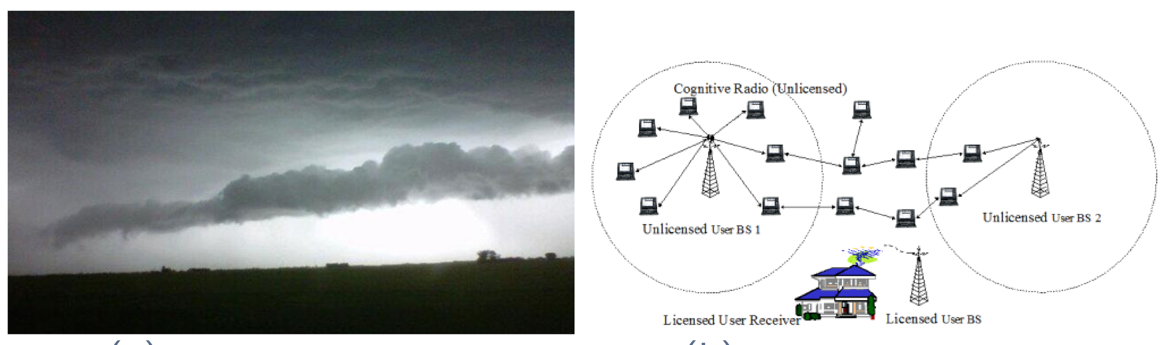
ESTIMATION OF THE ATMOSPHERIC REFRACTIVITY FROM WEATHER RADAR DATA

Rubén Nocelo López
Advisor: Verónica Santalla del Rio
Signal Theory and Communications Department - University of Vigo

Motivation of the work

- The atmospheric refraction is the anomalous propagation phenomenon that describes how the electromagnetic waves path departs from a straight line through the air due to variation of the temperature, the water vapor pressure (humidity) and the air pressure.
- Knowledge of temporal and spatial variations of the refractivity in the lowest part of the atmosphere is of importance in numerous fields, such as:
  - Meteorology where it is used to derive temperature and humidity which is important because the convergence of moisture at low-levels is related to the initiation of severe storms and large horizontal variations in moisture are related to initiation of deep convection [1].
  - Electromagnetic wave propagation coverage prediction, where in this case, it is important to reduce interference between nearby stations and to ensure the required signal level within the whole coverage area. Besides, knowledge of the refractivity gradient with enough temporal resolution will be of interest in the dynamic management of the spectrum.



(a) Meteorology Field (b) Coverage Prediction
Figure 1: Examples of application.

- Nevertheless, the most commonly used techniques such as radiosonde launches, radio occultation techniques using a GPS signal or the use of signals of opportunity are not able to provide sufficient spatial or temporal resolution and they are not suitable for measuring near surface refractivity.
- Recently it has been shown that refractivity can also be obtained from radar measurements [2, 3]. In particular, it can be obtained from measurements of phase variation between responses from different stationary targets at different instants of time. This method has the advantage of being able to achieve high spatial and temporal resolution.

$$\Delta N(\Delta_r, \Delta_t) = \frac{c}{4\pi f \Delta_r} 10^6 \Delta(\Delta\phi(\Delta_r, \Delta_t))$$

- Several experiments have been conducted to measure the refractivity using weather radars. However, all of them have been performed over flat terrain so that, the vertical variation of the refractivity has not been taken into account neither could be estimated. Furthermore, other factors that may lead to errors in the refractivity, as vegetation sway, frequency drift, uncertain position of targets in a cell or variations in target height, require further analysis. Hence, remaining challenges are to quantify these errors, to estimate the vertical gradient of the refractivity and to characterize statistically its temporal and spatial variation.

Thesis objective

- The objective of this thesis is to study, analyse and improve the actual algorithms for estimating refractivity by means of weather radar data. With this purpose the work lines considered will be:
  - On one side, a more accurate description of the phenomena involved to reduce uncertainties improving the existing algorithms to estimate the refractivity taking into account the height variation between the selected targets whose paths might be misaligned and the vertical variation of the atmospheric refractivity.

$$\Delta N(\Delta_r, \Delta_t) = \Delta N_0(\Delta_r, \Delta_t) + \Delta h(\Delta_r) \cdot \Delta\left(\frac{\partial N(\Delta_r, \Delta_t)}{\partial h}\right)$$

  - On the other side, a study of the statistics of the temporal and spatial variations of the data looking to improve the actual refractivity estimators.

$$V(r_k, t) = \int_v S(v, t) e^{-j\frac{4\pi}{\lambda}\int_0^{r(v)} n(r_k, t) dr} dv = I(r_k, t) + j \cdot Q(r_k, t)$$

Research Plan

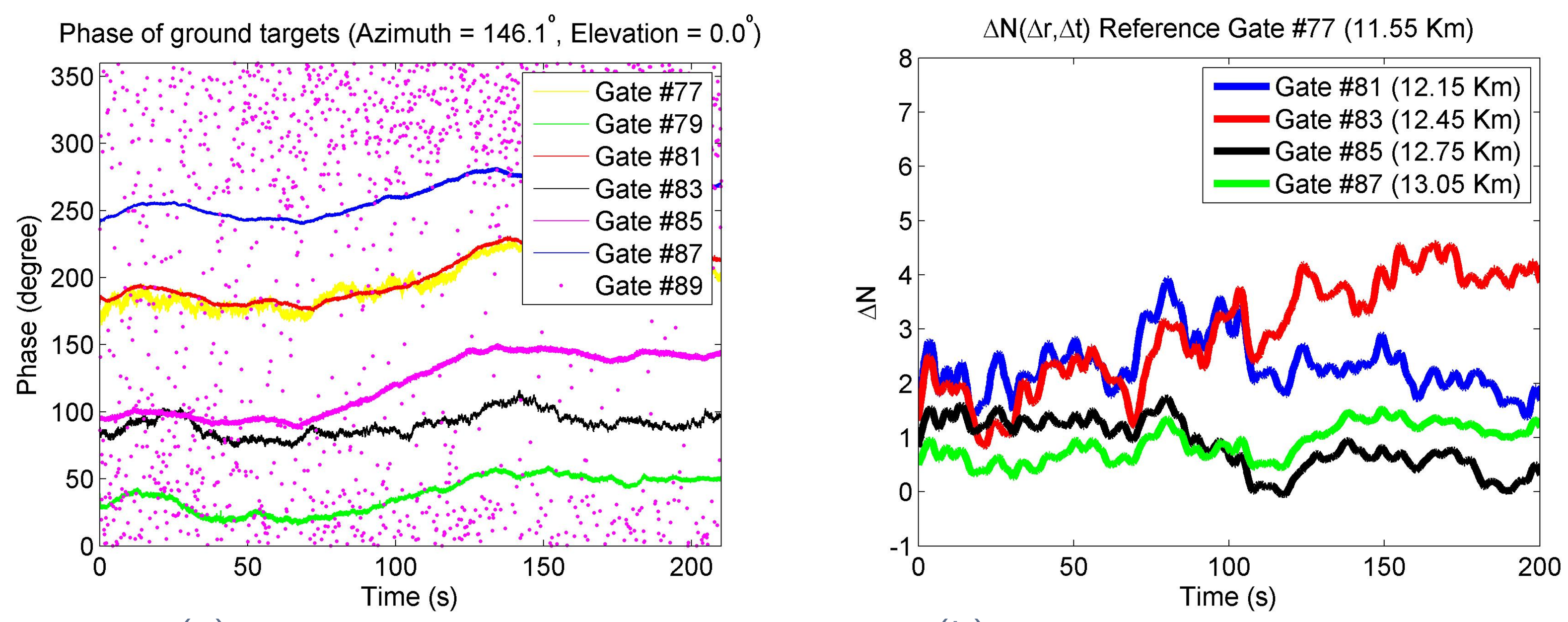
- In order to achieve the objectives proposed the following research plan is considered. This plan is revised after each task in view of the results obtained.
  - Bibliographical review. Critical discussion of the benefits and drawbacks of using weather radar data (Sept. 2013-Febr. 2014).
  - Analysis and improvement of wave propagation models. First proposal of an estimation algorithm for the refractivity (March 2013-Aug. 2014).
  - Evaluation of available technological resources (March 2013-Aug. 2014).
  - Planning of measurement campaign (March 2013-Aug. 2014).
  - Implementation of the proposed algorithm (Sept. 2014-Aug. 2015)
  - Analysis and comparison, in different sceneries, of the proposed algorithm and others in the related literature (March 2015-Febr. 2016)
  - Dissemination of the results (Thesis) (March 2015-Aug. 2016).

Next Year Planning

- Future works will be focused on including height variations of refractivity, whenever the radar and the clutter are not at the same height, and correspondingly, modifying the estimation algorithms.
- For this purpose, Square Trihedral Reflector Antennas will be placed in known positions to improve the accuracy of the results.

First Results

- The polarimetric weather radar data provided by the C-Band radar (Vaisala WRM200) of Meteogalicia located in Monte Xesteiras over mountainous terrain (Galician Region, Spain) will be used with the proposed algorithm to estimate refractivity and to analyze its statistical properties.
- The radar data provided by the Sigmet RVP8 Digital Receiver and Signal Processor of Vaisala does not contain the phase information required to obtain the refractivity. To solve this, the TS ARCHIVE software packet was acquired to record time series and playback I/Q data.
- Real data have been processed to identify stationary targets. This is a fundamental step as small variations in the target can lead to useless results. It is done analyzing the phase variations of radar returns.
- Using the phase of the received signals from stationary targets, the refractivity variations between different gates have been obtained using the algorithm described in [3].



(a) Phase of ground targets (b) Averaged Refractivity Variations
Figure 2: Measurements from stationary targets.

  - **R. Nocelo, V. Santalla and A. Pettazzi.** "Estimation of the Atmospheric Refractivity Using a C-Band Polarimetric Weather Radar". In the **8th** European Conference on Antennas and Propagation (EuCAP), The Hague, The Netherlands, April 2014.
- The phase error due to different sources of uncertainty such as the position of the target in a resolution cell, the temporal variation of the target (vegetation sway), the spatial variation of the refractive index and the frequency drift of the magnetron transmitter is being quantified to obtain a more accurate estimation of the refractivity.
  - **R. Nocelo and V. Santalla.** "Statistical Characterization of the Atmospheric Refractivity from Weather Radar Data". In the **8th** European Conference on Radar in Meteorology and Hydrology. (ERAD), Garmisch-Partenkirchen, Germany, September 2014.

References

[1] C. Ziegler, T. Lee and R. Pielke.
Convective initiation at the dryline: A modeling study.
In Mon. Weather Rev., Vol. 125, June 1997.

[2] F. Fabry, C. Frush, I. Zawadzki and A. Kilambi.
On the Extraction of Near-Surface Index of Refraction Using Radar Phase Measurements from Ground Targets
In Journal of Atmospheric and Oceanic Technology, Vol. 14, December 1996.

[3] F. Fabry.
Meteorological Value of Ground Target Measurement by Radar
In Journal of Atmospheric and Oceanic Technology, Vol. 21, September 2003.