Sampling Error and Resolution of COSMIC and CHAMP RO Data

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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”.

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Sampling Error

- Simulation
- Interpolation
- Form closure
- Comparison
Sampling Error

- Simulation
- Interpolation
- Form 200-hP lines
- Comparisons

![Graph showing sampling error with height in km on the y-axis and geographical data on the x-axis.](image-url)
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:
\[ P(t | B, R) = \alpha_{MP}^{k/2} \left( \frac{\beta_{MP}}{2 \pi e} \right)^{N/2} \left( \frac{|C|}{|A|} \right)^{1/2} \Delta \alpha \Delta \beta \]
Example fits: CHAMP and COSMIC
Tunable parameters

• **Basis**
  - maximum degree of spherical harmonic expansion $l_{\text{max}}$, 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 $v$

$\rho = 1.0 \cdot 10^0$
$\rho = 1.0 \cdot 10^{-1}$
$\rho = 1.0 \cdot 10^{-2}$
$\rho = 1.0 \cdot 10^{-3}$
$\rho = 1.0 \cdot 10^{-4}$
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

![Graphs showing standard deviation vs. max degree of expansion for different regions and penalty exponents.](image)
Sampling error: Reduce time time window

Northern mid-latitudes  | Tropics  | Southern mid-latitudes

(a)  

(b)  CHAMP (2-day)  
     CHAMP (5-day)  
     COSMIC (2-day)  
     COSMIC (5-day)

(c)  

Standard deviation [m]

Max degree of expansion

0  5  10  15  20  25

0  10  12  14  16  18  20

0  10  12  14  16  18  20
Systematic Sampling Error

Binning and averaging
Systematic Sampling Error

Binning and averaging

Bayesian interpolation
Systematic sampling error cause

Latitude = 48.84°, 21.14° N & S
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.


- **OceanSat**, Indian Space Agency, carrying ROSA.

- **EQUARS**, Brazil-Japan.

- **COSMIC-2**, Taiwan-US.