Sampling Error and Resolution of COSMIC and CHAMP RO Data

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CLARREO Science Definition Team Meeting

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Outline

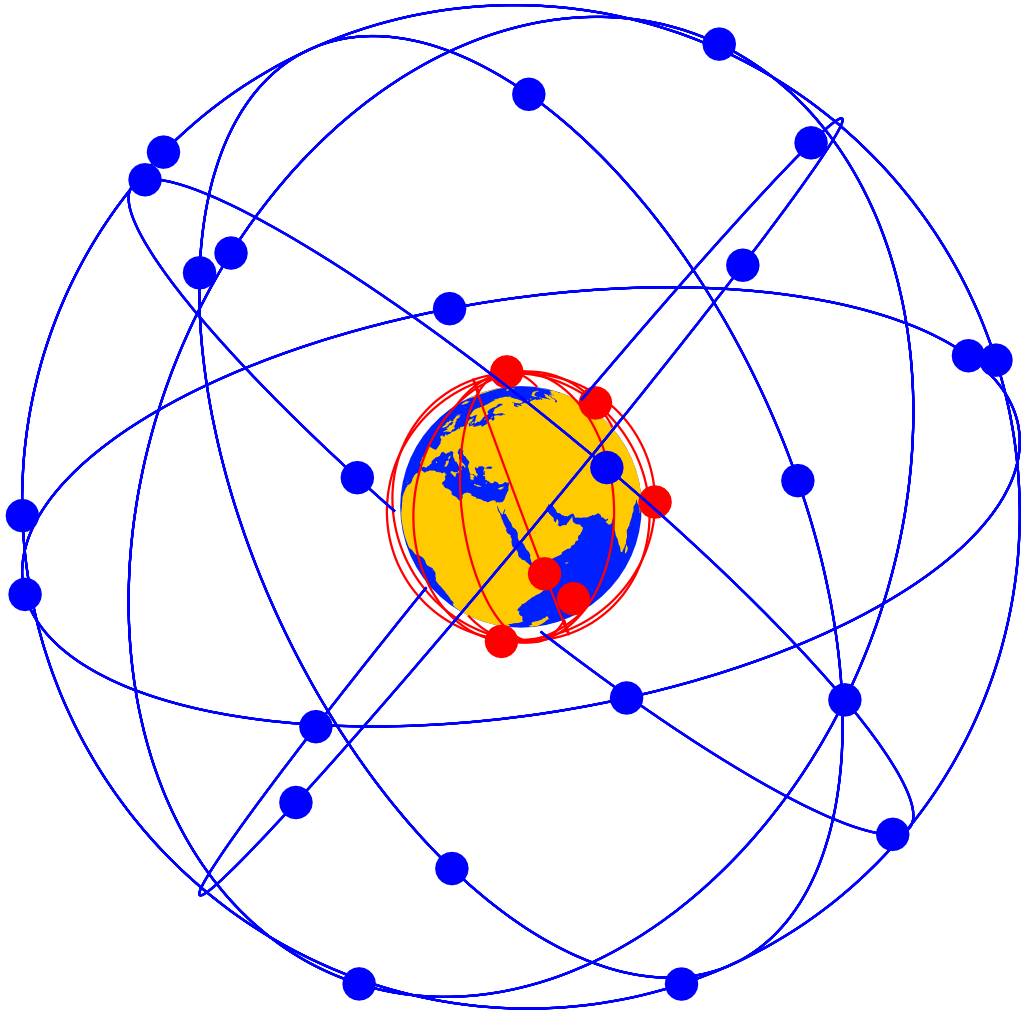
- Introduction to sampling error for GPS RO
- Bayesian interpolation
  - *Under-fitting and over-fitting*
  - *Two levels of inference*
- Application to CHAMP and COSMIC
  - *Evidence for basis and regularizer*
  - *Simulations of sampling error*
- Systematic sampling error
  - *Singularities in sampling 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

- Simulat
- Interpo
  soundi
- Form c
  200-hP
- Compa



height of

Sampling Error

- Simulat
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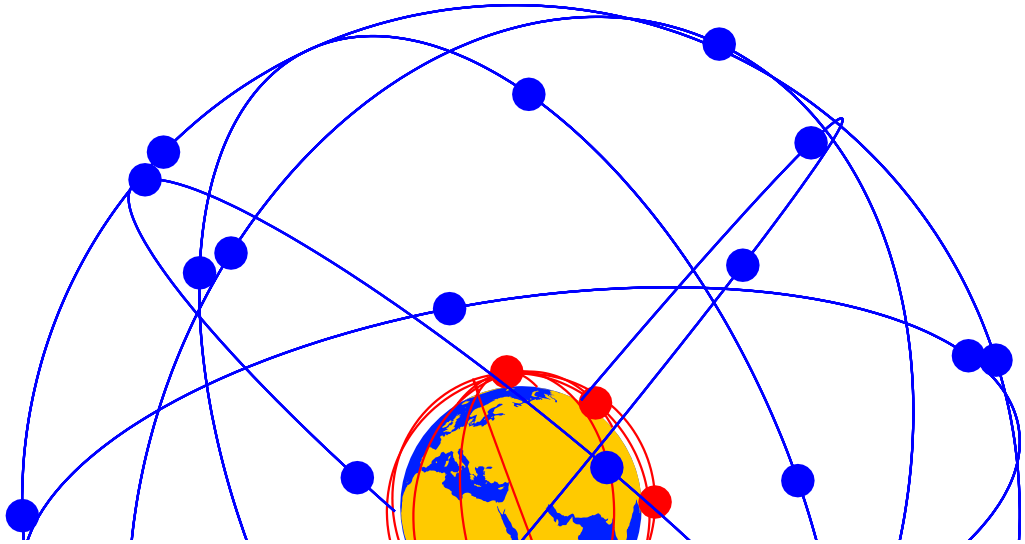
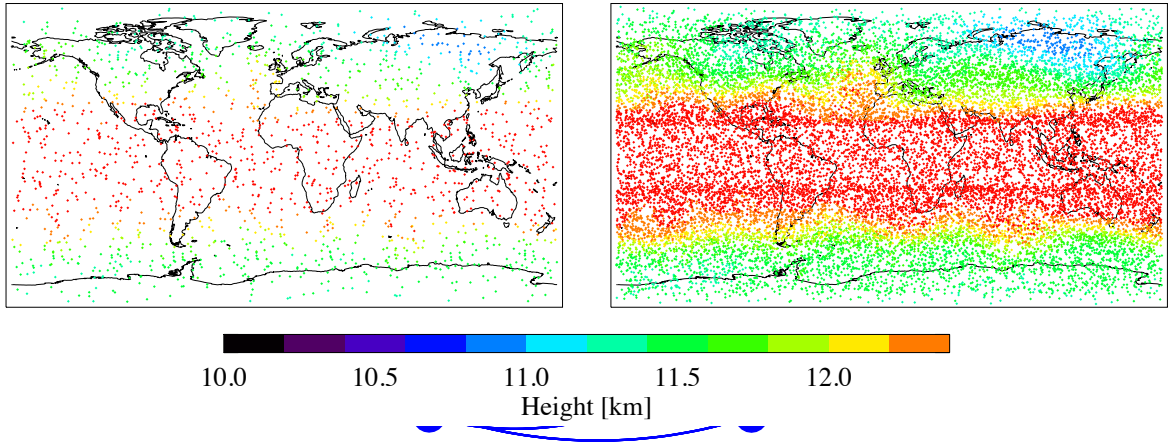


height of



Analysis: Bayesian Interpolation

$$\chi^2 = \beta\left|\mathbf{t} - \phi\mathbf{w}\right|^2 + \alpha\,\mathbf{w}'\mathbf{C}\mathbf{w}$$

$$\mathbf{B} = \phi'\phi$$

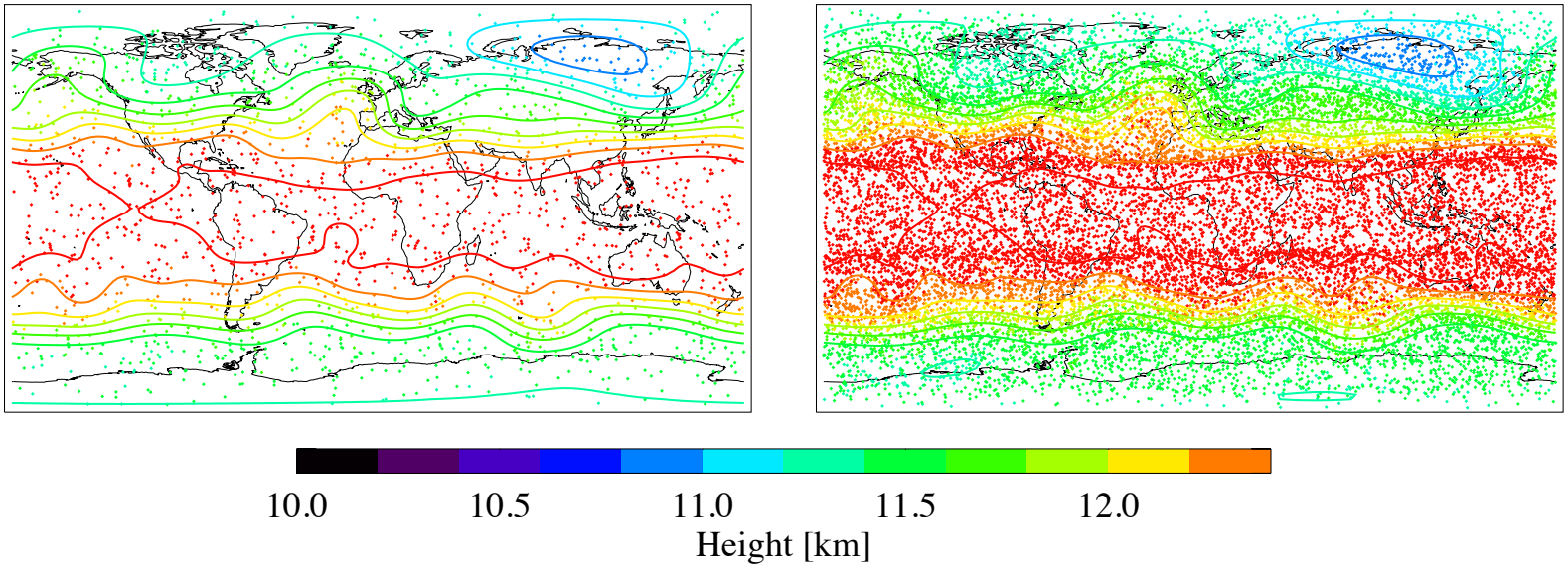
$$\mathbf{A} = \beta\mathbf{B} + \alpha\mathbf{C}$$

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

Second inference: $\gamma = k - \alpha\,\mathrm{Trace}\,\mathbf{A}^{-1}\mathbf{C} = N - \beta\left|\mathbf{t} - \phi\mathbf{w}\right|^2$

Evidence: $P(\mathbf{t}\,|\,B,R) = \alpha_{\mathrm{MP}}^{k/2}\left(\dfrac{\beta_{\mathrm{MP}}}{2\pi e}\right)^{N/2}\left(\dfrac{|\mathbf{C}|}{|\mathbf{A}|}\right)^{1/2}\Delta\alpha\,\Delta\beta$

Example fits: CHAMP and COSMIC



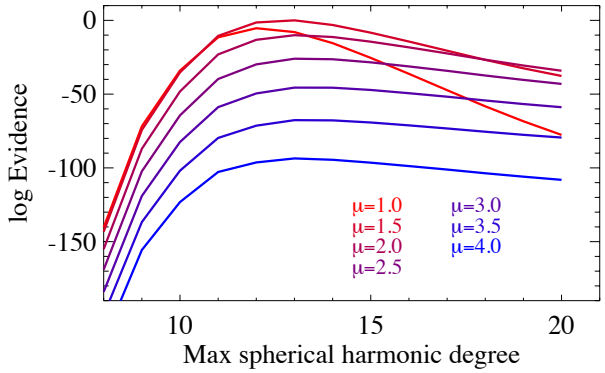
Tunable parameters

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

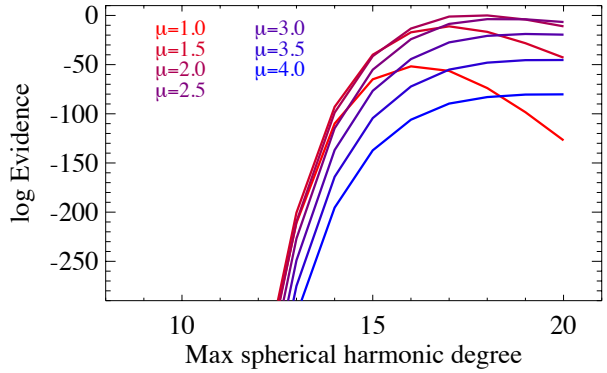
- Regularizer
  - Exponent of curvature penalty μ
  - Relaxation of global mean penalty ρ
  - Relaxation of meridional gradient penalty ν

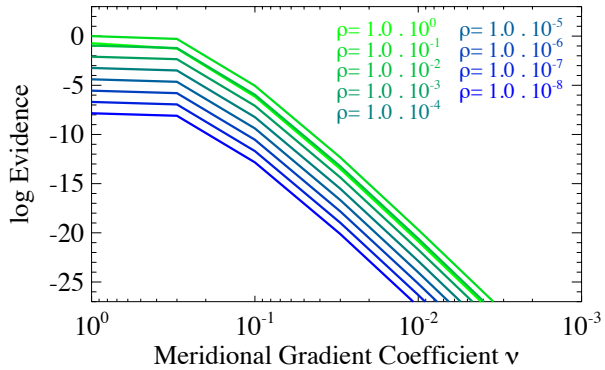
Evidence

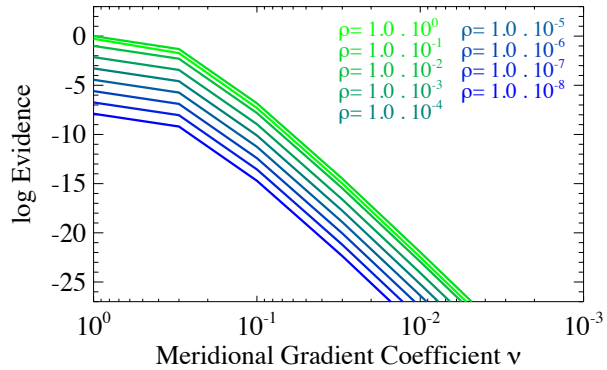
CHAMP



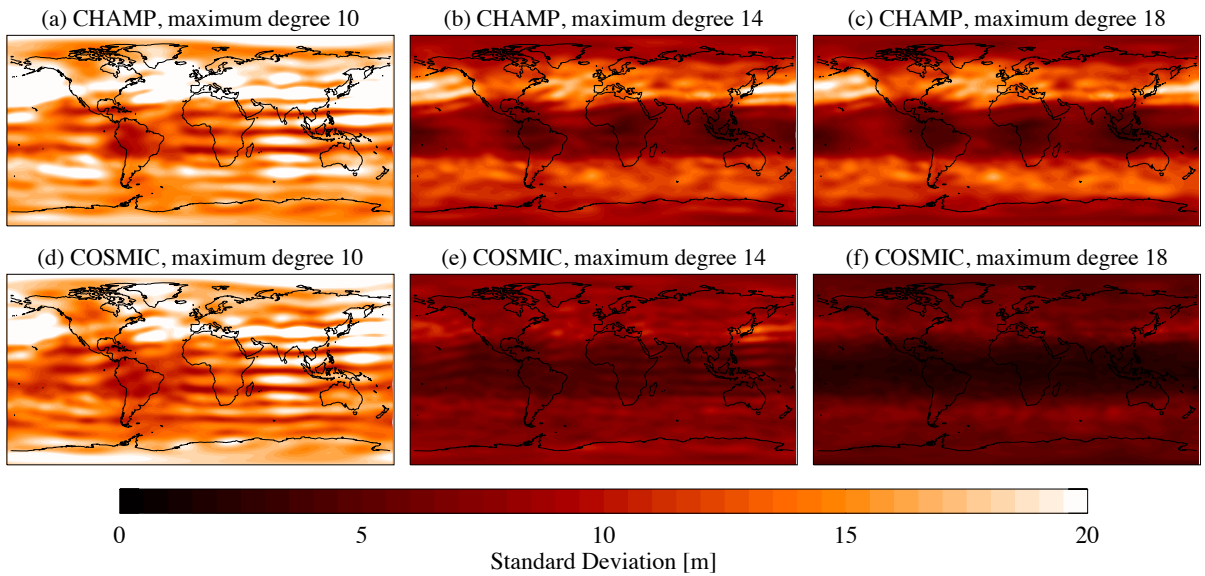
COSMIC







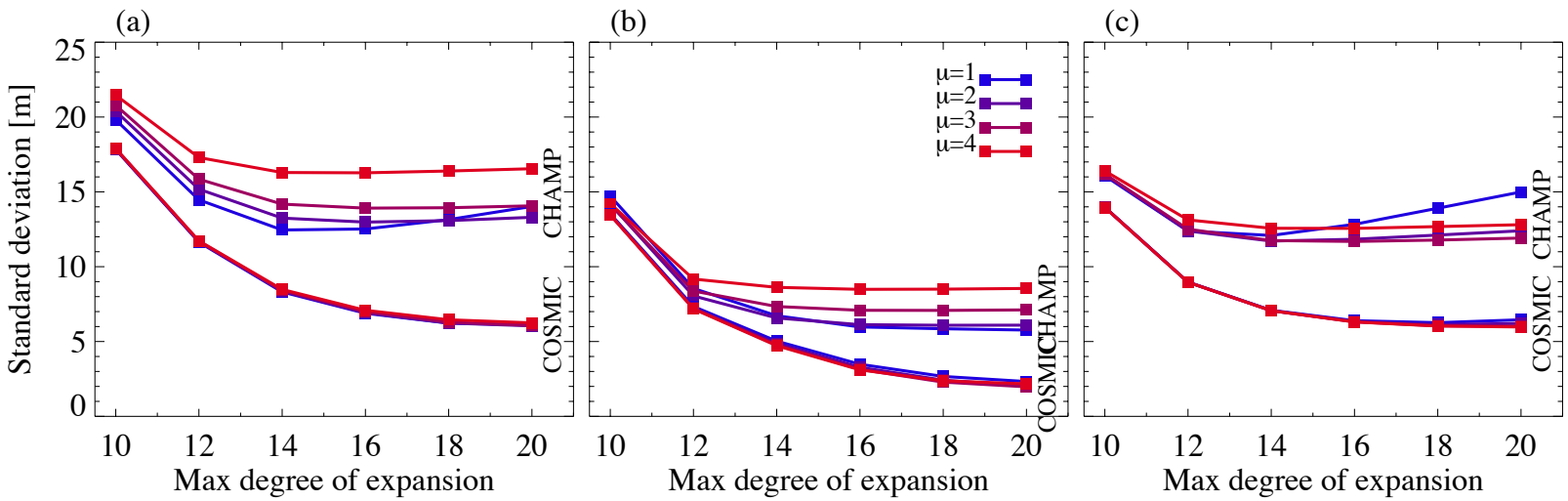
Sampling error: Monthly averages



- 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

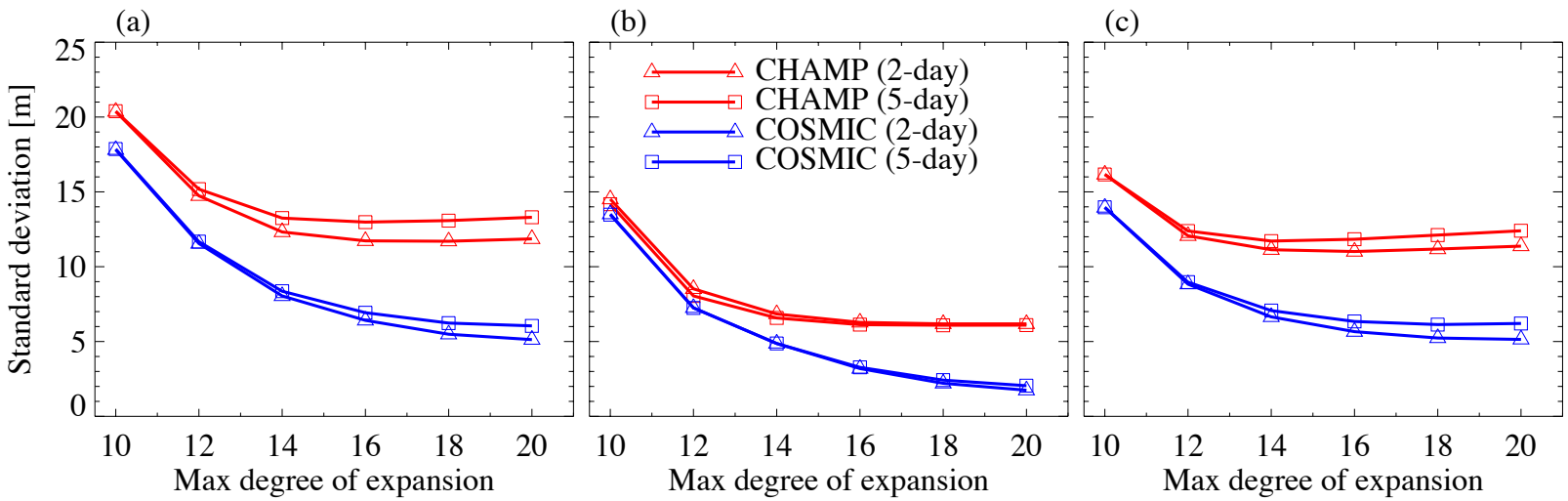
Sampling error: Penalty exponent

Northern mid-latitudes Tropics Southern mid-latitudes

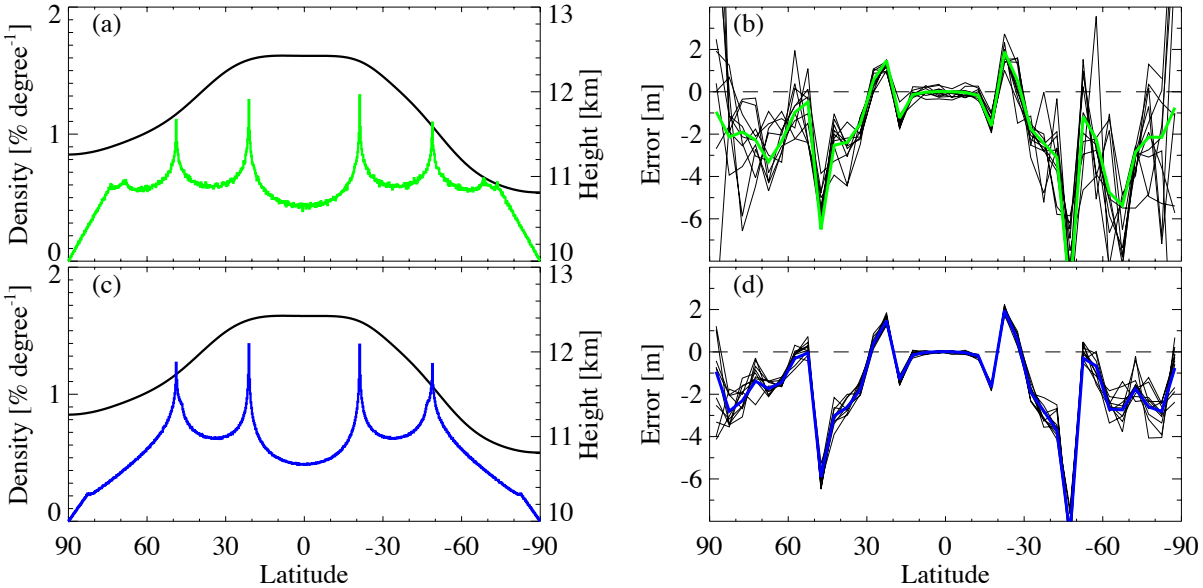


Sampling error: Reduce time window

Northern mid-latitudes | Tropics | Southern mid-latitudes

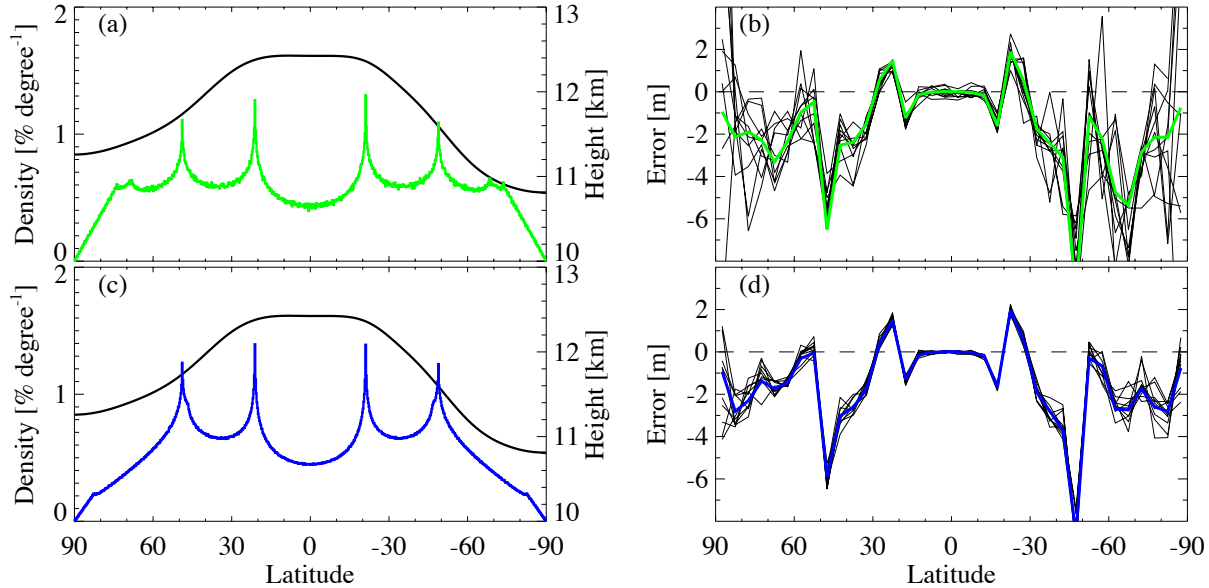


Systematic Sampling Error

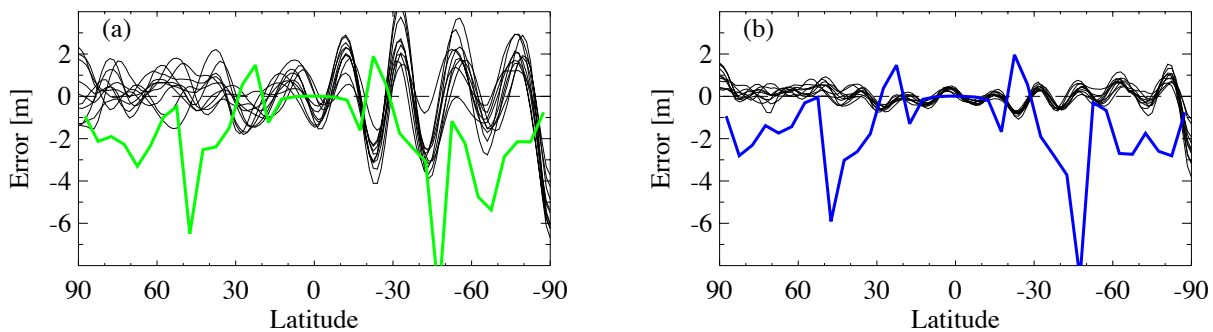


Binning and averaging

Systematic Sampling Error

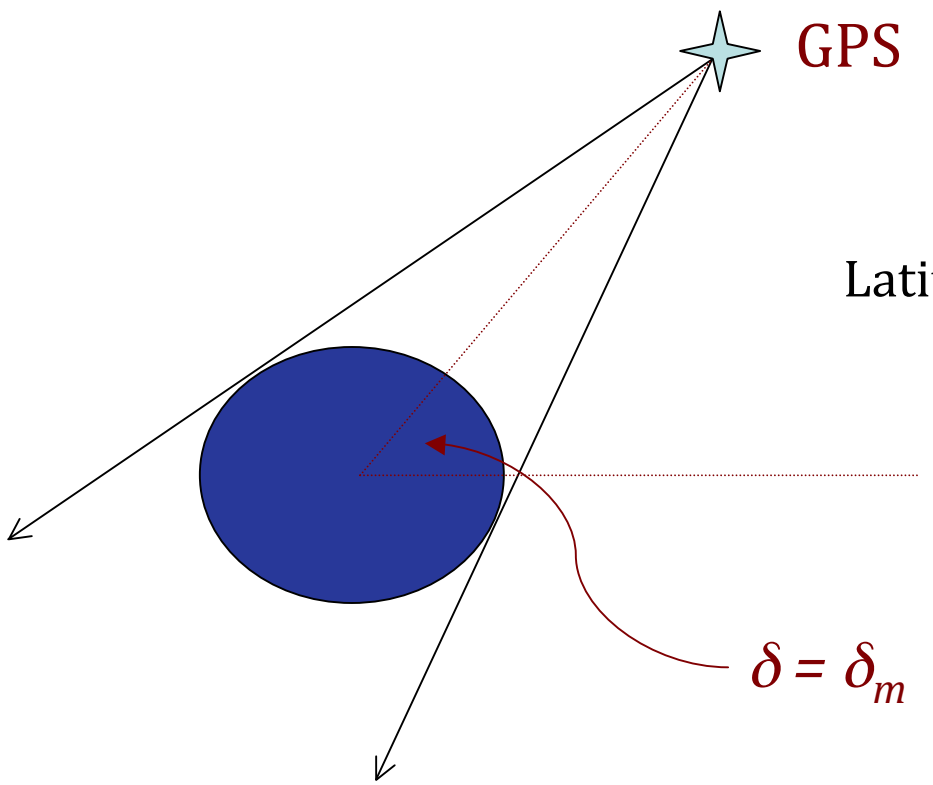


Binning and averaging



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.

Leroy, S.S., C.O. Ao, and O. Verkhoglyadova, 2011: Mapping GPS radio occultation data by Bayesian interpolation. Submitted to *J. Atmos. Ocean. Tech.*

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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.