GNSS RO Sampling for Climate Purposes

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Outline

- Introduction to sampling error for GPS RO
- Bayesian interpolation
  - Under-fitting and over-fitting
  - Two levels of inference
- Application to CHAMP and COSMIC
  - Evidence for basis and regularizer
  - Simulations of sampling error
- Systematic sampling error
  - Singularities in sampling density
  - Under-resolution of atmospheric structure
- Conclusions
Sampling Error

- Simulate a distribution of soundings.
- Interpolate reanalysis to time and location of soundings.
- Form climatology based on reanalysis “data”: height of 200-hPa dry pressure surface.
- Compare to reanalysis gridded “truth”.
Sampling Error

- Simulation
- Interpolation
- Form closure correction
- Comparison

height of
Sampling Error

- Simulation
- Interpolation
- Form closure
- Comparison
Analysis: Bayesian Interpolation

\[ \chi^2 = \beta |t - \phi w|^2 + \alpha w'Cw \]

\[ B = \phi'\phi \]

\[ A = \beta B + \alpha C \]

First inference: \[ w = A^{-1} \beta \phi' t \]

Second inference: \[ \gamma = k - \alpha \text{Trace} A^{-1} C = N - \beta |t - \phi w|^2 \]

Evidence: \[ P(t \mid B, R) = \alpha_{\text{MP}}^{k/2} \left( \frac{\beta_{\text{MP}}}{2\pi e} \right)^{N/2} \left( \frac{|C|}{|A|} \right)^{1/2} \Delta \alpha \Delta \beta \]
Example fits: CHAMP and COSMIC
Tunable parameters

• **Basis**
  - maximum degree of spherical harmonic expansion $l_{max}$, bears on spatial resolution

• **Regularizer**
  - Exponent of curvature penalty $\mu$
  - Relaxation of global mean penalty $\rho$
  - Relaxation of meridional gradient penalty $\nu$
Evidence

CHAMP

COSMIC

Meridional Gradient Coefficient $v$

Meridional Gradient Coefficient $v$
Sampling error: Monthly averages

- Minimum number of spherical harmonic degrees to resolve atmospheric structure
- Denser data means smaller sampling error
- Mid-latitudes have largest sampling error because of synoptic variability
Sampling error: Penalty exponent

Northern mid-latitudes

Tropics

Southern mid-latitudes

(a) 

(b) 

(c) 

Max degree of expansion

Standard deviation [m]
Sampling error: Reduce time window

Northern mid-latitudes

Tropics

Southern mid-latitudes

![Graphs showing standard deviation vs. max degree of expansion for different regions and satellite types.](image)
Systematic Sampling Error

Binning and averaging
Systematic Sampling Error

Binning and averaging

Bayesian interpolation

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Leroy et al.: GPS RO Sampling
Systematic sampling error cause

Latitude = 48.84°, 21.14° N & S

δ = δ_m
Summary

- Using the height of the 200-hPa dry pressure surface, CHAMP requires a 14th degree spherical harmonic fit, COSMIC a 20th degree fit.
- Little gained from relaxing penalty for meridional gradients, global mean. Optimum penalty is the square of the curvature.
- Reducing the sampling time permits better resolution of both spatial and temporal structure of synoptic variability.
- Bayesian interpolation eliminates problem of systematic error in binning and averaging climatologies but introduces another due to spherical harmonic truncation. Fingerprinting studies should truncate spatial fingerprints accordingly.


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Extra slides
Present and Planned GNSS RO Missions

- **MetOp-A, EUMETSAT, 2006-present.** ~500 soundings daily; intermittent availability.
- **COSMIC, Taiwan (UCAR), 2006-present.** ~2800 soundings daily; degrading because of age.
- **TerraSAR-X, Tandem-X, DLR, 2008-present.** Both operational.
- **OceanSat, Indian Space Agency, carrying ROSA.**
- **EQUARS, Brazil-Japan.**
- **COSMIC-2, Taiwan-US.**