Testing of a new gravity wave based clear-air turbulence diagnostic

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Introduction

The coincidence between gravity waves (GW) and clear-air turbulence (CAT) has been evident for a long time (e.g. Bekofske and Liu, 1972). In recent years due to better data availability and improving understanding of GW dynamics possibilities of predicting CAT induced by GW are being researched (e.g. Kopec et al., 2011; Sharman et al., 2012; Knox et al., 2008). In the presented work we investigate application of an approach based on work by Haman (1962). This approach uses the amplitude evolution equation for slantwise propagating gravity waves to predict possible occurrences of Clear-Air Turbulence (CAT) near wave breaking regions.

Vertical Evolution of a Monochromatic GW Amplitude

- The idea by Haman (1962): shallow convection arises a spectrum of monochromatic GW immediately above cloud tops.
- The vertical evolution of the amplitude of a monochromatic GW (wavenumber k and phase speed ϵ) is predicted using:

$$s'' + \left(\frac{u'}{u-\epsilon} - \frac{\mathrm{g}}{\mathrm{c}^2} - \beta\right) s' + \left(\frac{\mathrm{g}\beta}{(u-\epsilon)^2} - \mathrm{k}^2\right) s = 0$$

- Wave is expected to break into turbulence when either it encounters critical level or $\mathrm{K} = \left|\frac{u-\epsilon}{u}\right| \left((2\pi)^{-1}\mathrm{k}|s| + |s'|\right)$ (Kopec et al., 2011)

Data used for verification

- 3 months (Jan-Mar 2010) of AMDAR observations (226989 observations)
- Filtered assure no cloud, cruise conditions (only 4011 observations remain)

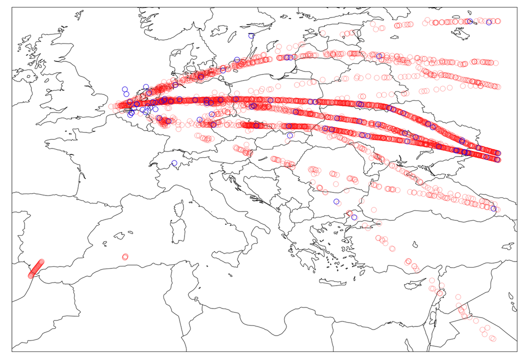

Figure: Geographical distribution of the observation set used for validation (blue dots - moderate or greater turbulence)

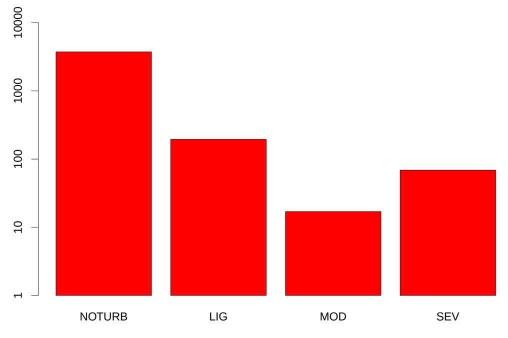

Figure: Turbulence intensity distribution of the observation set used for validation (logarithmic scale)

Index Construction

For each atmospheric profile breaking heights of a set of 1890 monochromatic waves are calculated. Wavelengths and phase speeds of the waves corresponded to scales of shallow convection and form a uniform and isotropic spectrum. Resulting index $N_\Delta(z)$ was the number of waves broken in some thickness interval Δ around height of interest z Due to lack of relevant information about convection the index was evaluated everywhere as a probabilistic measure.

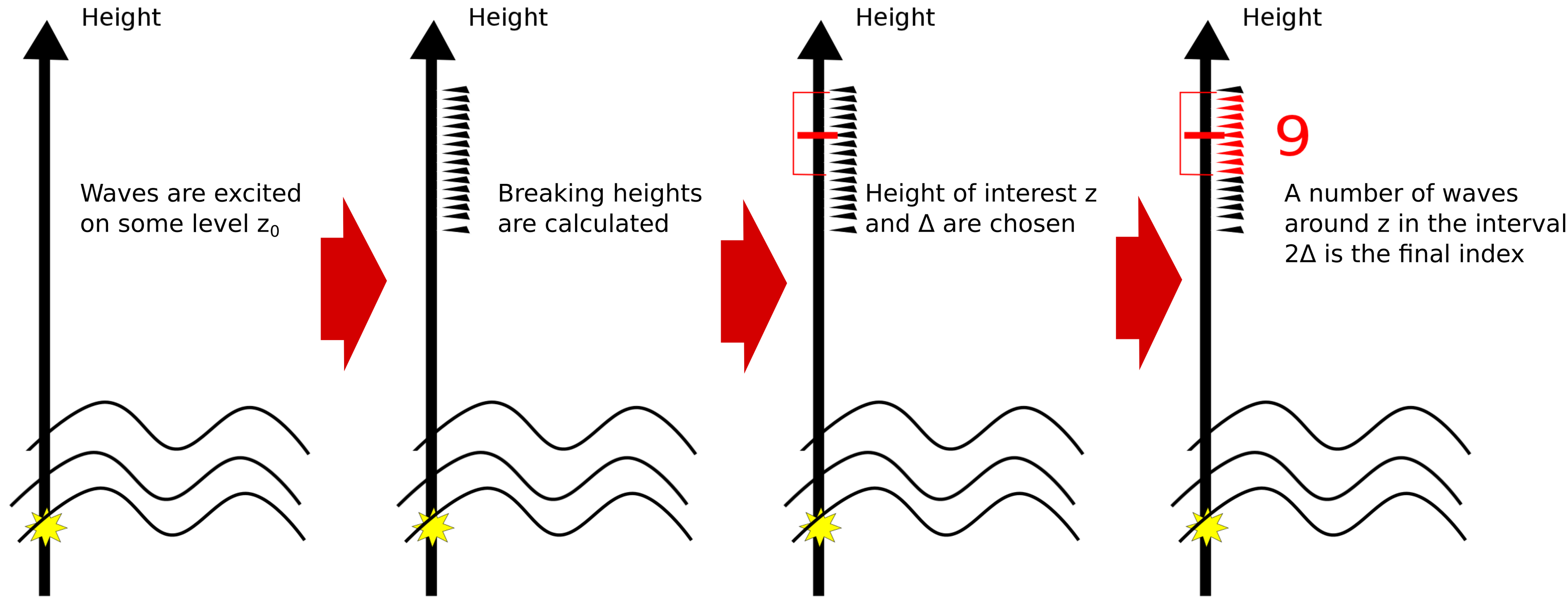

Figure: Scheme of $N_\Delta(z)$ calculation

Verification procedure

- The index N_Δ was tested for detection of moderate or greater (MOG) turbulence
- The index was calculated for a set of 180 values of Δ uniformly distributed in the interval $(45m, 8995m)$
- The indices for small Δ result from the waves broken near the aircraft larger Δ means less localized information
- The measure of skill was Area Under ROC Curve (AUC)
- Verification was conducted for all observations, 3 months separately and 8 11-day periods.

Verification results

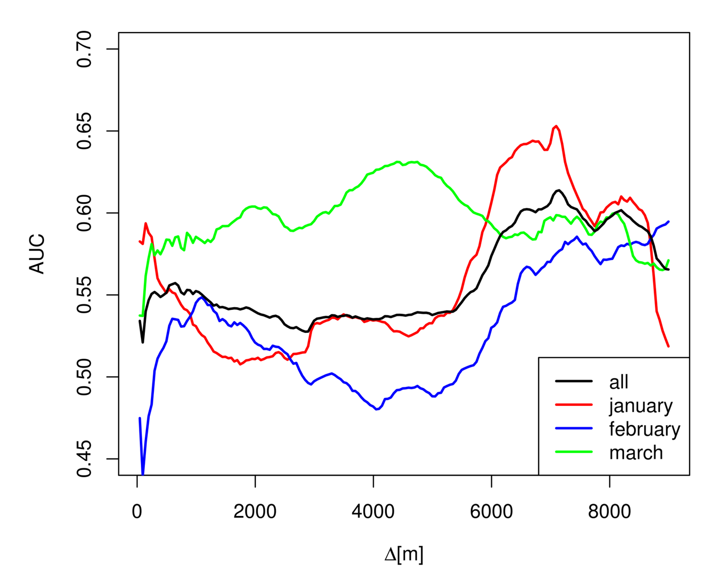

Figure: AUC for set of 180 values of Δ uniformly distributed in the interval $(45m, 8995m)$ for all data and separately for each of the three months

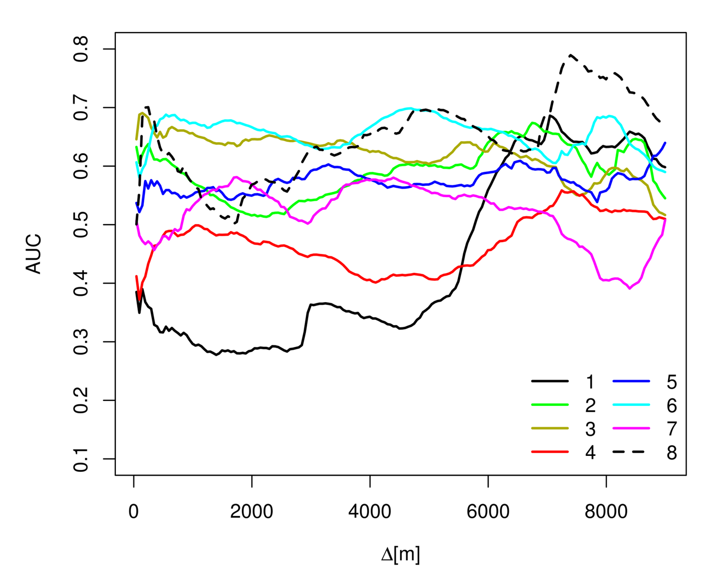

Figure: AUC for set of 180 values of Δ uniformly distributed in the interval $(45m, 8995m)$ for 11 day periods ranging from 01.01.2010 to 31.03.2010. The numbers in the legend denote the order of the periods.

Random forest based ensemble index

In order to use a possibly distinct information provided by N_Δ with varioius Δ we have used a random forest algorithm (Breiman, 2001) in the version ported to R language (Liaw and Wiener, 2002). As a training set the January data were used. First the model reduction was run based on Boruta algorithm (Kursa and Rudnicki, 2010) (45 runs). It showed that only 6 of 180 N_Δ are enough for construction of the ensemble. 600 ensembles were trained using random subsets of January data that were chosen in the way that assured balanced turbulence class composition.

Verification Procedure

- Ensembles were tested for detection of moderate or greater turbulence
- Ensembles were tested against January data (minus trainaing set), February data and March data.
- The measure of skill was Area Under ROC Curve (AUC)

Verification Presults

- The January tests show that there exist ensembles that are good short time predictors (AUC up to 0.759), comparable with GTG1!
- Ensembles with extreme values of AUC tend to maintain this feature but from month to month they change from good predictors to 'perverse' predictors.

Verification Results

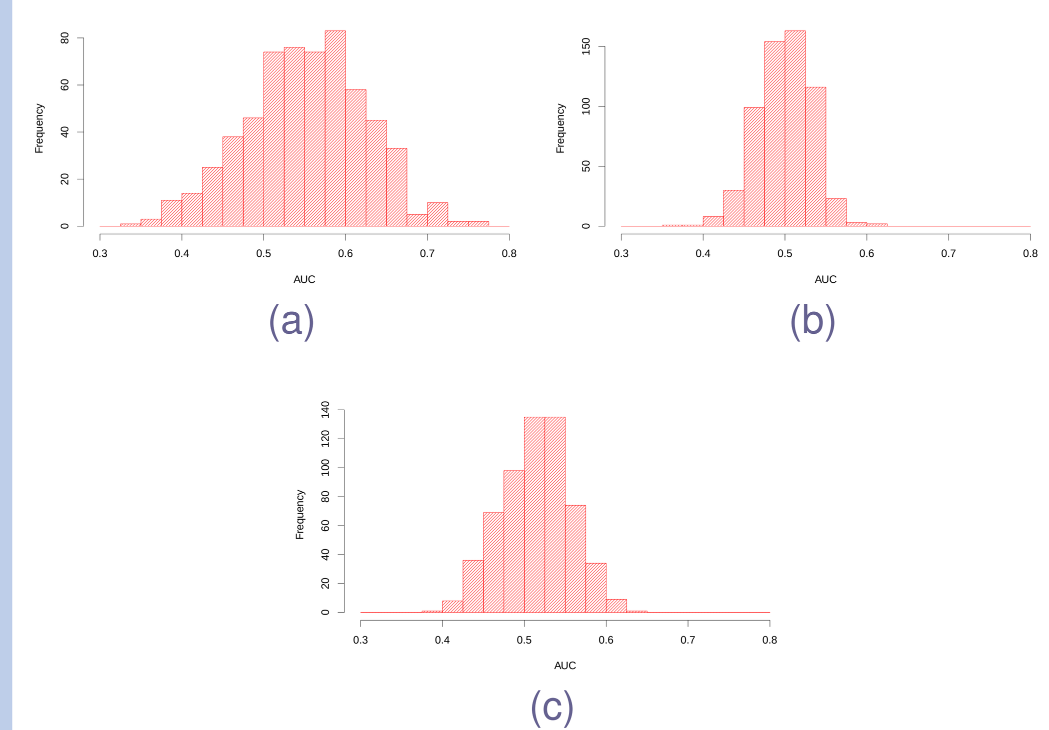

Figure: AUC distribution for tested 600 random forest predictors. 6a depicts the test using January data, 6b using February data and 6c using March data.

Conclusion

- Indices N_Δ show chaotic behaviour possibly caused by lack of consideration of shallow convection which was assumed a GW forcing
- Indices N_Δ usually bear relevant information about CAT but the most relevant Δ changes with time thus they could be used as a member ensemble predictor but not as standalone index
- We have combined N_Δ indices using random forest based method and the resulting ensembles display more predictable behaviour and show potential to be good short-time predictors.

Acknowledgements

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