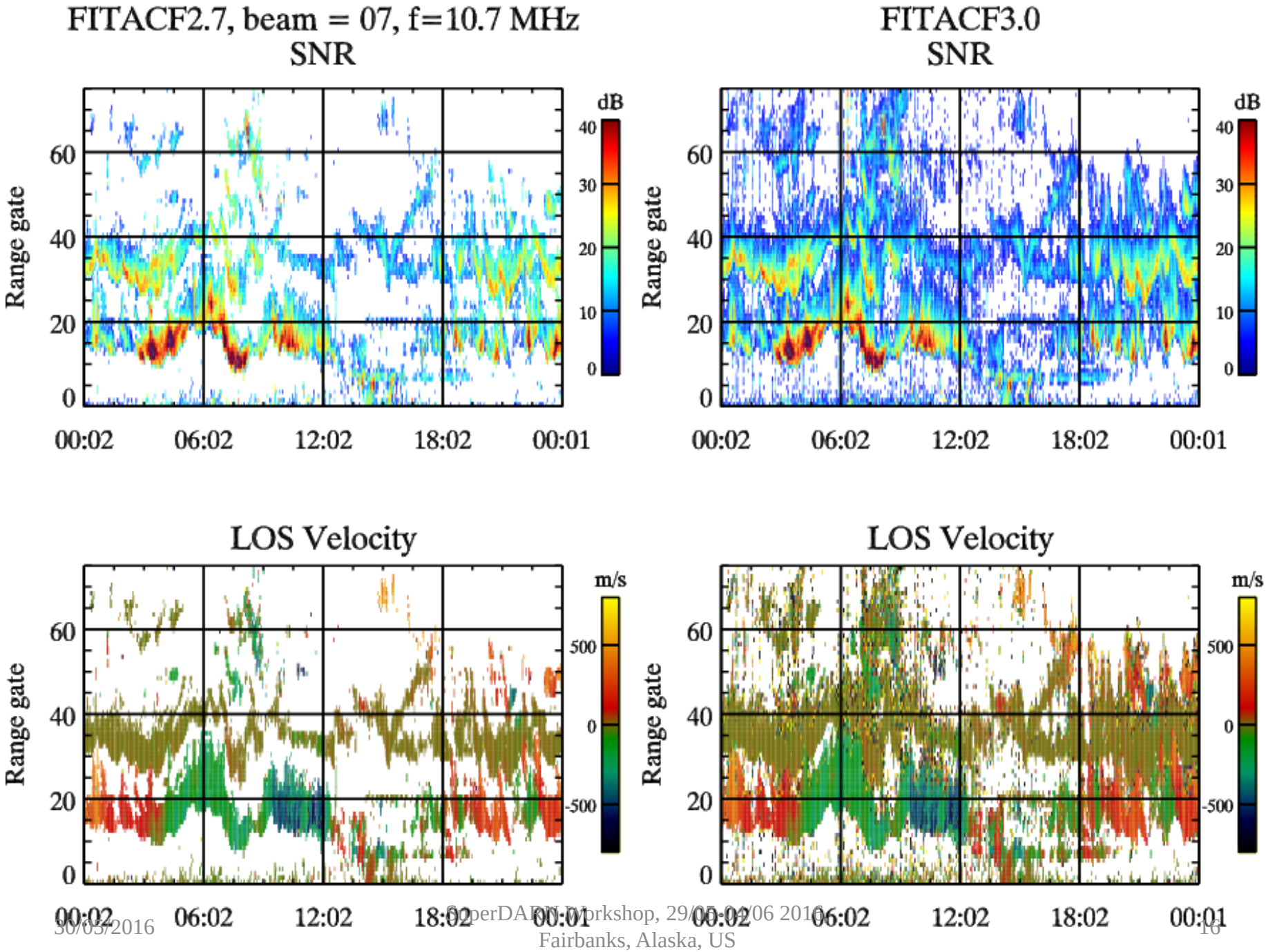


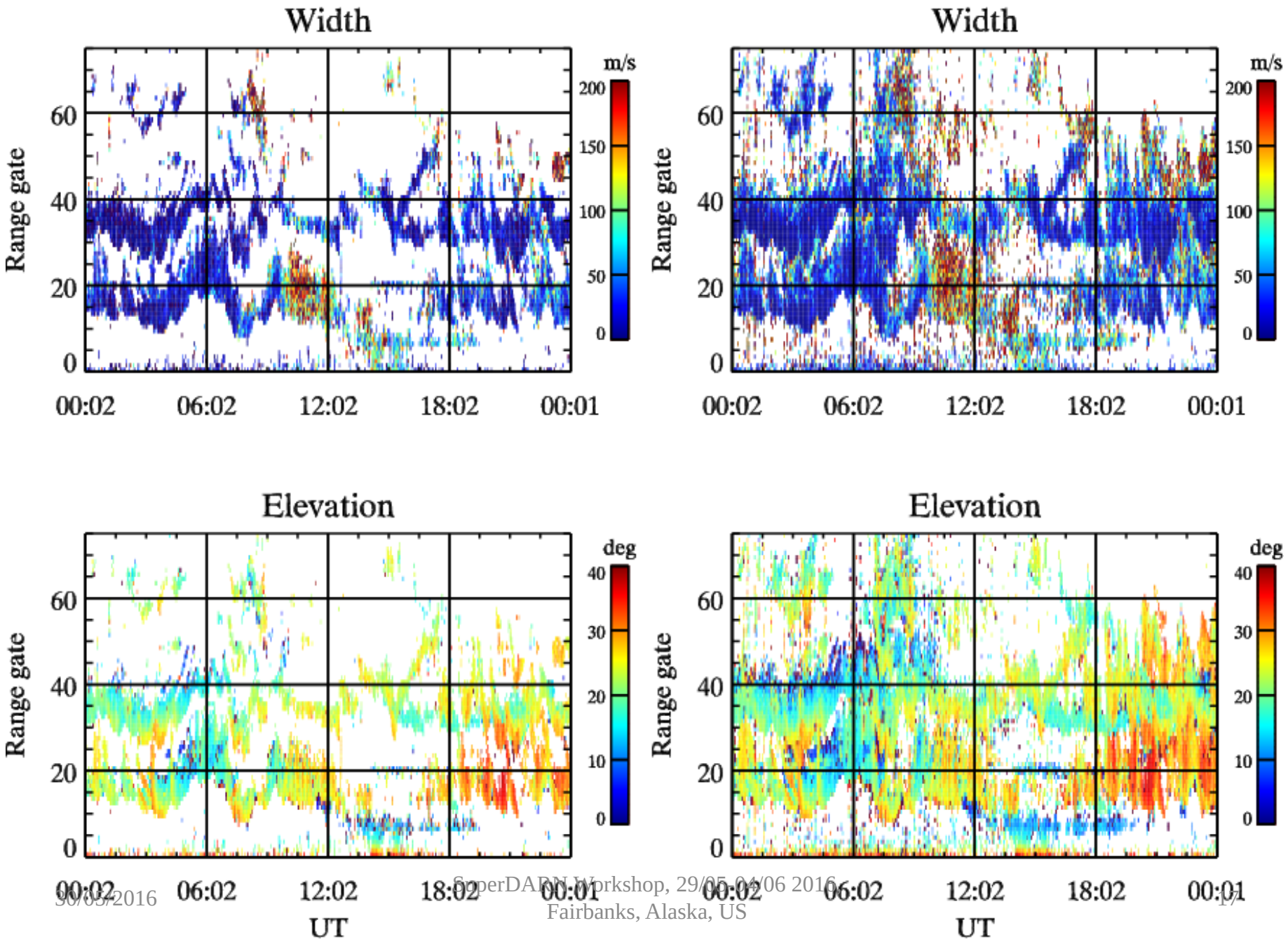
Spectral width



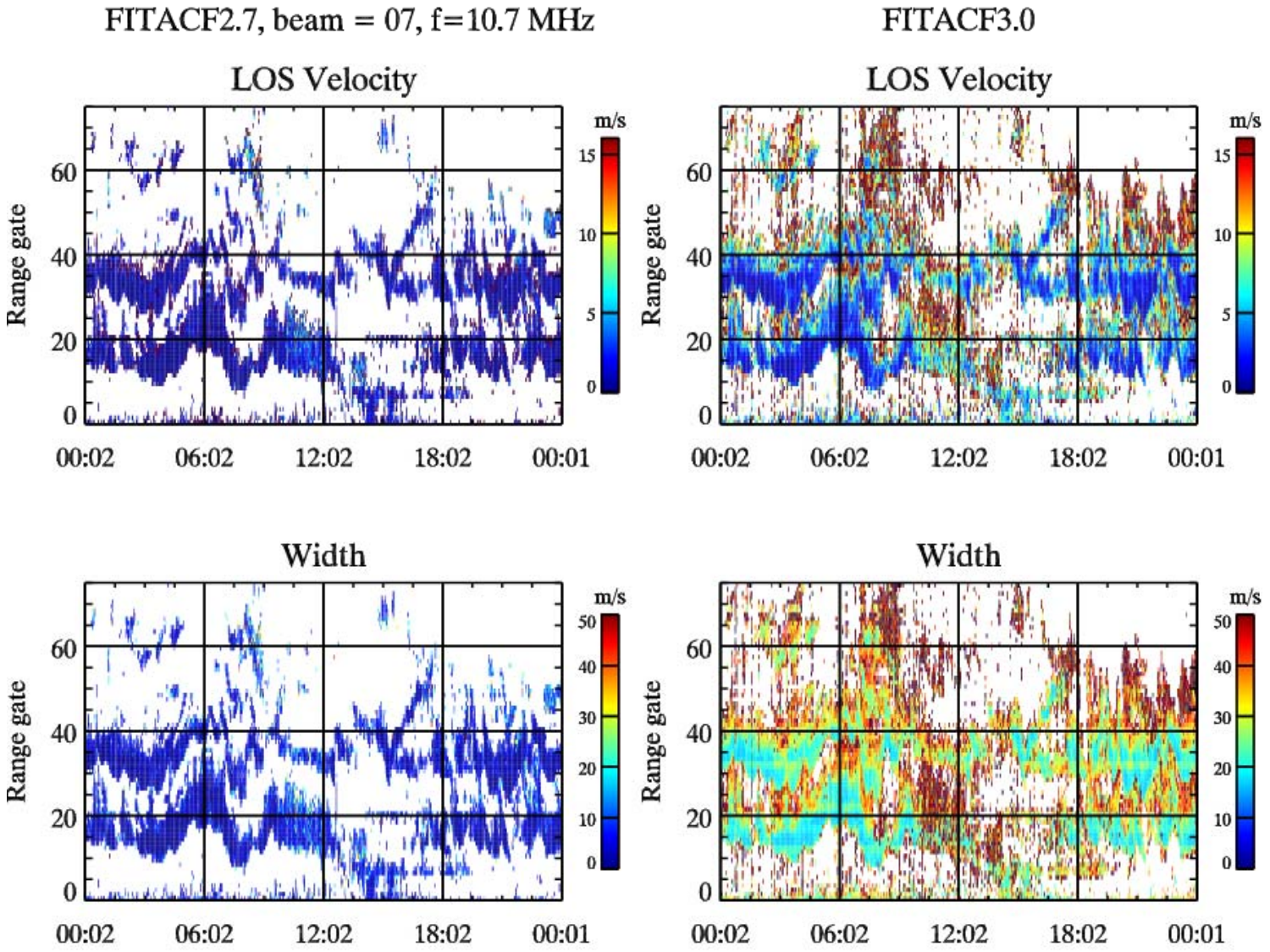
Testing: Real data

CLY(10.7 MHz): 0 dB threshold


FITACF2.7, beam = 07, f=10.7 MHz
SNR
FITACF3.0
SNR
LOS Velocity
LOS Velocity
Range gate
dB
m/s
00:02
06:02
12:02
18:02
00:01


Width
Width
Elevation
Elevation
Range gate
m/s
deg
UT
00:02
06:02
12:02
18:02
00:01

Errors


FITACF2.7, beam = 07, f=10.7 MHz
FITACF3.0
LOS Velocity
LOS Velocity
Width
Width
Range gate
m/s
15
10
5
0
50
40
30
20
0
60
40
20
00:02
06:02
12:02
18:02
00:01

Conclusions

- FITACF3 *vs* previous versions:
  - Optimal fitting has been applied, including proper treatment of cross-range interference
  - The package is user-friendly and flexible
  - It has been successfully tested against lots of simulated data as well as against some real data
- Output:
  - Utilising all available lags **significantly increased the amount of obtained data**
  - **Fitting errors are realistic** and are much easier to interpret than before

Future work

- Closer perspective: An extensive testing by other researchers and a bit more fine tuning will be necessary before the package is ready to be released to the community.

- Farther perspective:
  - Refractive index (electron density) estimates based on elevation (*GRL* 2011)
  - Separating ionospheric and ground components in mixed scatter echoes (*AG* 2008)
  - ...