Operational radar refractivity retrieval and its potential use in Numerical Weather Prediction

John Nicol[1], Anthony Illingworth[1], Tim Darlington[2], James Ovens[2] and Nicolas Gaussiat[2]

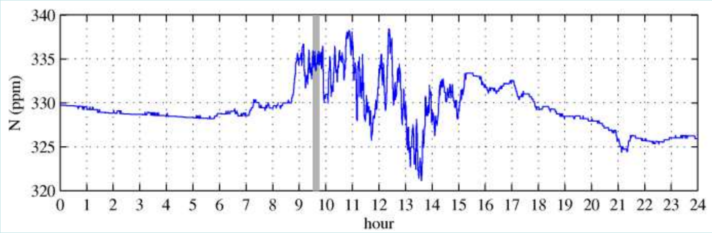
[1] NCAS (FGAM), University of Reading
[2] UK Met Office

ERAD 2012, Toulouse, France
25-29 June 2012

Refractivity Retrieval: Background

- ★ Radar signal travels more slowly through more humid air, the phase change from stationary targets (ground clutter) can be used to infer these changes (Fabry et al., JTech, 1997)
- ★ Refractivity information from the UK radar network (C-band, magnetron) throughout the year
- ★ 2D fields of low-level refractivity/humidity may be of great benefit for modelling the initiation of convection
- ★ Are near-surface refractivity changes likely to be useful/suitable for data assimilation in NWP?

Near-surface refractivity observations



daily

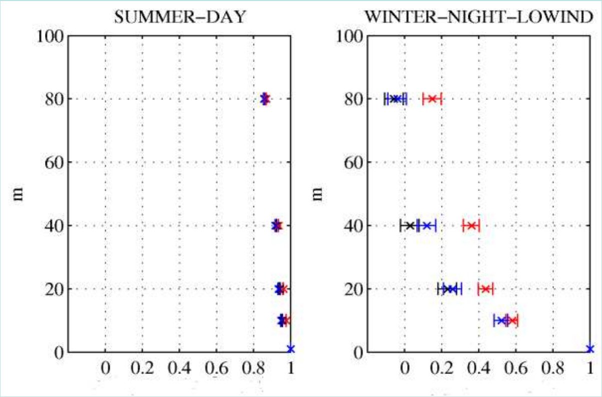
$$N = (n-1)10^6 = \frac{77.6P}{T} + 3.73\times10^5\frac{e}{T^2}$$

Dry Wet

Variability over 15 minutes (~4km) reachs 3ppm (3% RH @ 20℃) during the day in summer

RMS diff. between two stations (36km apart) = 5ppm; sub-4km variability = 2ppm

Correlation of refractivity changes with height



Observations from a 200-m instrumented tower at Cabauw, Netherlands (3 years)

Hourly near-surface refractivity changes are strongly correlated up to 50m during the day; not when surface layer becomes stratified
(e.g. at night with light winds; <1m/s)

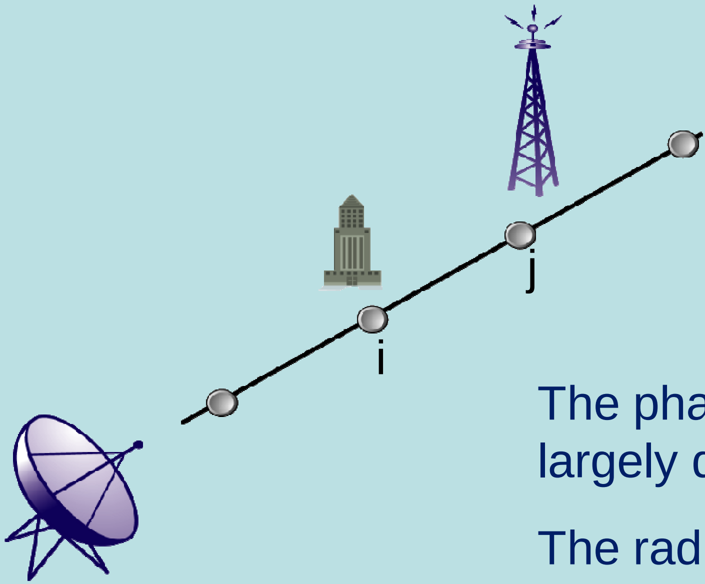
Height of ground targets determine the representative height of radar retrievals
(<10m in US Great Plains; Park and Fabry, 2010)

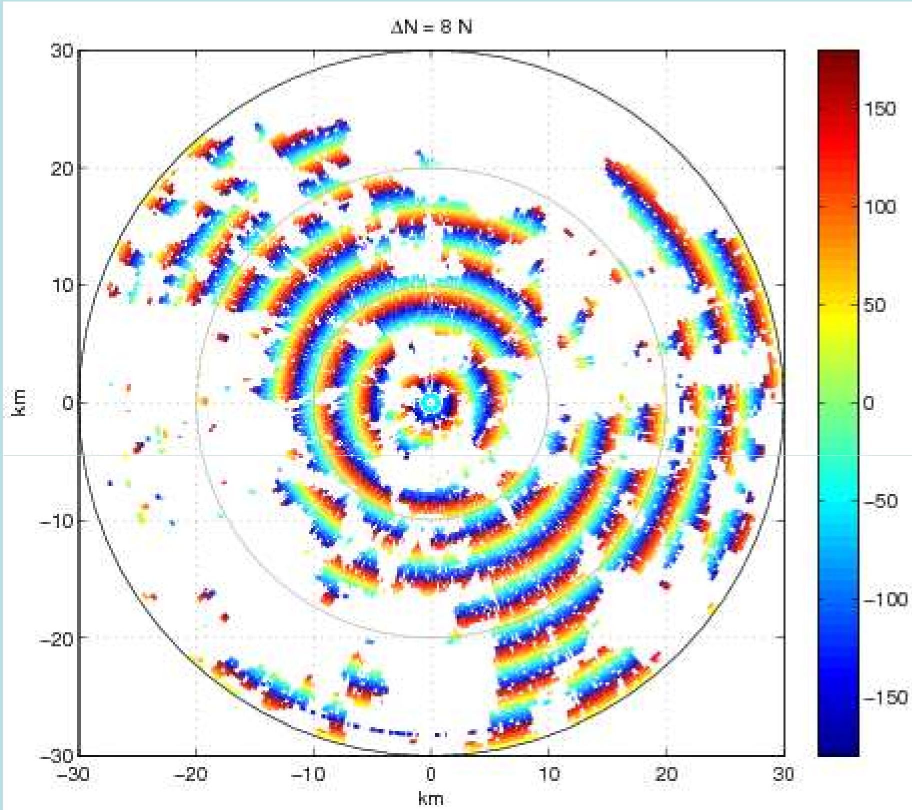
Radar retrievals representative of a 50-m layer in conditions suitable for surface-driven convection

Radar refractivity retrieval

$$\Delta N \approx \frac{c}{4\pi f_t} \frac{10^6}{G_{ij}}$$

$$G_{ij} \approx \frac{\Delta\phi(d_j) - \Delta\phi(d_i)}{d_j - d_i}$$





The phase change between scans made at two times is largely determined by humidity changes

The radial rate of change between nearby stationary targets is proportional to the refractivity change

Phase change noise (at C-band)

1 Target motion

Use Power Ratio to identify stationary targets (CPA; Hubbert et al., JTech, 2009)

$\sigma_{\Delta ø} \simeq 20 - 90^\circ$ $\sigma_{\Delta d}$(rms target displacements)$\simeq 1 - 4.5$mm

2 Changes in the vertical gradient of refractivity

Target height variability and range (Park and Fabry, JTech, 2010)

$\sigma_{\Delta ø} \simeq 30^\circ$ for $\Delta(dn/dz)$=20ppm/km with 10m rms target height variability at 20km

3 Target location uncertainty

Target distance from the range-gate centre (∂) $\sigma_{\partial} \simeq$ (pulse length/4)

and refractivity changes or transmitter frequency changes (magnetron)

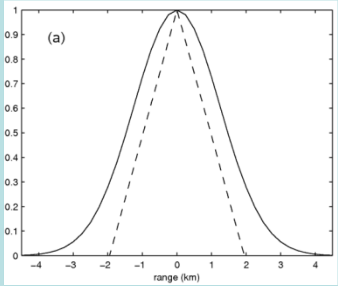
e.g. ΔN=30 or Δf=170kHz $\sigma_{\Delta ø} \simeq 60^\circ$ with 2µs

Nicol, Illingworth, Darlington and Kitchen, 2012: Improving errors in refractivity retrievals due to transmitter frequency drifts and target position uncertainty (under review; JTech.)

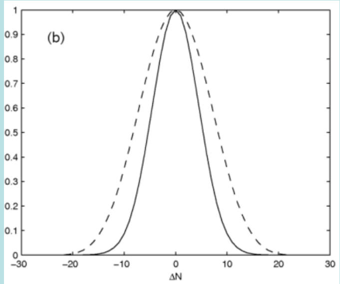
★ Phase change noise greater during summer

★ Phase change noise scales with frequency

Phase change smoothing kernel



Smoothing kernel with respect to range



Equivalent low-pass filter

Trade-off:

Excessive smoothing (underestimate large ΔN)

or insufficient smoothing (noisy retrievals)

Nicol and Illingworth, 2012: The effect of phase-correlated returns and spatial smoothing on the accuracy of radar refractivity retrievals (accepted subject to minor revision; JTech)

Refractivity retrievals (C-band) often break-down after several hours during summer

Solution:

Limit time between scans to an hour (limits changes in refractivity, vertical refractivity gradient and transmitter frequency) to reduce $\sigma_{\Delta \phi}$

Overview (hourly ΔN)

1. Identify stationary targets (PR>0.7)

2. Range-dependent correction for local oscillator frequency changes

   ($\sigma<0.25$ ppm; Nicol et al., 2012)

3. Smooth phase change field

   (2D Gaussian; σ_{range}=375m, $\sigma_{azimuth}$=1500m)

4. Calculate the phase change gradient w.r.t. range for all target pairs

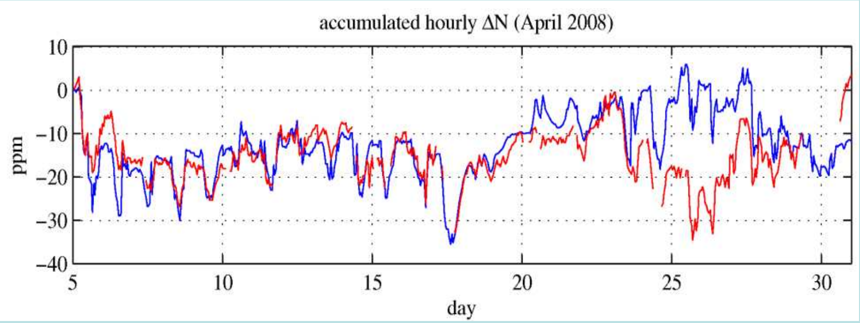
5. Derive maps of refractivity changes (ΔN) and errors ($\sigma_{\Delta N}$)

   weighted mean → refractivity change   weighted std. dev. → error estimate

   (2D Gaussian; σ_{range}=1500m, $\sigma_{azimuth}$=1500m)

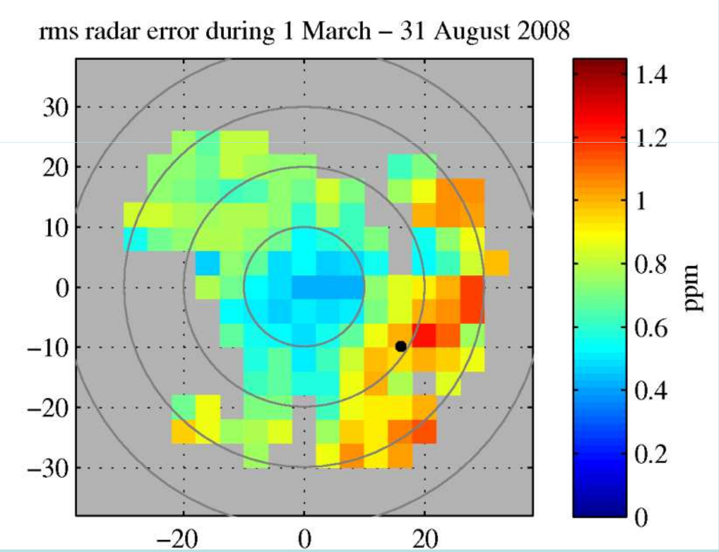
Validation of estimation errors using surface obs.

Refractivity time series derived by accumulating hourly radar refractivity changes (red) and surface observations (blue) throughout April 2008



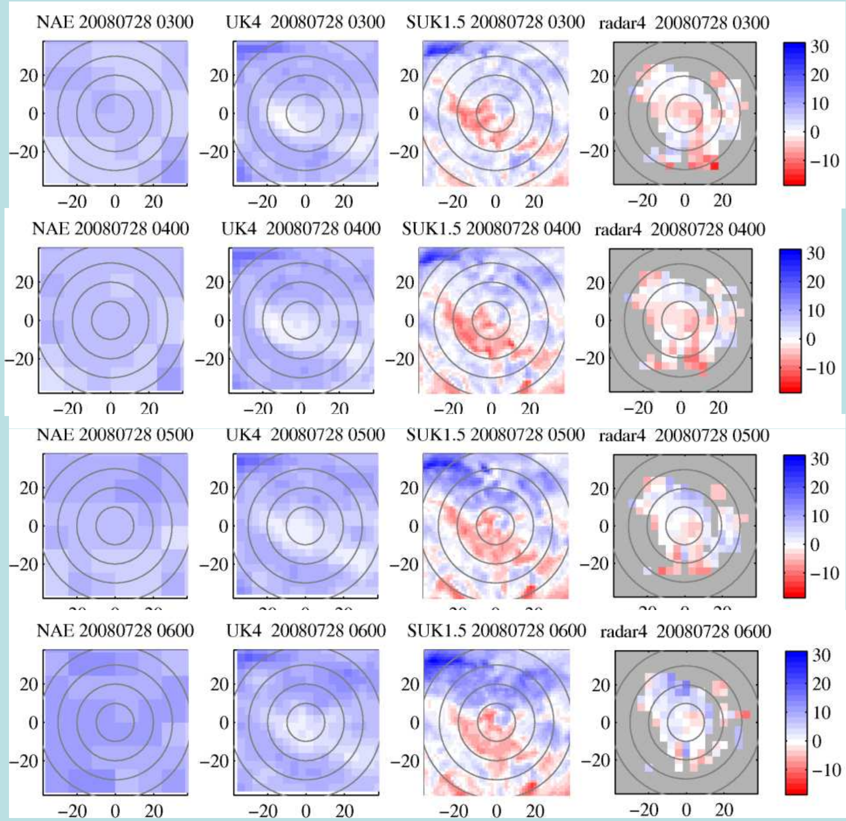
Radar estimation error
$\sigma_{\Delta N} \simeq 1.0$ ppm (at surface station)

March-August 2008 (>3000 hourly changes)



Validation: consider the rms deviation of accumulation over 24 hours
Error in hourly changes $\simeq$ 1.2 ppm

Representation of refractivity in the UK Met Office Unified Model (UM)



NAE(12km) UK4(4km) SUK(1.5 km) Radar

In comparison with surface observations, refractivity shows less variability in the 4-km and 12-km models.

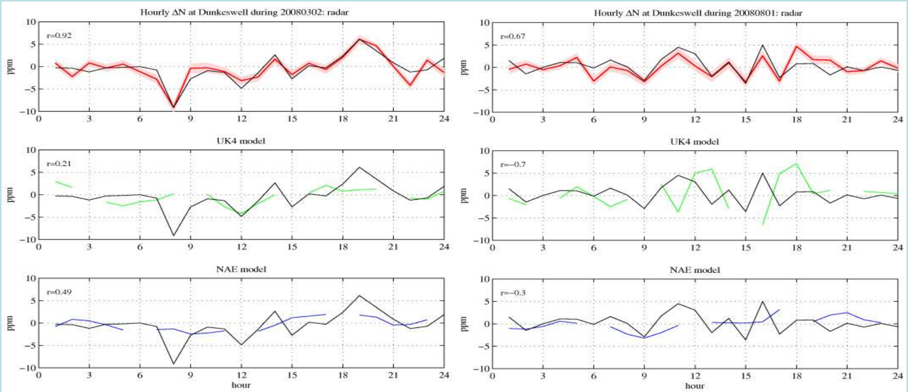
The 1.5-km model seems to have more realistic structures.

Refractivity changes at 0300, 0400, 0500 and 0600 UTC relative to midnight; 28 July 2008

Comparison with surface observations

Examples of time series of hourly ΔN during two days

Surface station observations (black)



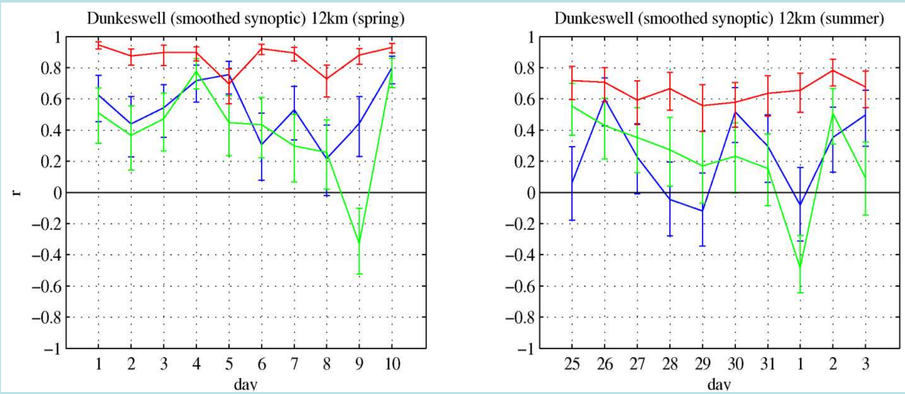
Radar (red)

UK4 [4-km] (green)

NAE [12-km] (blue)

2 March 2008 1 Aug. 2008

Correlation of hourly ΔN with surface observations for 10 consecutive days in spring and summer



Radar (red)

UK4 [4-km] (green)

NAE [12-km] (blue)

Spring (1-10 March 2008) Summer (25 July-3 Aug. 2008)

Model represents temperature and pressure well; humidity poorly

Conclusions

- Radar refractivity retrievals are most challenging during summer and progressively more difficult at shorter wavelengths (long pulses undesirable)

- During the day in summer, retrievals are representative over the lowest 50m or so of the atmosphere and can capture changes at the scale of several kilometres horizontally

- Radar retrievals of hourly refractivity changes and errors agree well with surface observations, forecast models show poorer agreement

- These retrievals are a good candidate for data assimilation as they should improve the representation of humidity in forecast models

Nicol, J. C. , A. J. Illingworth and K. Bartholomew, 2012: The potential of ground-based radar refractivity observations for NWP validation and data assimilation (under review; Quart. J. Royal Met. Soc.).

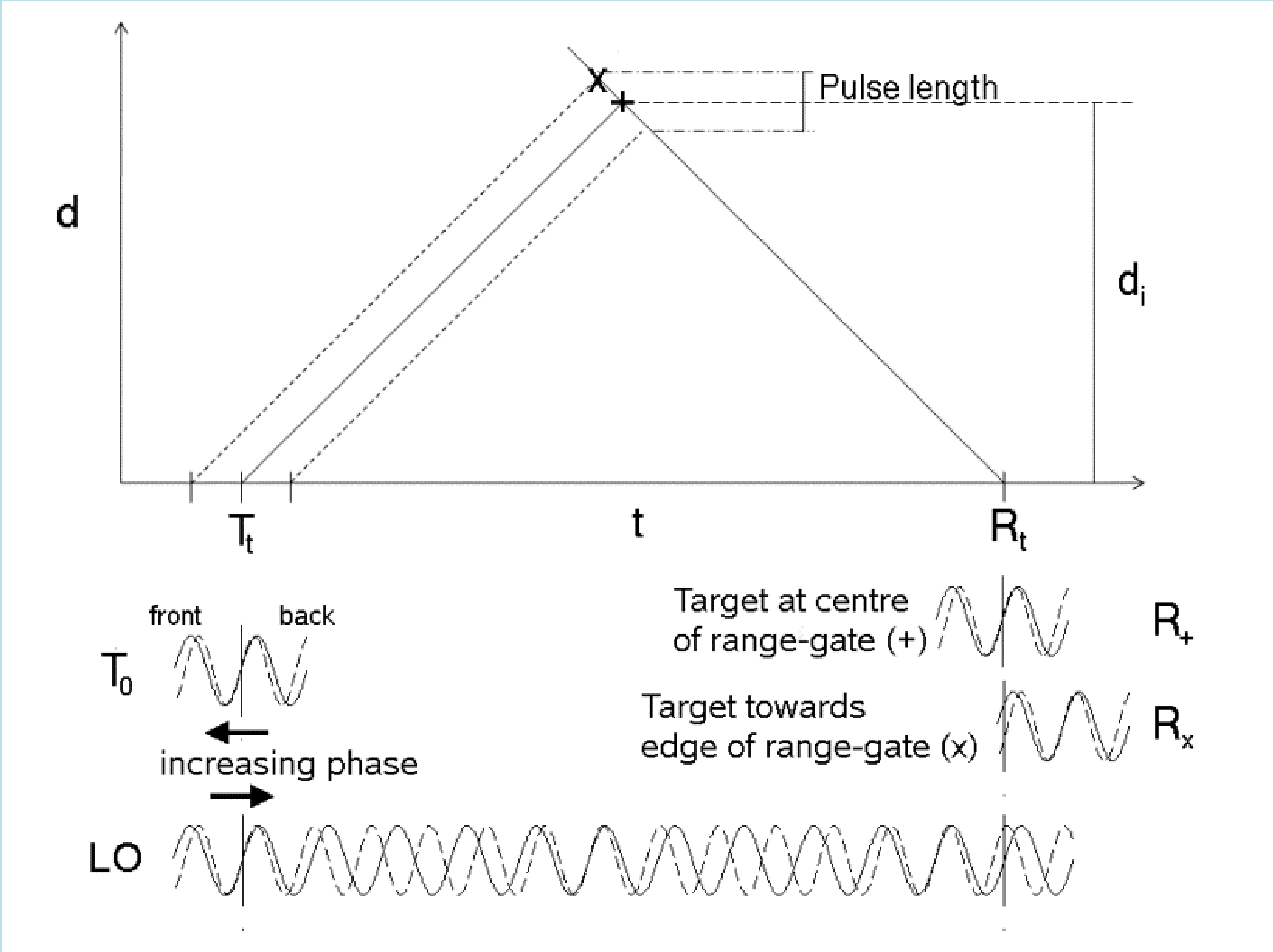


Figure 1 from Nicol et al., 2012: Improving errors in refractivity retrievals due to transmitter frequency drifts and target position uncertainty (under review; JTech.)

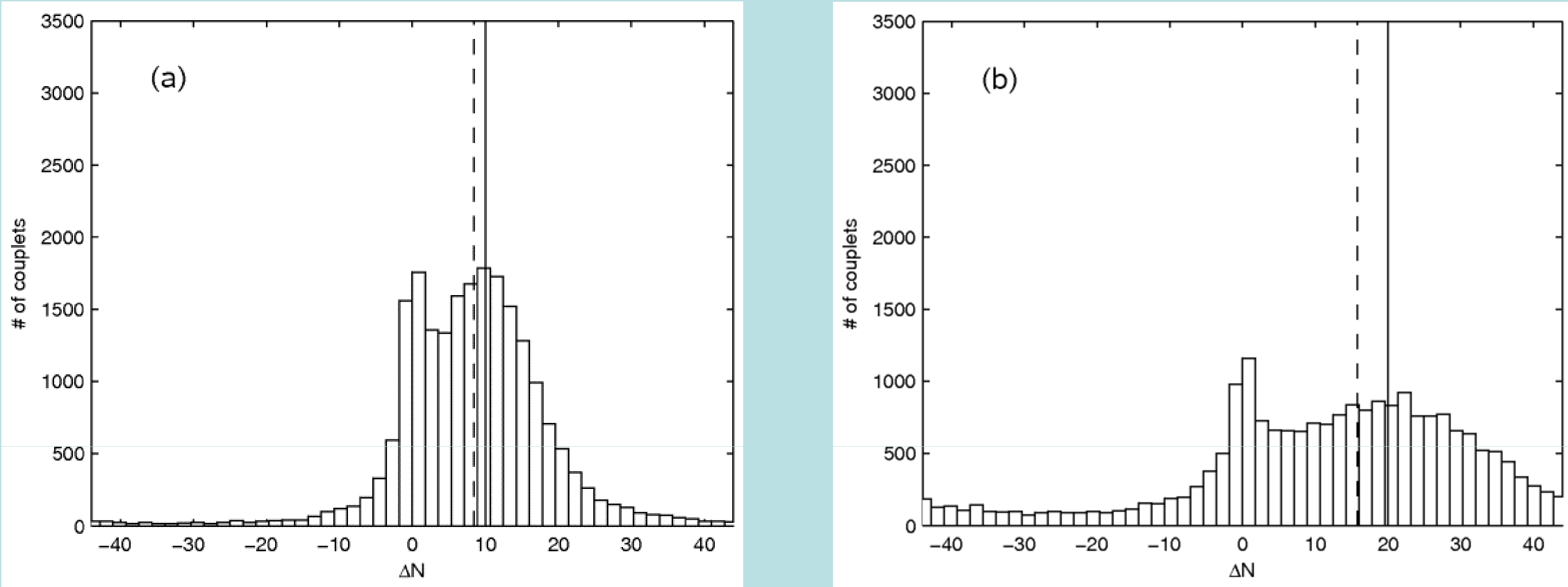


Figure 5a and 5b from Nicol and Illingworth, 2012: The effect of phase-correlated returns and spatial smoothing on the accuracy of radar refractivity retrievals (accepted subject to minor revision; JTech)