

---

# GNSS RO Sampling for Climate Purposes

Stephen Leroy, Chi Ao, Olga Verkhoglyadova  
*International Radio Occultation Working Group Meeting*  
*Estes Park, Colorado*  
*April 2, 2012*

# 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

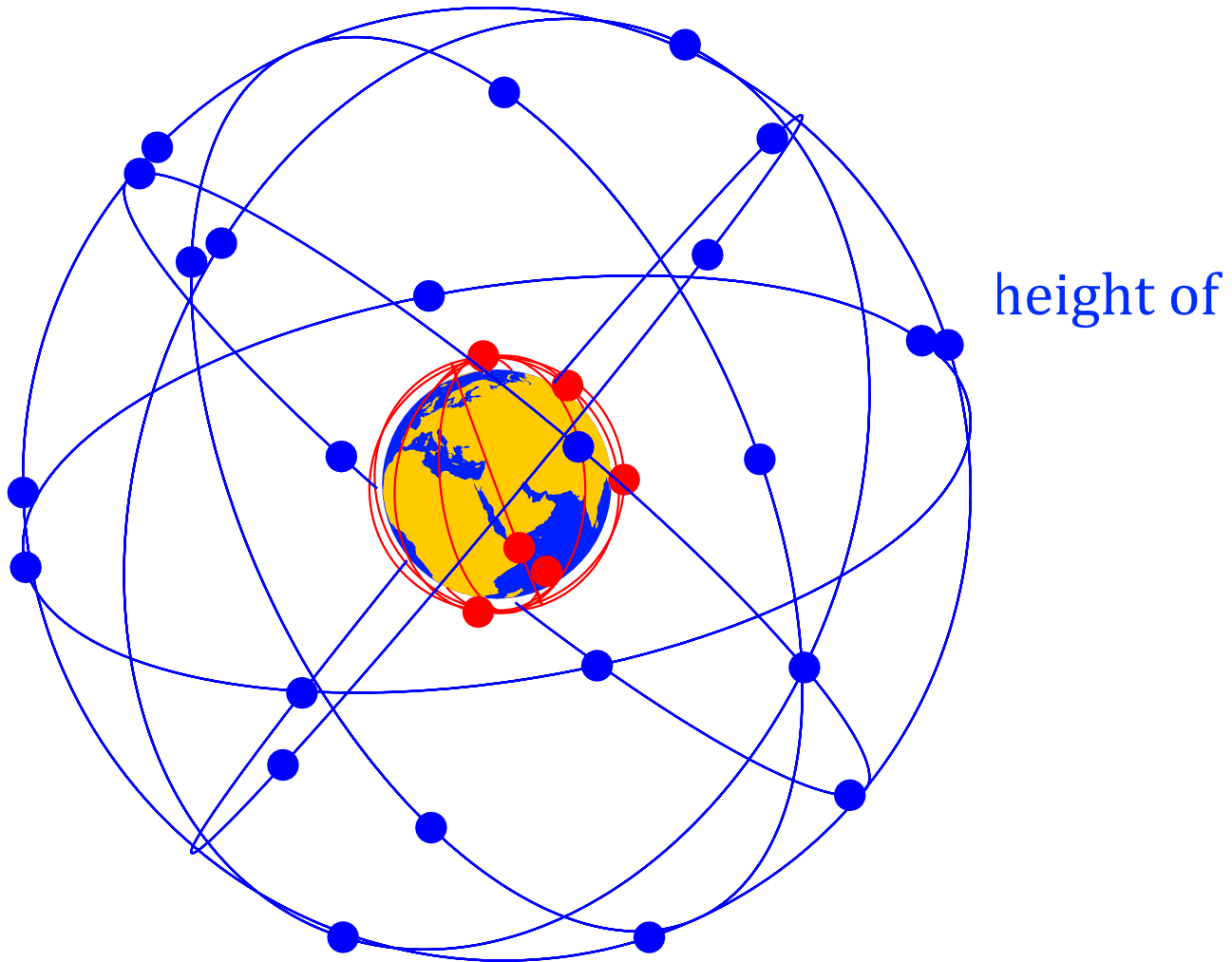
---

- 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

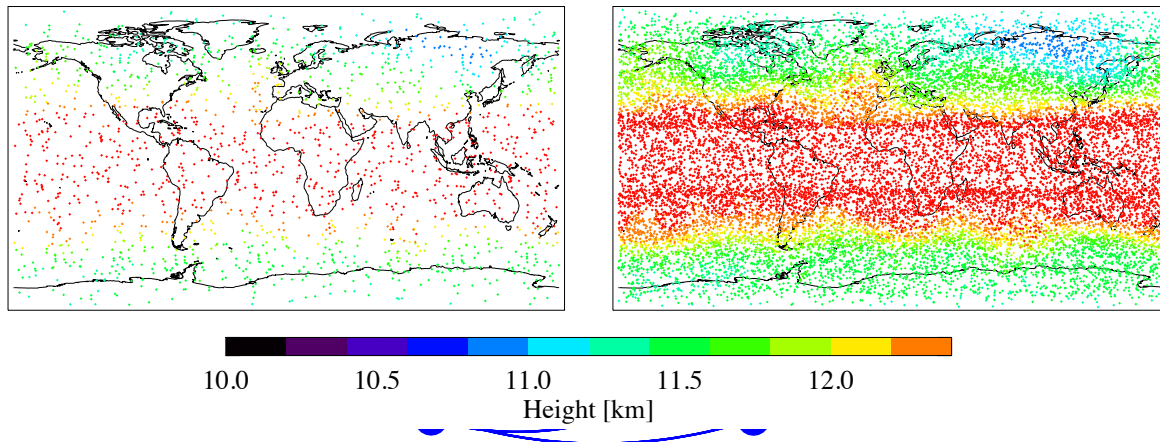
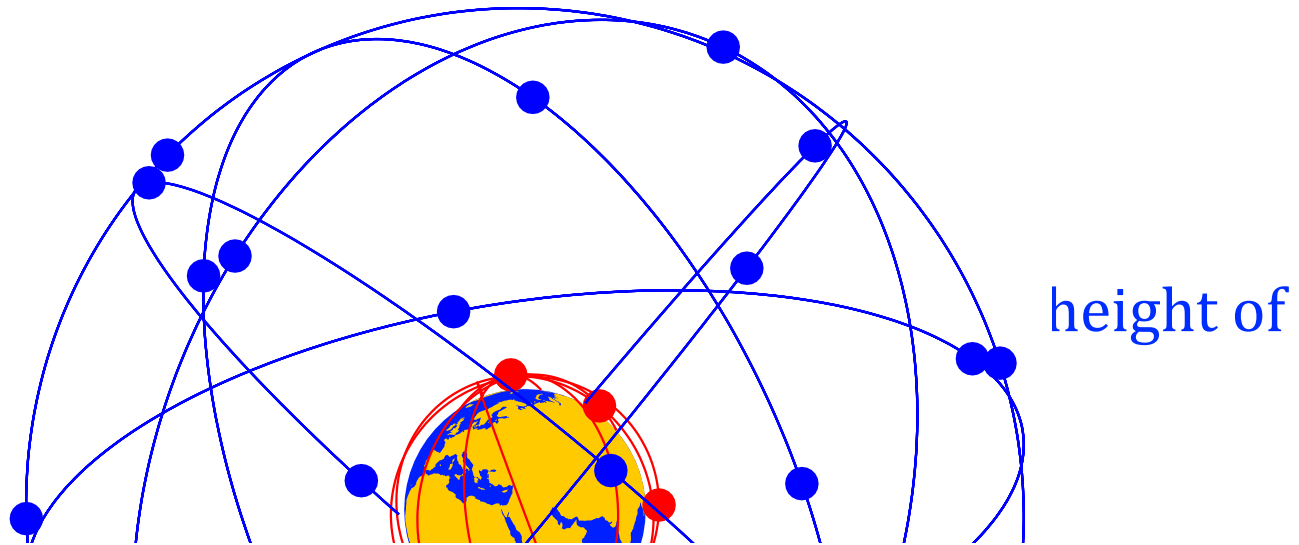
---

- Simulat
- Interpo
- soundi
- Form cl
- 200-hP
- Compai



# Sampling Error

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



# Analysis: Bayesian Interpolation

---

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

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

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

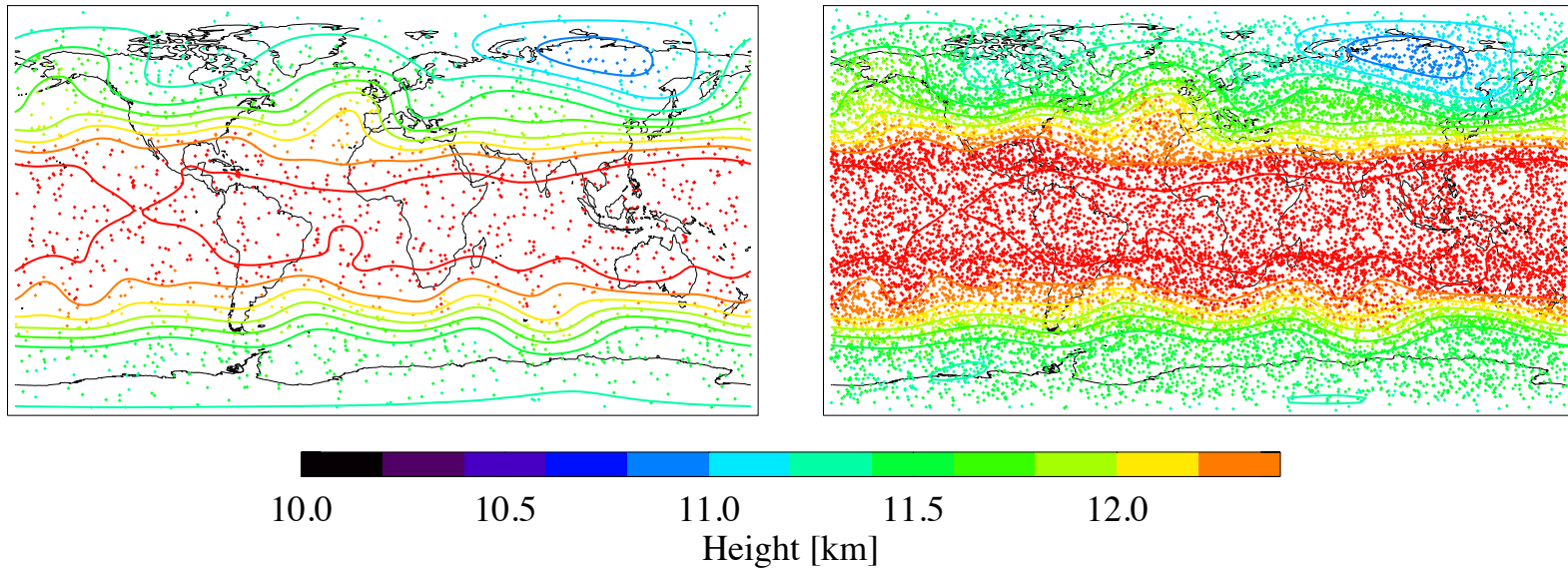
First inference:  $\mathbf{w} = \mathbf{A}^{-1} \beta \phi' \mathbf{t}$

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

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

# Example fits: CHAMP and COSMIC

---



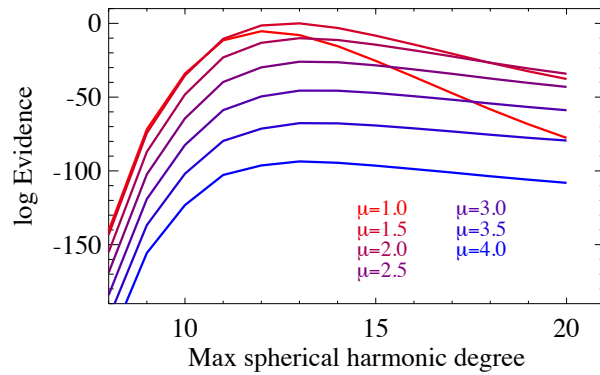
# Tunable parameters

---

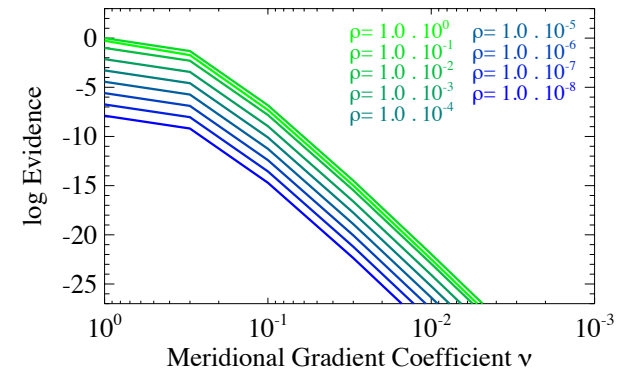
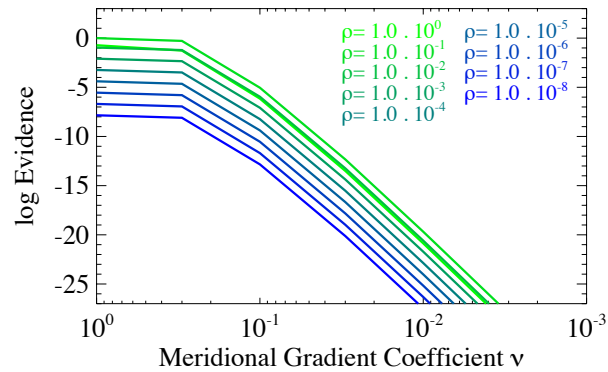
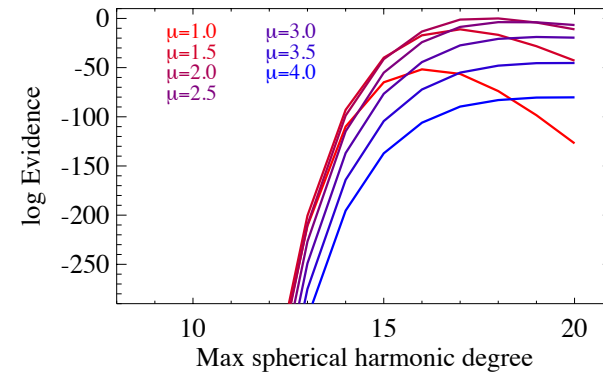
- Basis
  - maximum degree of spherical harmonic expansion  $l_{\max}$ , bears on spatial resolution
- Regularizer
  - Exponent of curvature penalty  $\mu$
  - Relaxation of global mean penalty  $\rho$
  - Relaxation of meridional gradient penalty  $\nu$

# Evidence

## CHAMP

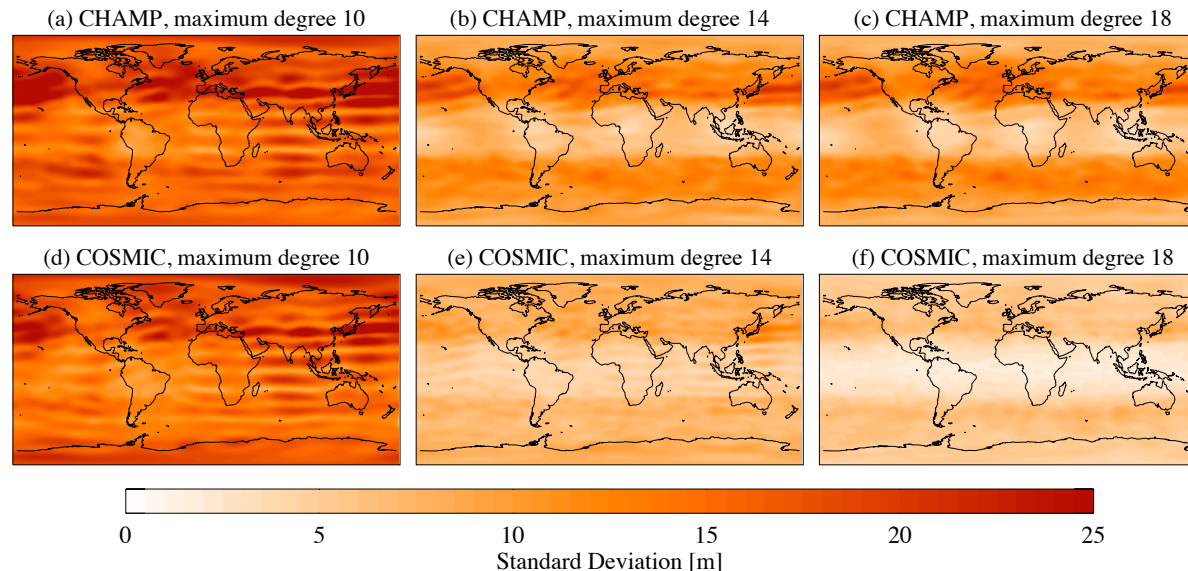


## COSMIC



# Sampling error: Monthly averages

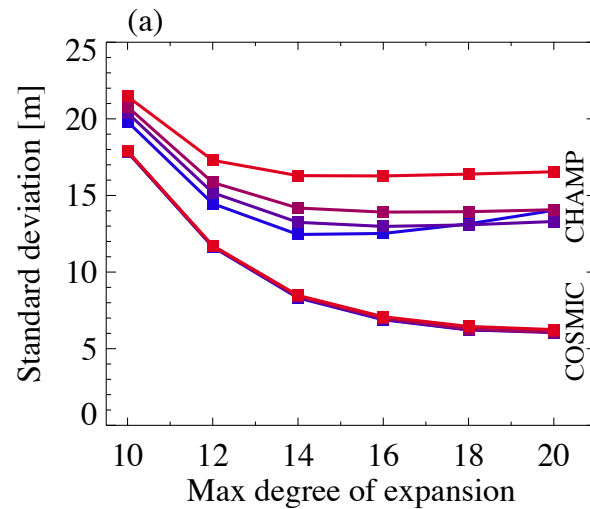
---



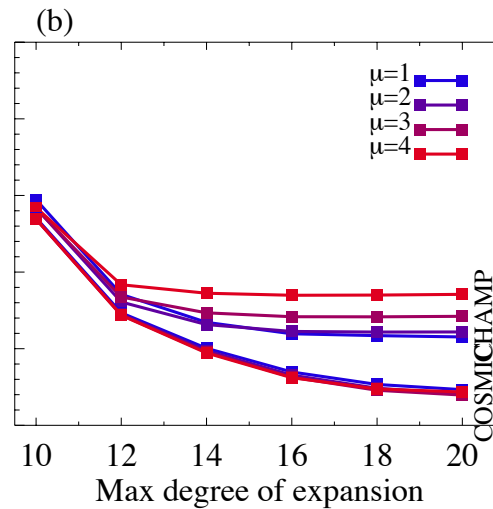
- Minimum number of spherical harmonic degrees to resolve atmospheric structure
- Denser data means smaller sampling error
- Mid-latitudes have largest sampling error because of synoptic variability

# Sampling error: Penalty exponent

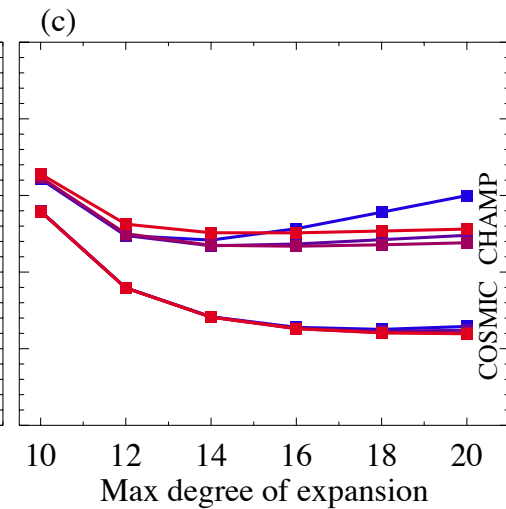
Northern mid-latitudes



Tropics

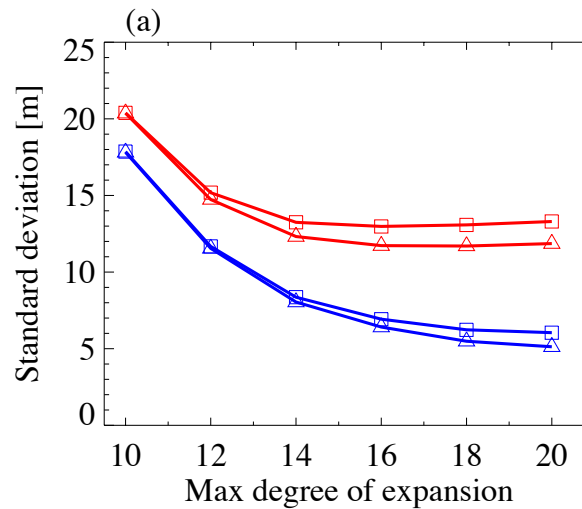


Southern mid-latitudes

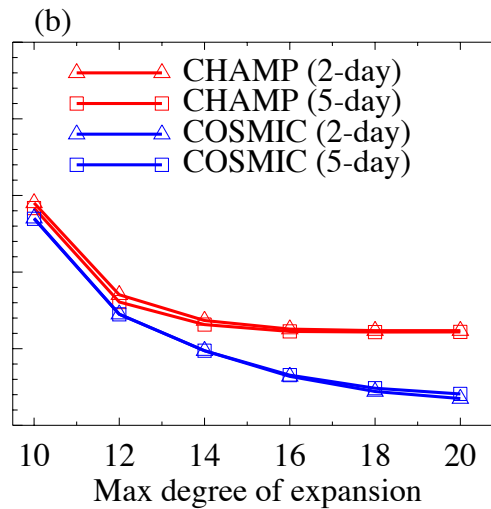


# Sampling error: Reduce time window

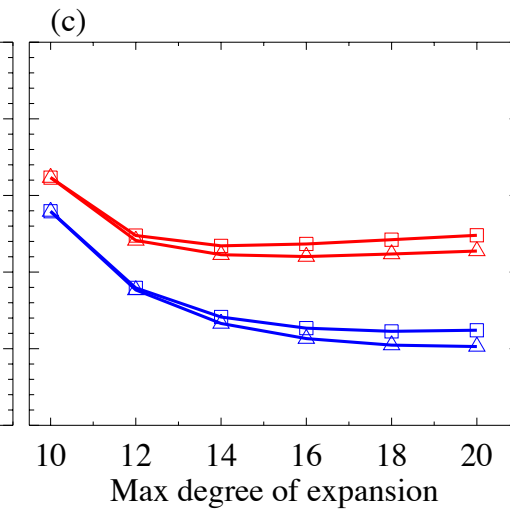
Northern mid-latitudes



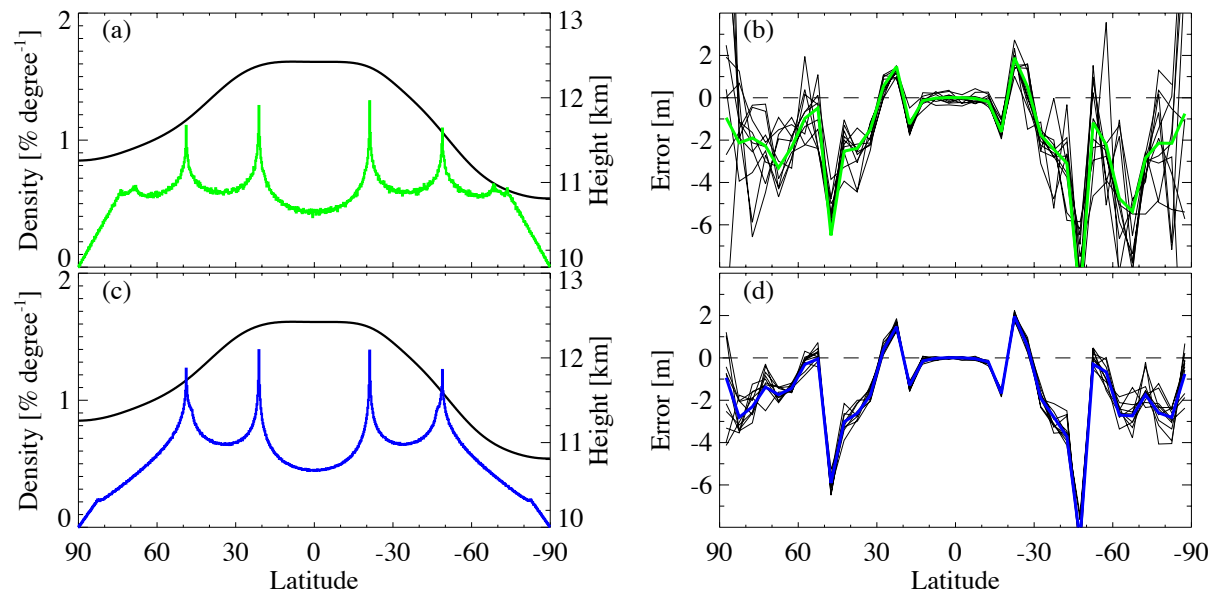
Tropics



Southern mid-latitudes

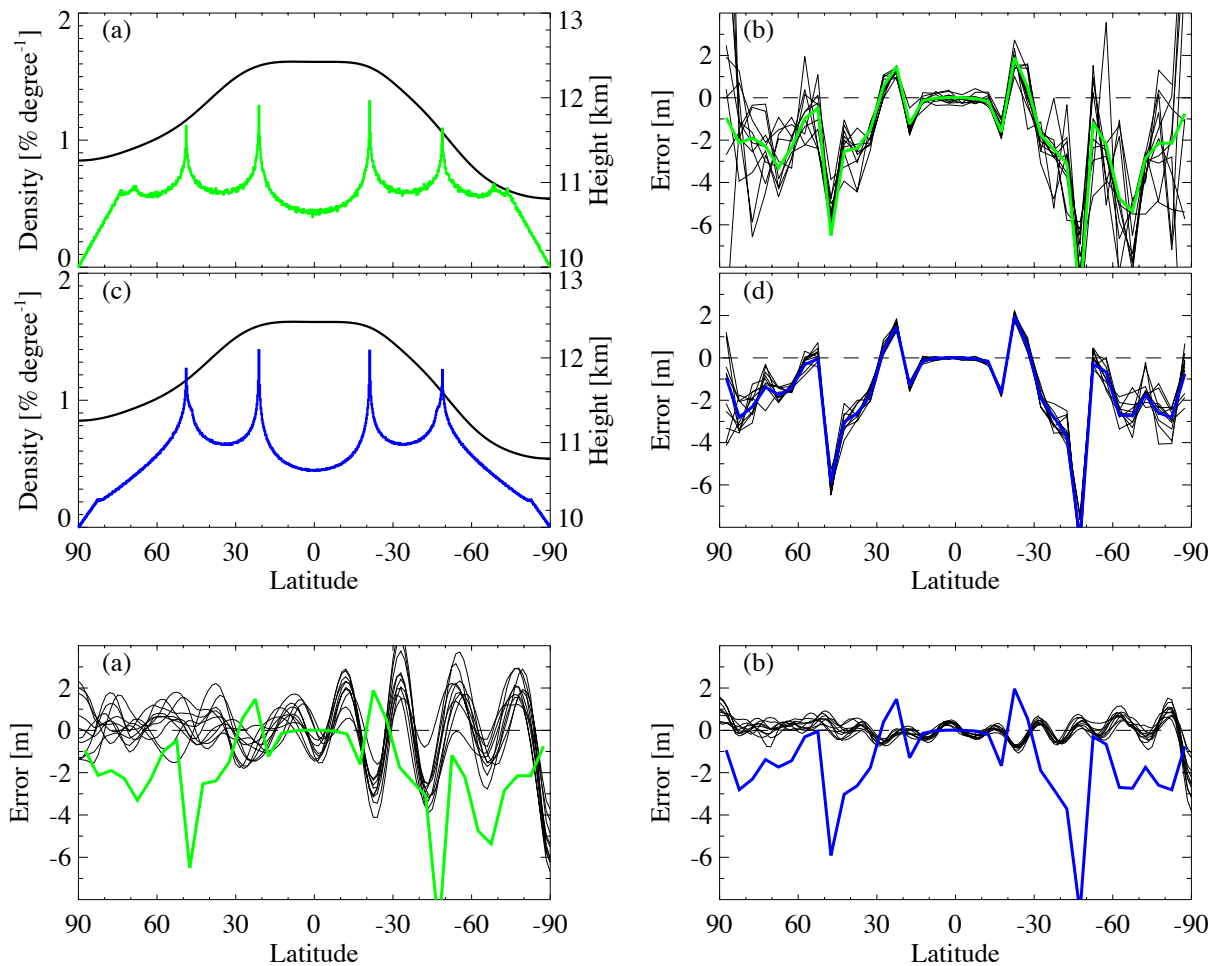


# Systematic Sampling Error



Binning and  
averaging

# Systematic Sampling Error

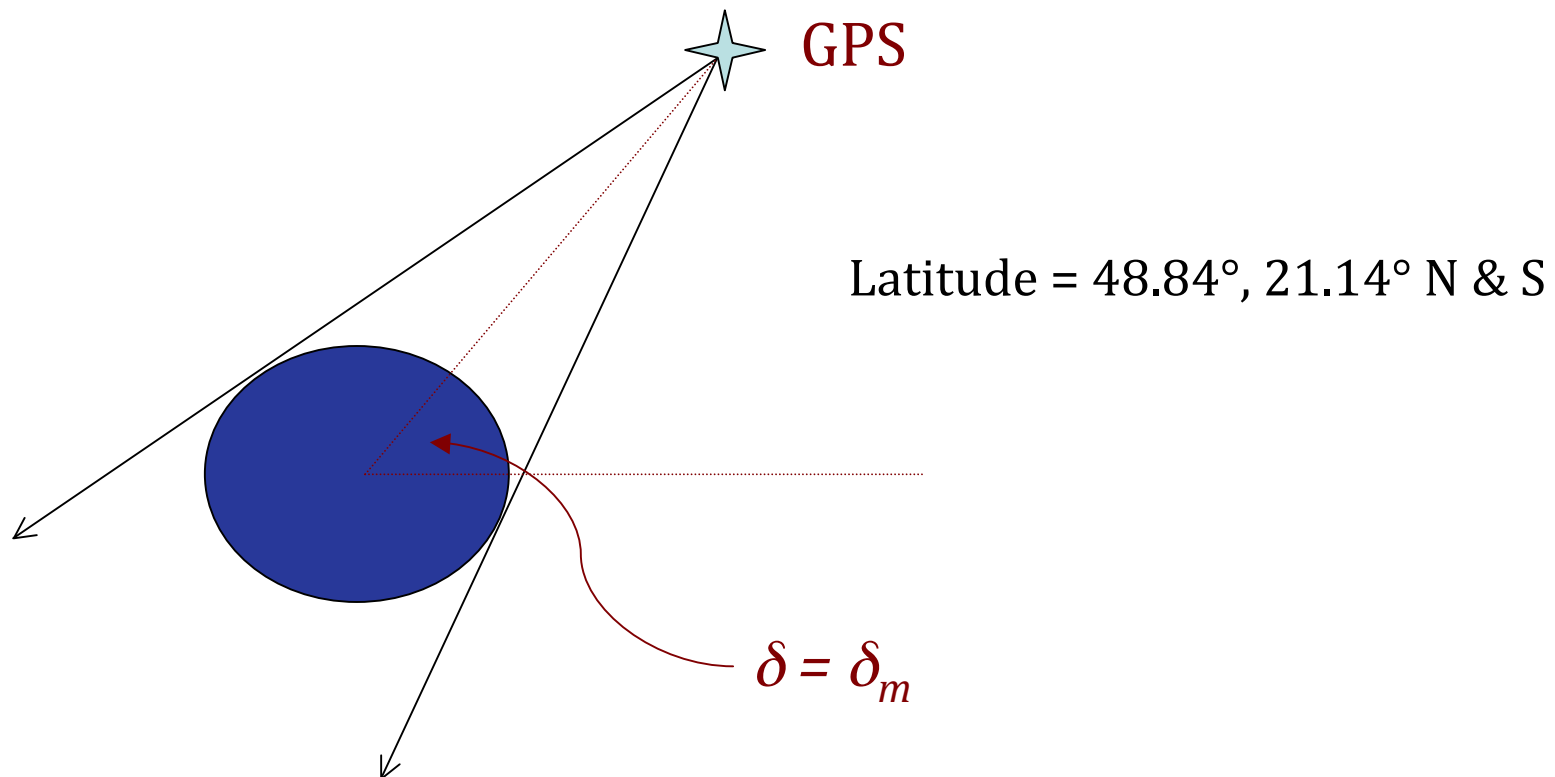


Binning and  
averaging

Bayesian  
interpolation

# Systematic sampling error cause

---



# 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.*

This work was funded by a grant from the NASA Jet Propulsion Laboratory's Director's Research and Discretionary Fund and by the CLARREO Project.

---

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.