Applications of the reflected signals found in GNSS radio occultation events

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Motivation

- 40 to 60 % of occultations present traces of reflected signals
- Reflected signals cross the atmosphere in a different geometry than direct radio-link --> useful complementary atmospheric information?
- Reflected signals might depend on properties of reflecting surface --> source of surface information? (altimetry, sea/ice properties...?)
- GRAS SAF CDOP: work package devoted to investigate potential use of reflected link to help operational weather (data assimilation) and climate GRAS applications

Outline

- Do reflected signals *contaminate* the standard atmospheric retrievals? Simulation work
- Empirical statistical work:
  - Automatic detection of reflected signals: Support Vector Machines (SVM) classification flag
  - Classification of 102,000+ occultations
  - Correlation between classification flag and quality of the retrieved profiles (comparison with ECMWF backgrounds)
- GOAL: potential use of reflection classification flag to help data assimilation?

Simulation Work

- Reflected electromagnetic field has different Doppler effects than direct-link.
- They both reach the receiver simultaneously (last seconds in setting occultation/initial seconds in rising occultation), and sum-up coherently
- They interfere generating interference patterns in both phase and amplitude
- HOW THIS INTERFERENCE AFFECTS THE STANDARD (i.e. CT-like) ATMOSPHERIC RETRIEVALS?

Simulation Work

- Multi-phase screen simulation of GNSS occultation with reflected signals off the Earth surface (M. Gorbunov): `original` level-1 synthetic data (time series phase/amplitude) with reflected signal present
- We have cleaned the reflected signal out:

(1) to generate radio-hologram (FFTs)

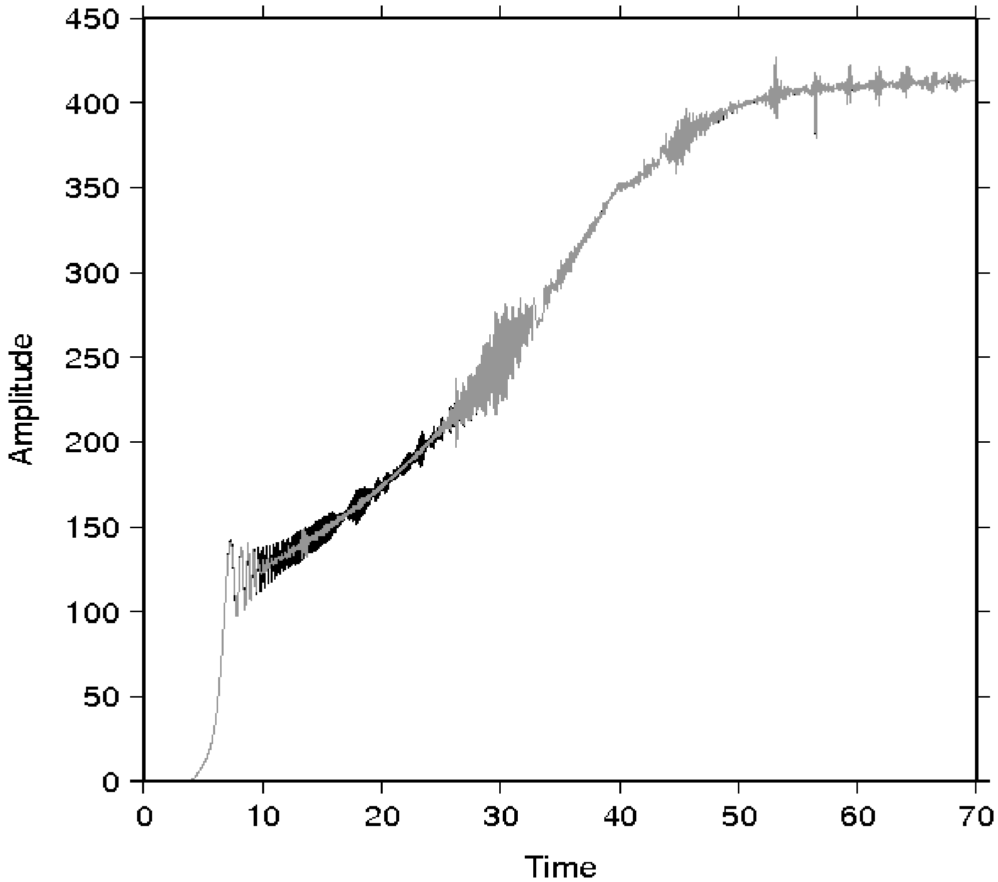
(2) to reduce reflection “horn” down to noise level

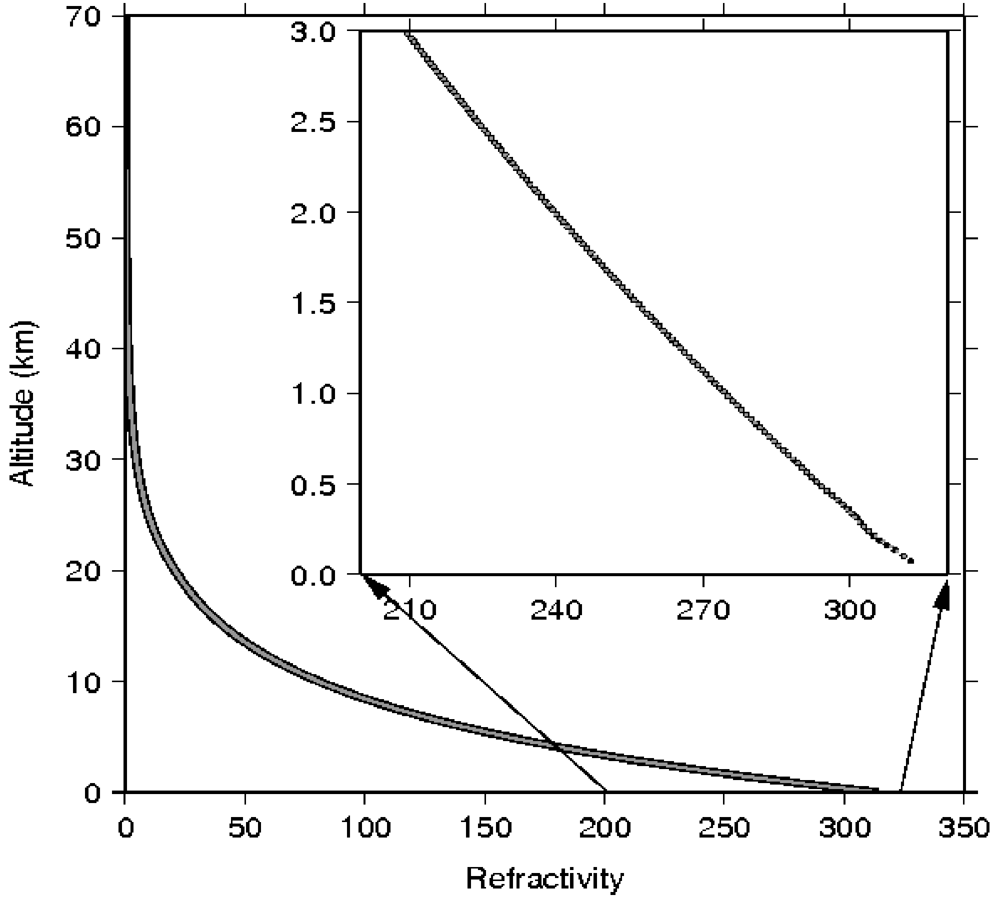
(3) to bring back to initial space (inverse FFTs)

as a result: level-1 `clean` data

- Both `original` and `clean` data inverted to atmospheric profiles (refractivity, bending angle, dry temperature)

Simulation Work





- CT-like inversion techniques implicitly filter out the reflected signals. SOLUTIONS INVARIANT TO PRESENCE OF REFLECTED SIGNALS

Empirical Work

In spite of simulation result, we aim to check whether the quality of the real retrieved profiles shows any relationship with presence of reflected signals:

Massive statistic comparisons (69,359 occultations) between COSMIC retrieved profiles and the ECMWF background (all from post-analysis)

Methodology:

(1) to implement a tool to automatically classify the occultations (from level-1 data) depending on the presence of reflected signals

(2) to compare both COSMIC and ECMWF post-processed background profiles

(3) to analyze the comparison as function of the reflection classification

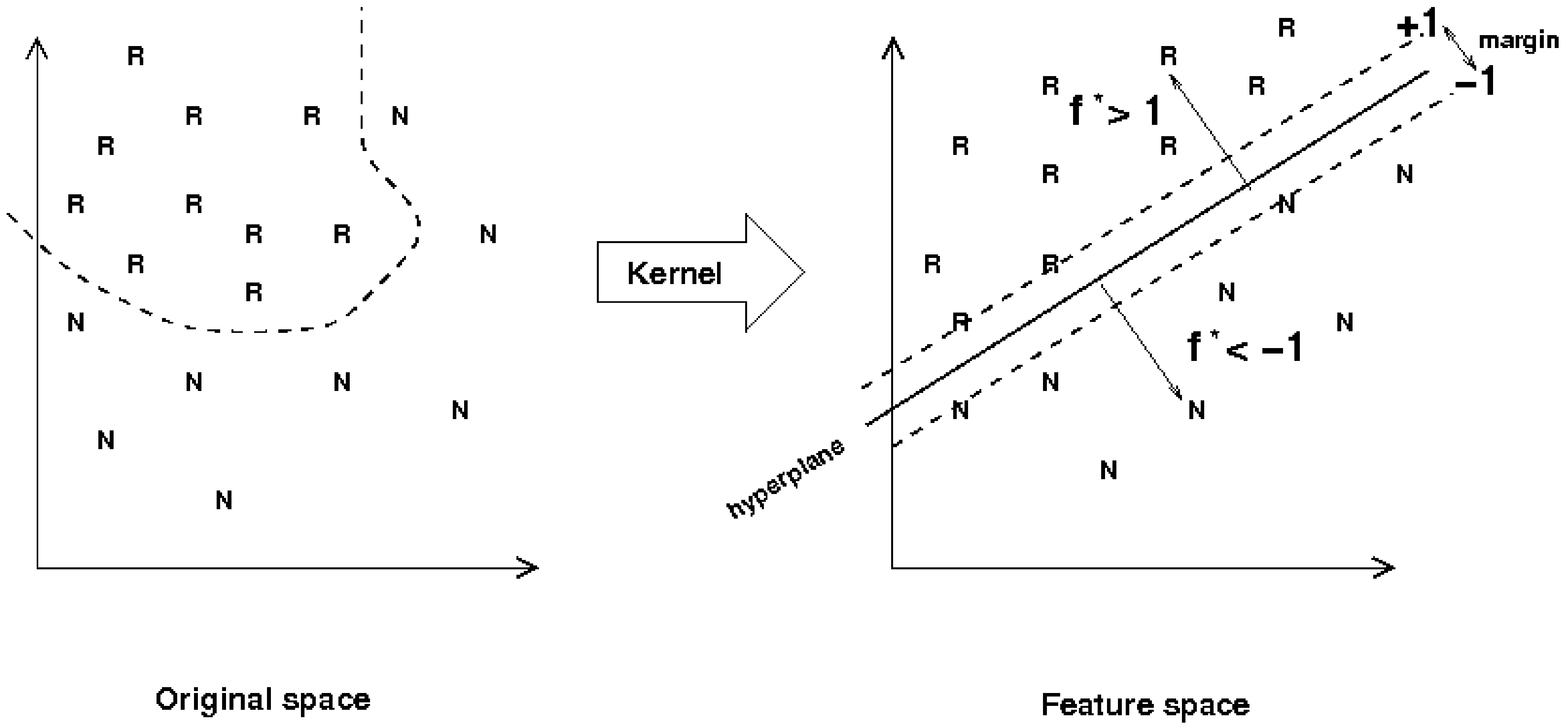
Automatic Detection

Support Vector Machine (SVM) is a supervised learning method based on **optimization theory**.

Given a *training set*, the SVM finds the linear function, f*, such that optimally separates the space of the samples to be classified, x, (occultations) in the desired classes.

Since the space of occultations cannot be linearly separated, a Kernel function (Phi) is used to map them into another *high dimensional feature space* (Phi(x))

Automatic Detection



Sketch of SVM approach in 2-D (two-pixel images)

Automatic Detection

In our case:

Samples, x= radio-holographic data of the occultations, of dimension 7236 (total number of pixels)

Kernel, Phi= exponential function (radial bases function)

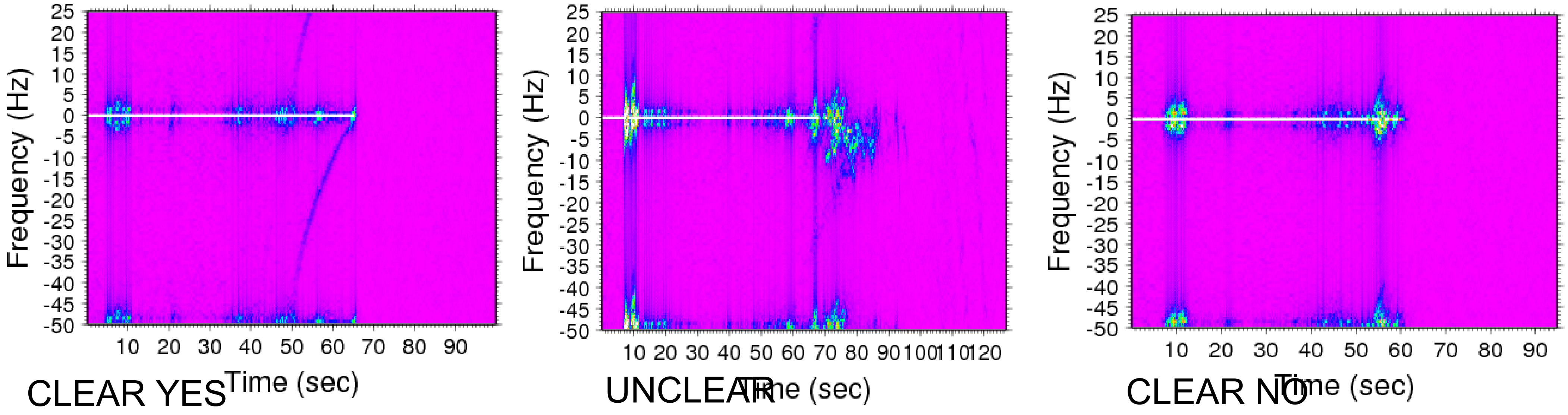
Feature space, space of Phi(x), in which we assume the reflection/no reflection points can be separated by an hyper-plane

Training set= 6468 COSMIC setting (including open-loop data) occultations and their user-given classification (visual inspection), 57% of them with CLEAR reflected signals, rest with CLEAR no-reflected signals

Classes= positive for reflection, negative for non-reflection

Algorithms, from *Joachims (2001)*

SVM: validation



Training with clear YES and clear NO solely

VALIDATION on 1666 occultations previously visually classified as clear YES and clear NO: 99.8% success beyond margin zone (yes/no when f*>1 and f*<-1 respectively); **98.5% success beyond 0.5 threshold** (yes/no when f*>0.5 and f*<-0.5 respectively)

VALIDATION on ~5000 occultations visually classified as unclear: 90% lie within the margin zone.

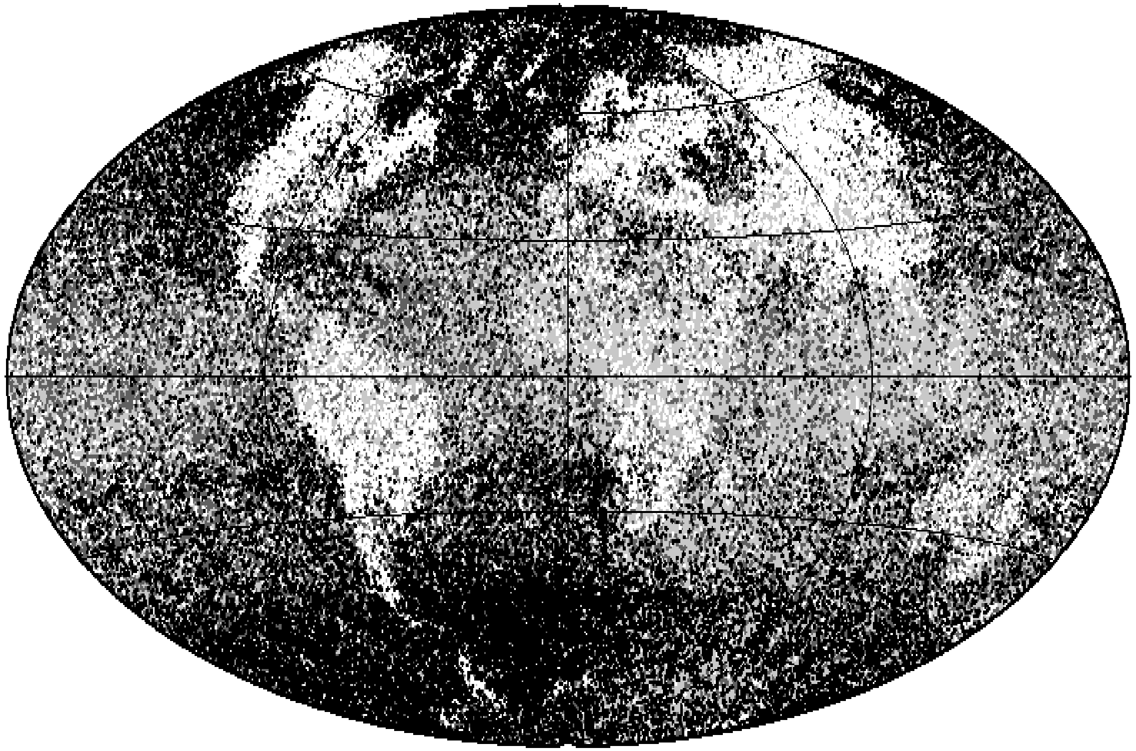
Reflections: seasons/geography

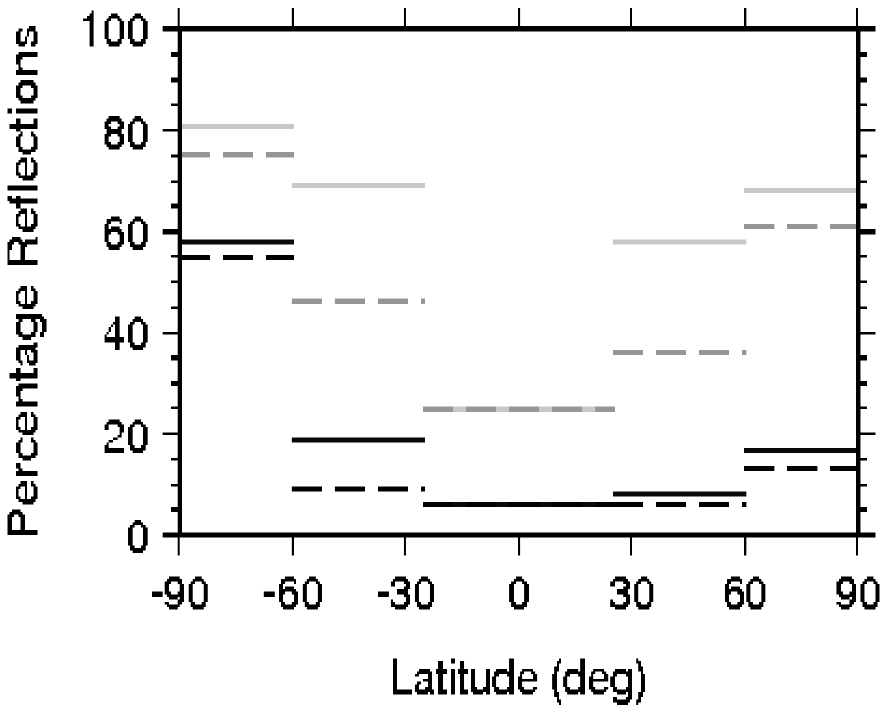
SVM used to classify 102,118 COSMIC setting occultations:

60% lie out of +-0.5 (reduced margin). We assume reflection when f*>0.5

Geographic pattern: reflections are only 7% of land occultations. Ocean much higher, depends on latitude

Seasonal effects: noticeable over oceans, more reflections in local winter times





Data Quality

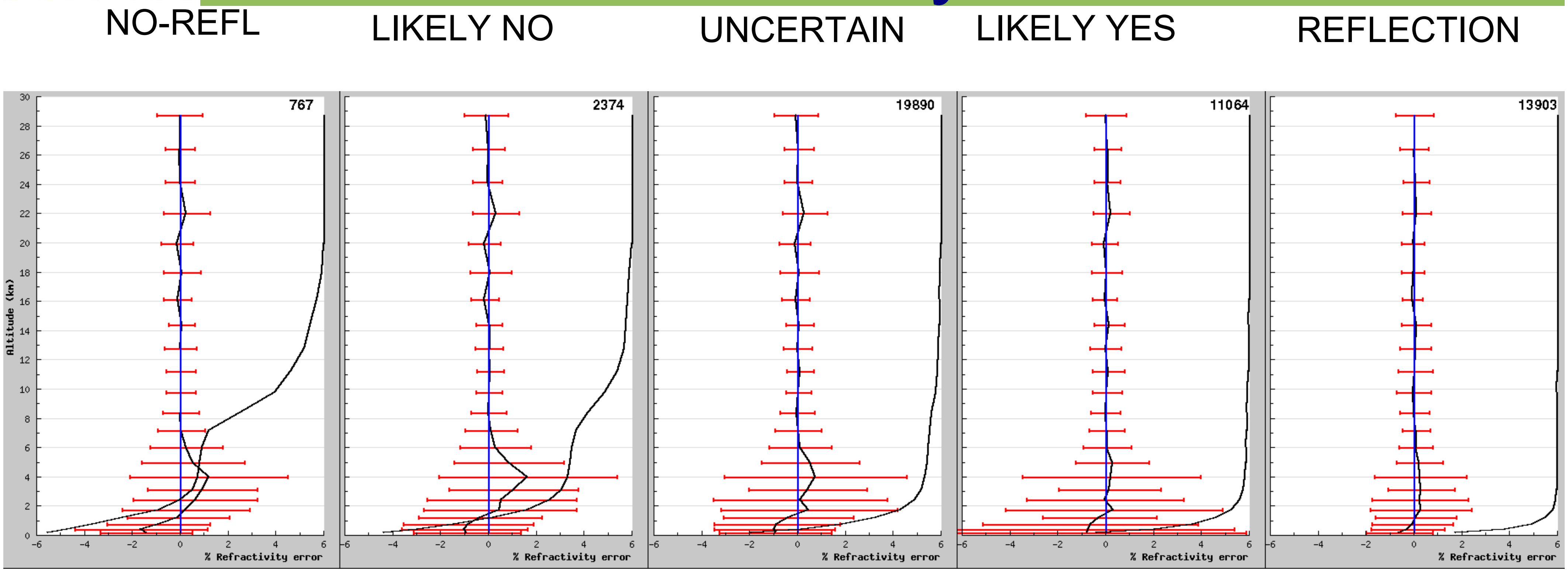
69359 SVM-classified occultations had Level-2 refractivity profiles/ECMWF background (post-analyzed) available:

Bias and Standard deviation: computed on each layer

Results grouped according to

- SVM-flag value
- Ocean/Land mask
- Latitude belt

Data Quality: 48,000 Ocean



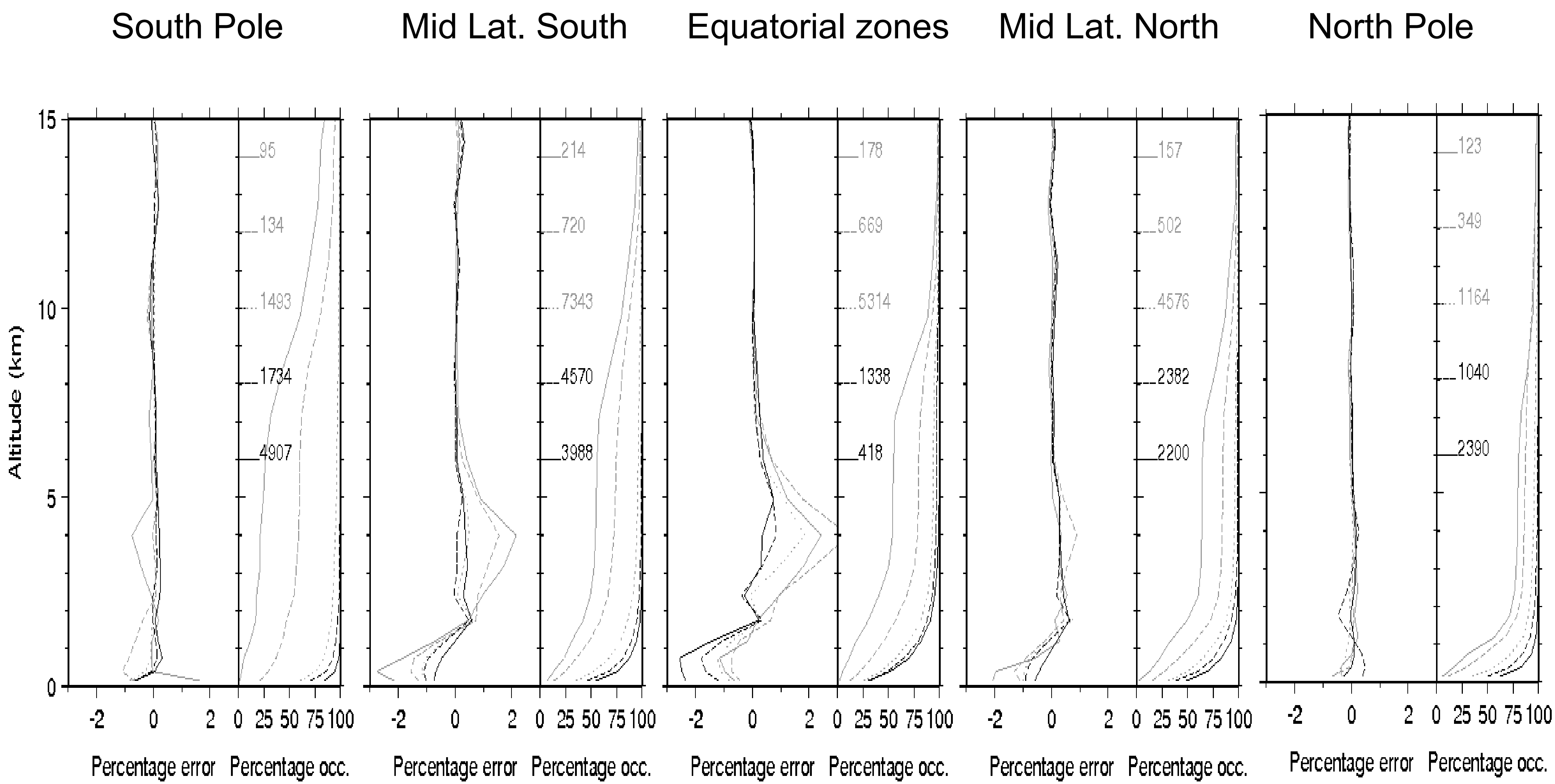
Positive bias (~4 km altitude): Significant in occultations without reflection. Almost disappear in occultations with reflections.

Negative bias (~1-2 km): reduced when reflected signals are present.

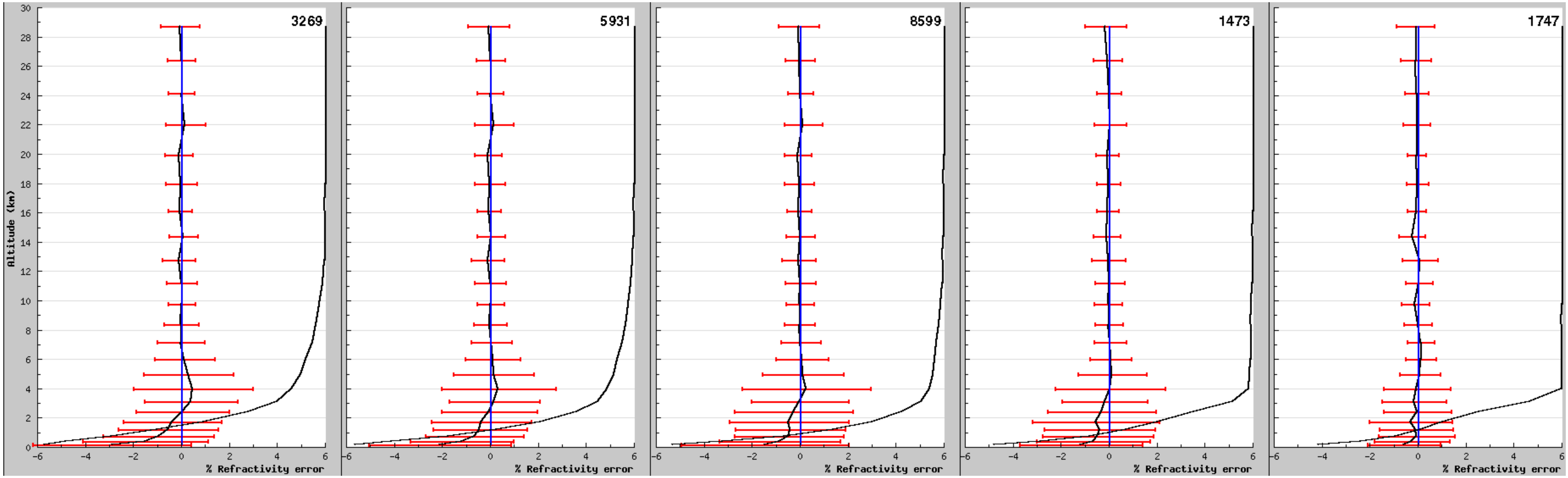
Standard deviation: smallest when clear reflections

Number of events at lower layers: reduced below 10 km when no-reflections present.

Quality: Ocean Latitudes



Data Quality: 21,000 Land



Land occultations represent 30% of the total

Only 7% of Land occultations present reflected signals

Both positive and negative biases reduced when presence of reflected signals

Conclusion

(1) Reflected signals interfere with direct link, but it **does not affect the atmospheric retrievals**, according to simulation work

(2) SVM implemented to **detect reflected signals** in Level-1 data. Trained on 6468 occultations, validated on 1666 clear YES/NO, ~5000 UNCERTAIN cases. Overall **success at 98.5%** level.

(3) 102,118 occultations classified with SVM. **Geographic/seasonal patterns**

(4) Atmospheric retrievals from occultations **with reflected signals compare better** to ECMWF.

→ **Towards operational reflection flag for GRAS**

→ **Need to investigate how to use this flag to help data assimilation**