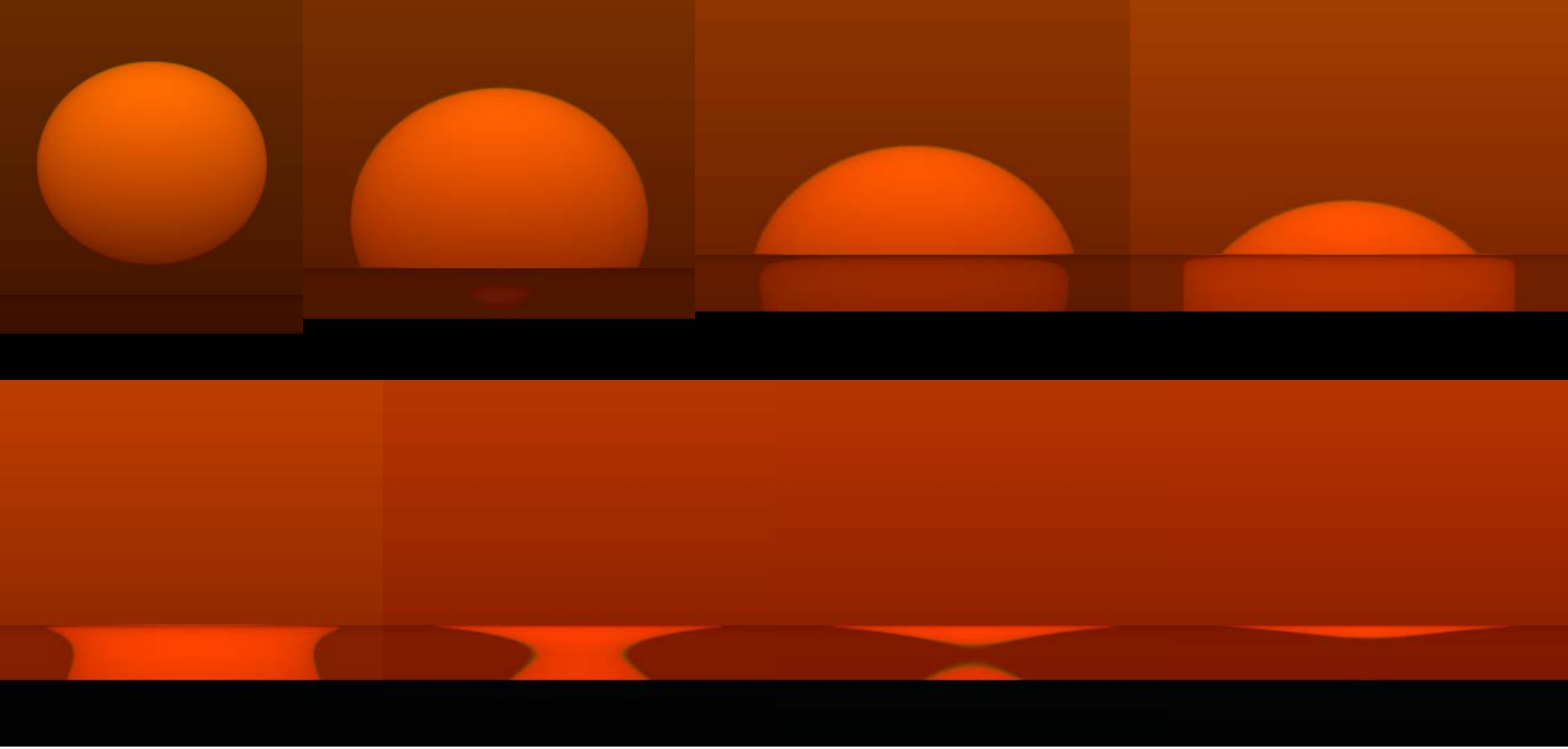


Radio Occultation Retrieval using Phase Matching & Optimization

Kuo-Nung Wang (Eric)

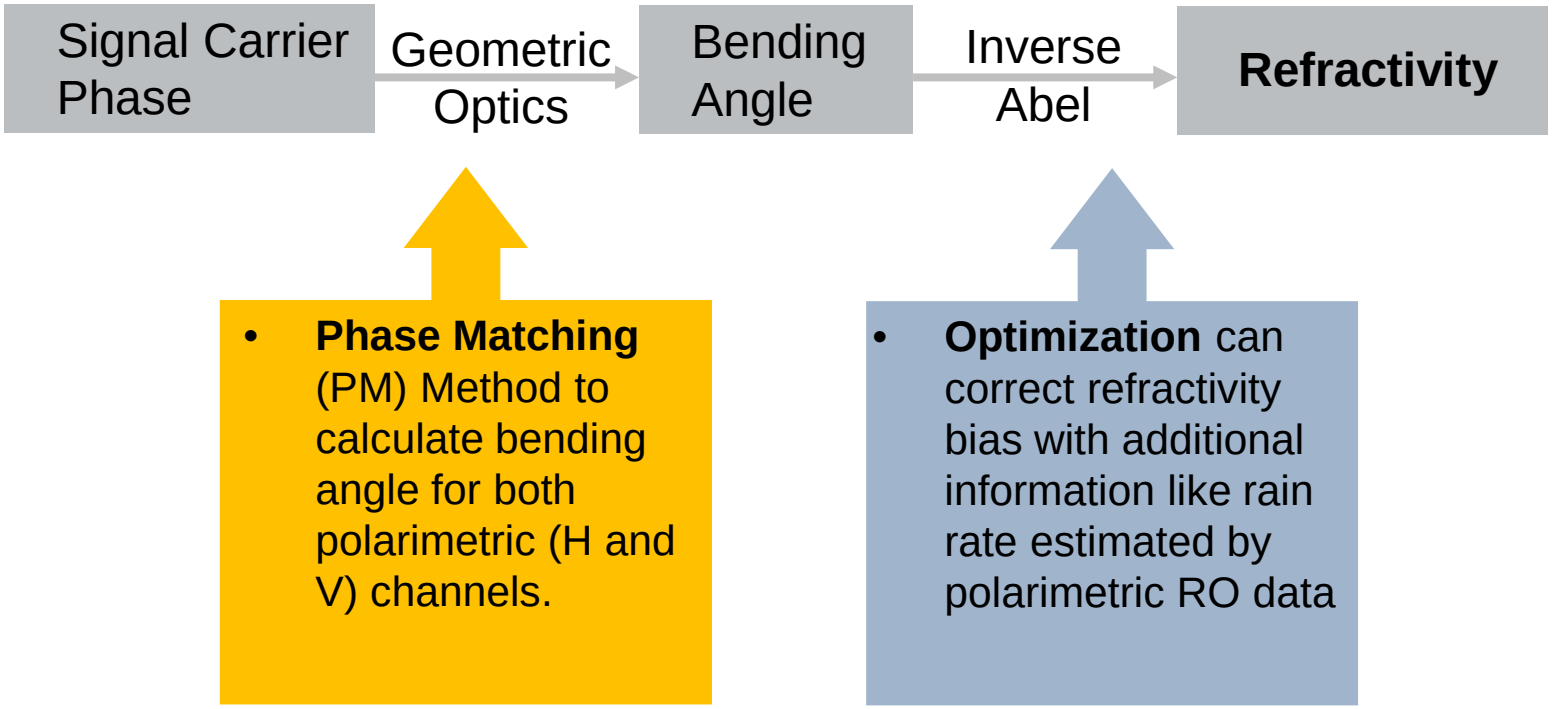
06-15-2016

Jet Propulsion Laboratory
California Institute of Technology

Retrieval Process

Bending angle and Refractivity

- Flow Chart



Retrieval Process

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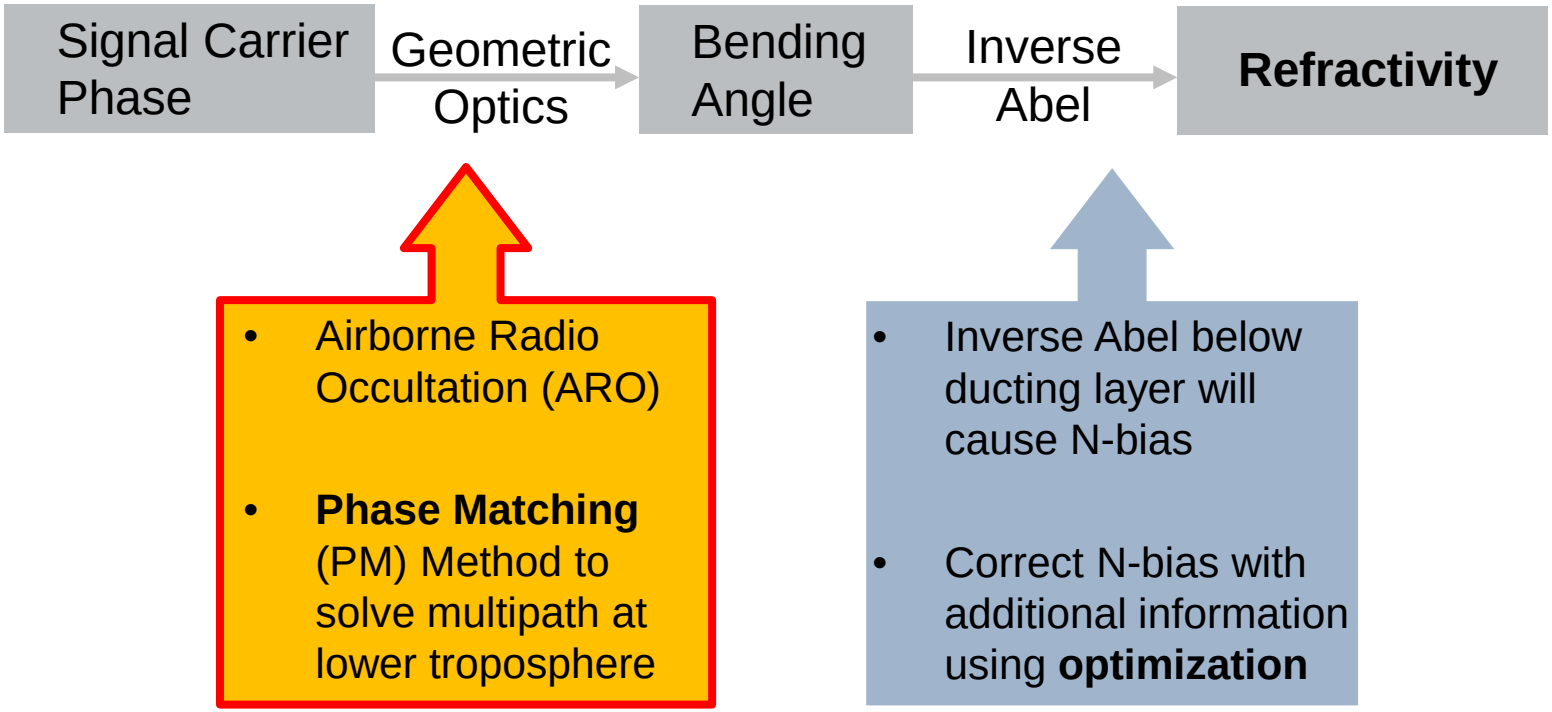
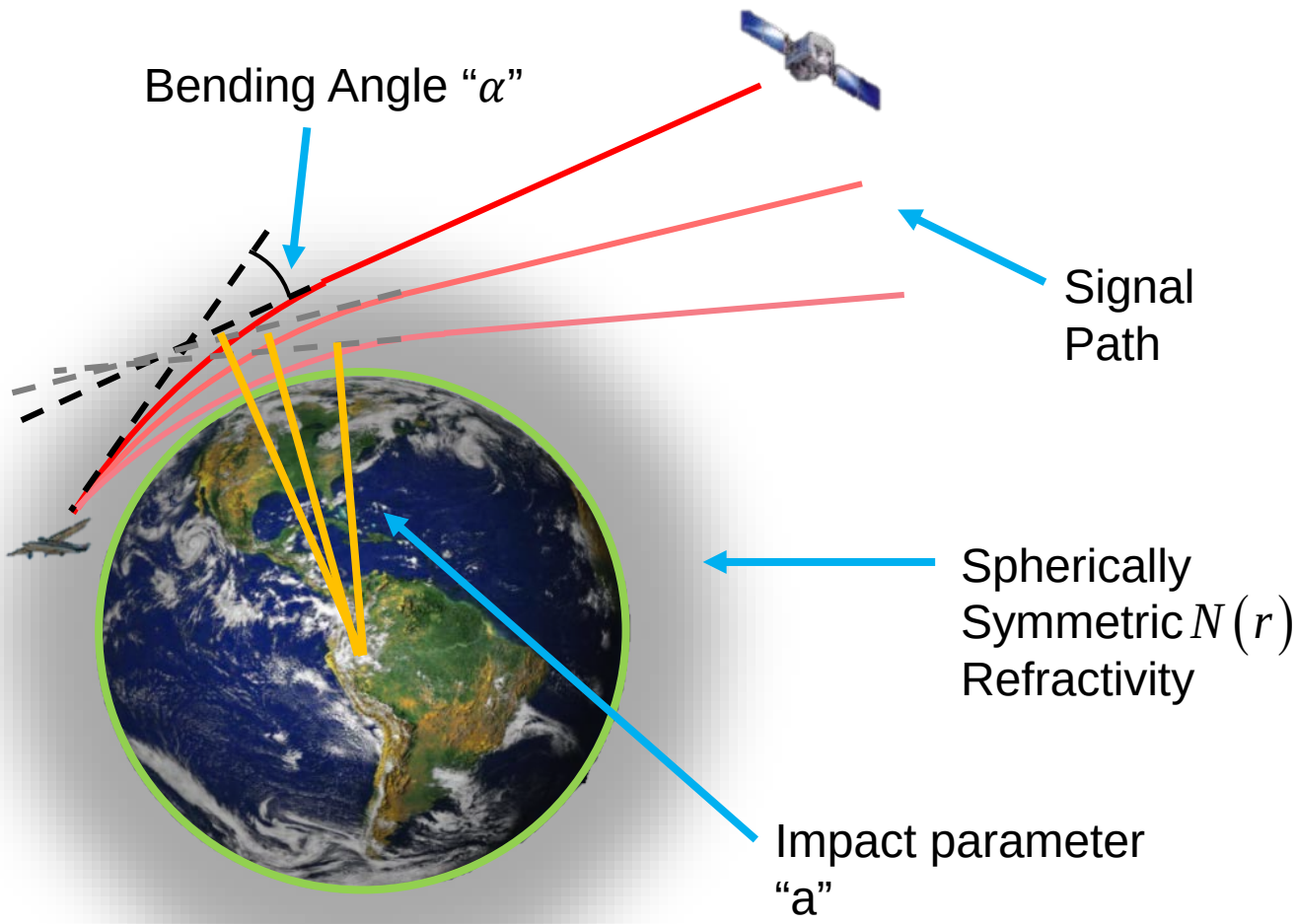


Phase Matching (PM)

Airborne RO (ARO)

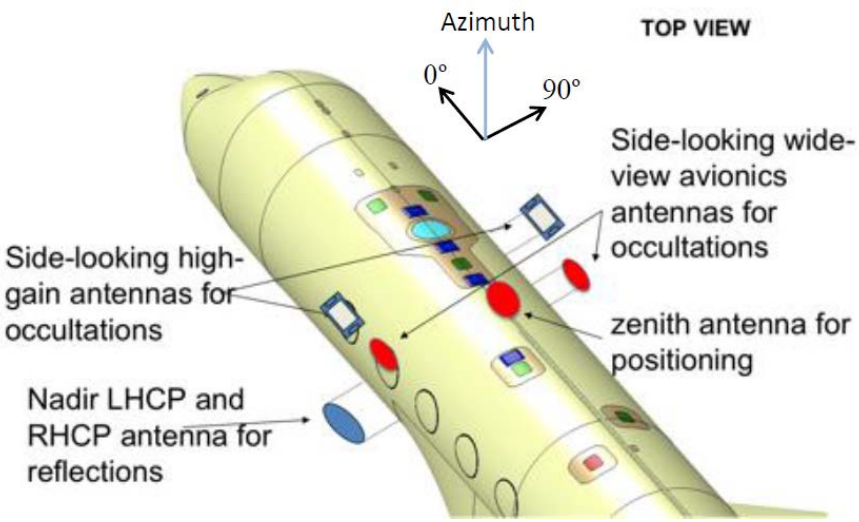
- Receive GPS signal inside atmosphere:

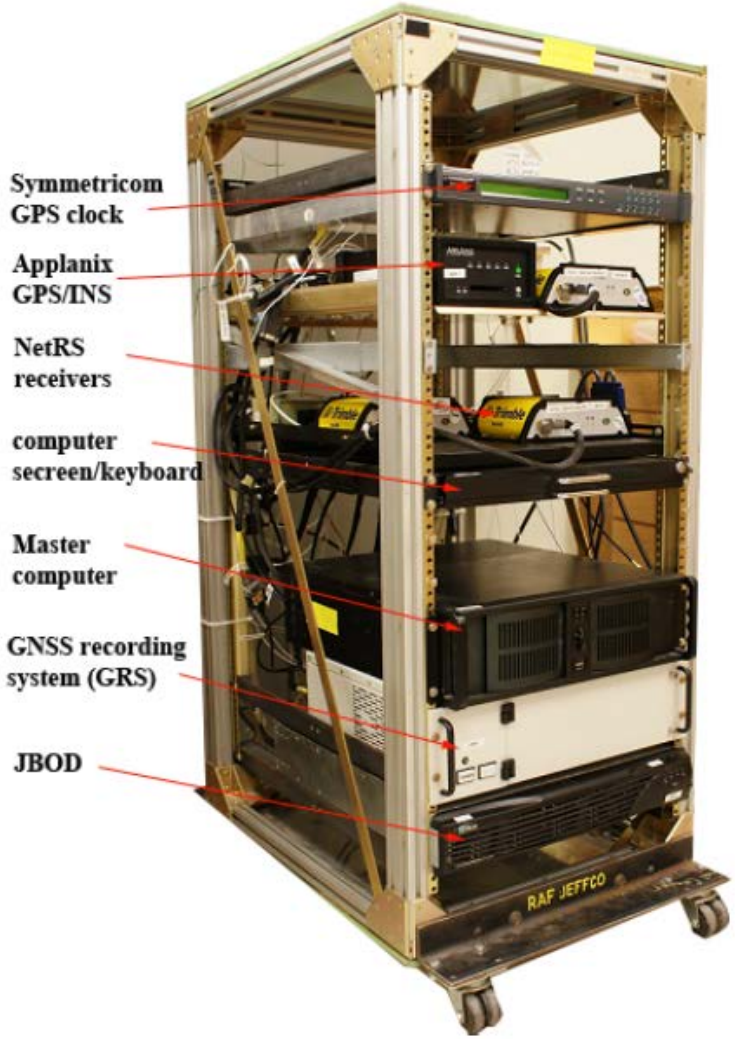


Phase Matching (PM)

Airborne RO (ARO)

- The GNSS Instrument System for Multistatic and Occultation Sensing (GISMOS) was designed to receive occulted GPS signals on the NSF/NCAR High-performance Instrumented Airborne Platform for Environmental Research (HIAPER) aircraft

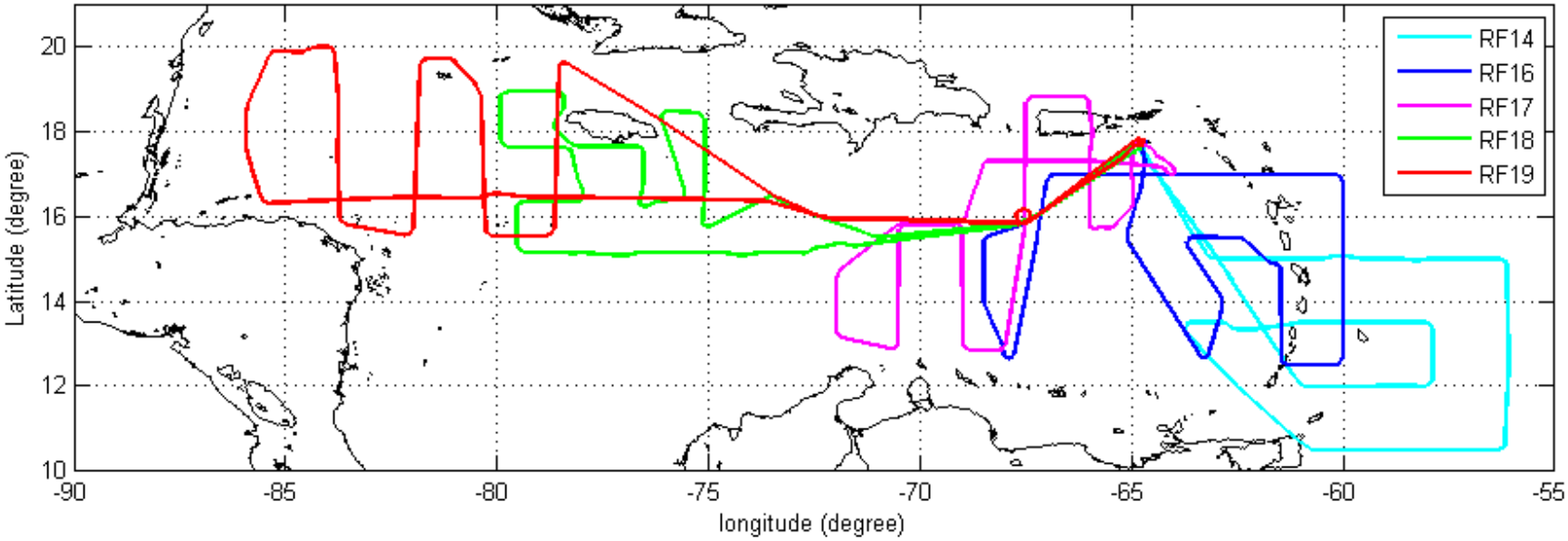




Phase Matching (PM)

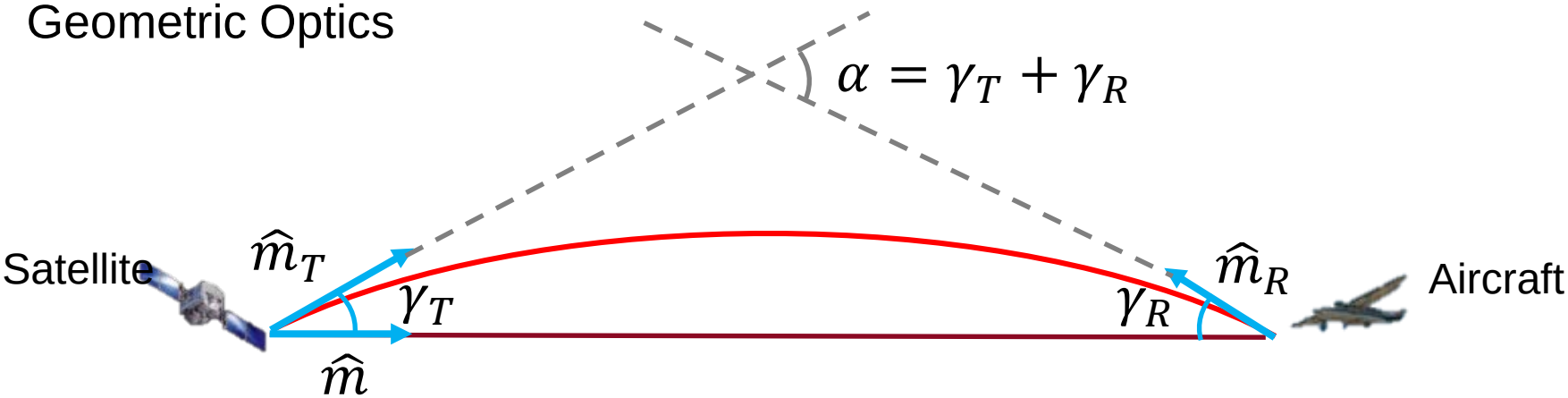
Airborne RO (ARO)

- PRE-Depression Investigation of Cloud systems in the Tropics (PREDICT) collects GPS RO data and investigate the moisture development during the genesis phase of hurricane Karl
- The data used in this research were collected in PREDICT campaign from Sep. 09 (RF14) to Sep. 14 (RF19)



Phase Matching (PM)

Geometric Optics



Excess Doppler: Differencing the Doppler shift observed in the presence of the atmosphere and the Doppler shift that would be observed for the same geometry without the atmosphere.

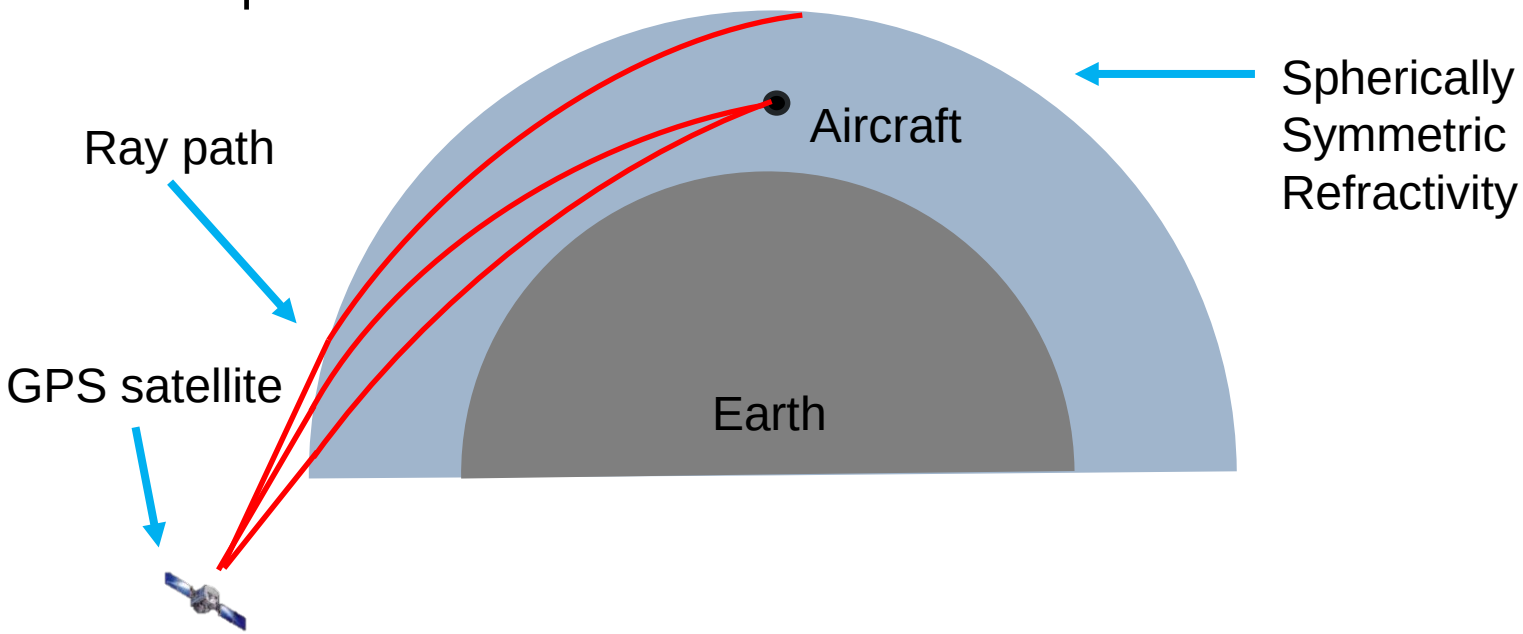
$$f_{ED} = \frac{d\Phi^E}{dt} = k\left[\dot{x} - \dot{x}^G\right] = k\left[n_T\vec{v}_T \cdot \hat{m}_T - n_R\vec{v}_R \cdot \hat{m}_R - \left(\vec{v}_T - \vec{v}_R\right) \cdot \hat{m}\right]$$

By solving this equation with Bouger's law iteratively we can acquire the angles γ_T and γ_R --- which can be used to calculate bending angle:

Bending Angle: $\alpha = \gamma_T + \gamma_R$

Phase Matching (PM)

Geometric Optics



- The signal instant frequency will be related to two or more signal path: the GO equation is not valid anymore.
- Assume: Different signal path have different impact parameters. We may distinguish different path with different impact parameters!

Phase Matching (PM)

Phase Matching

- (Received) signal $f(t) = A(t)e^{i\phi(t)} = A(t)e^{i[\Phi^E(t)+\Phi^G(t)]}$
- (Reference) signal $e^{i[S(a_j,t)]}$
- Inner product:

$$v(a_j) = \int A(t)exp[i\phi(t) - iS(a_j,t)]dt$$
$$= B(a_j)exp[i\Psi(a_j)]$$

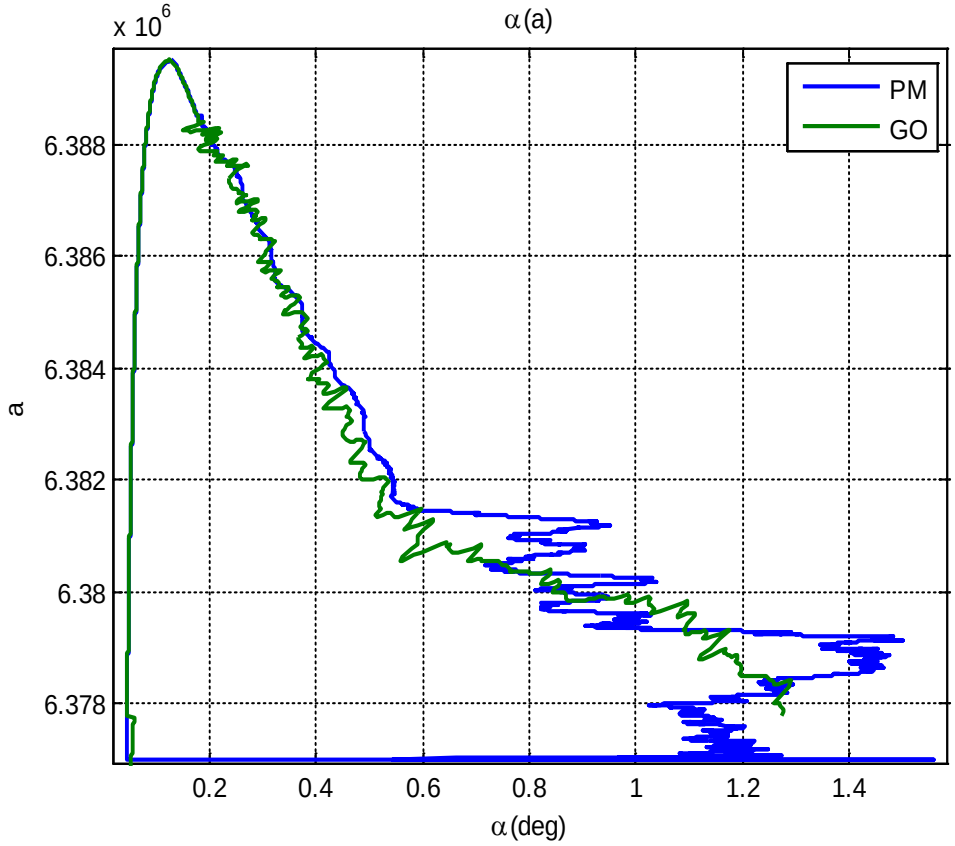
- Bending angle can be simply calculated as:

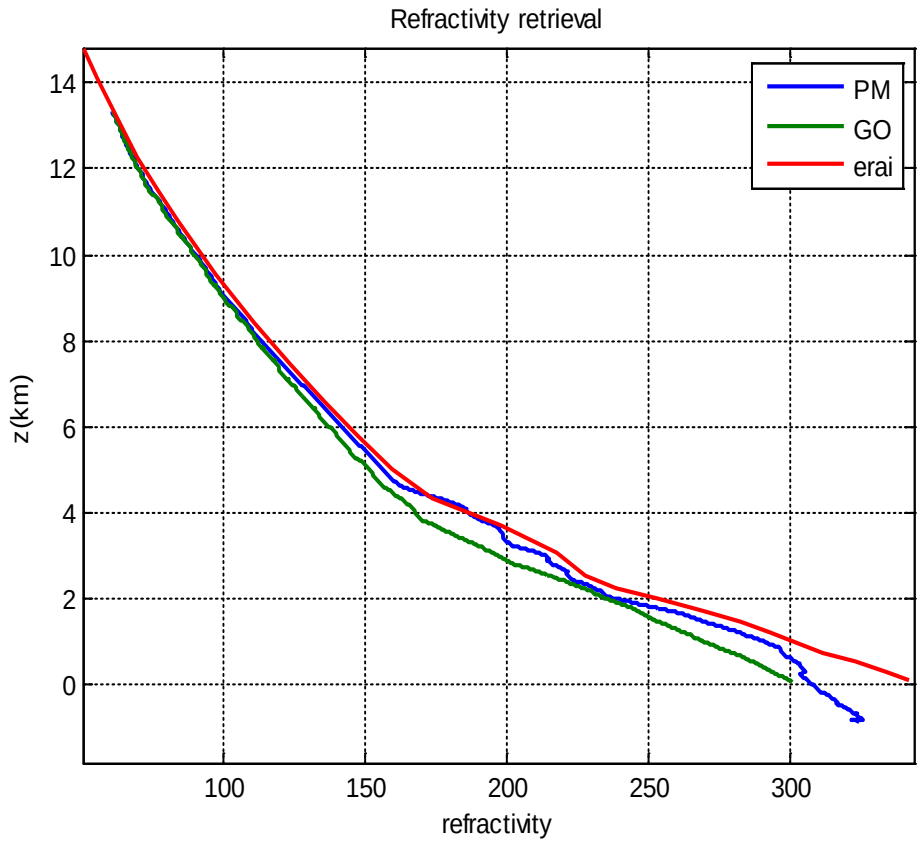
$$\alpha(a) = -\frac{d\Psi_N(a)}{da}$$

Phase Matching (PM)

Phase Matching

- Results

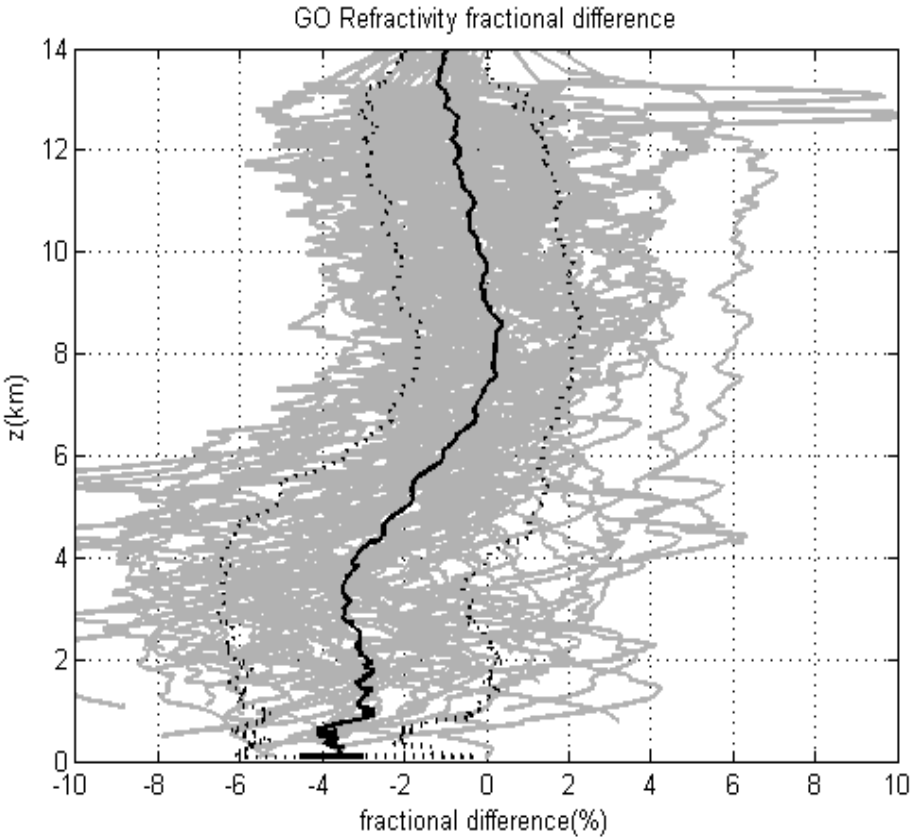


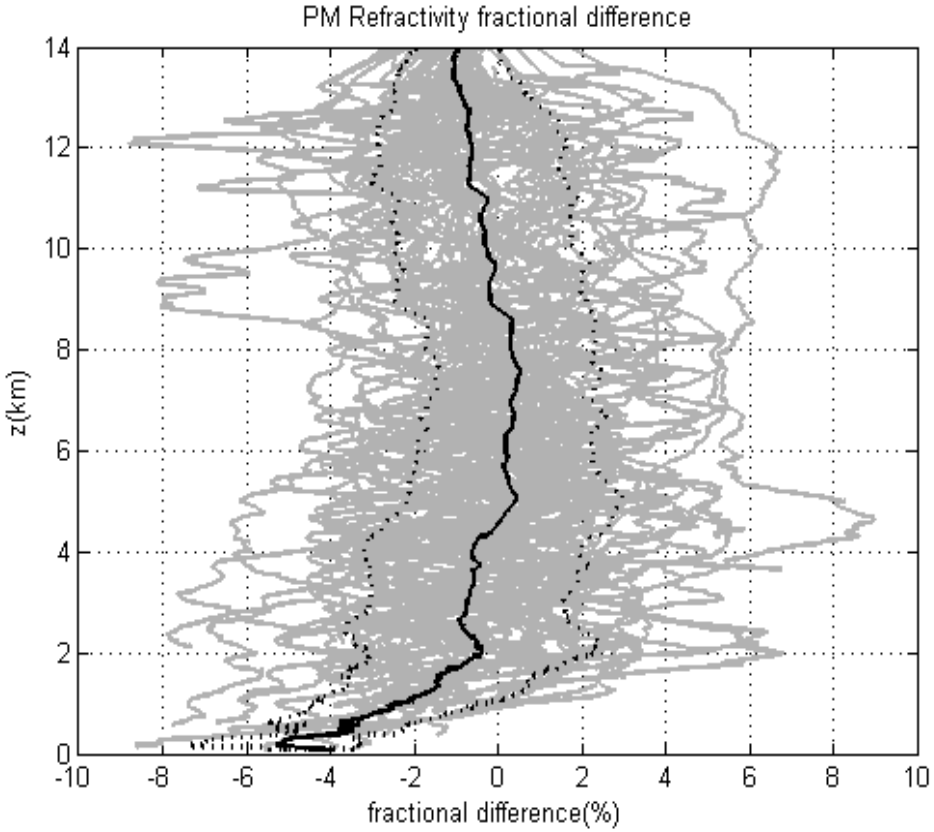


Phase Matching (PM)

Phase Matching

- Results

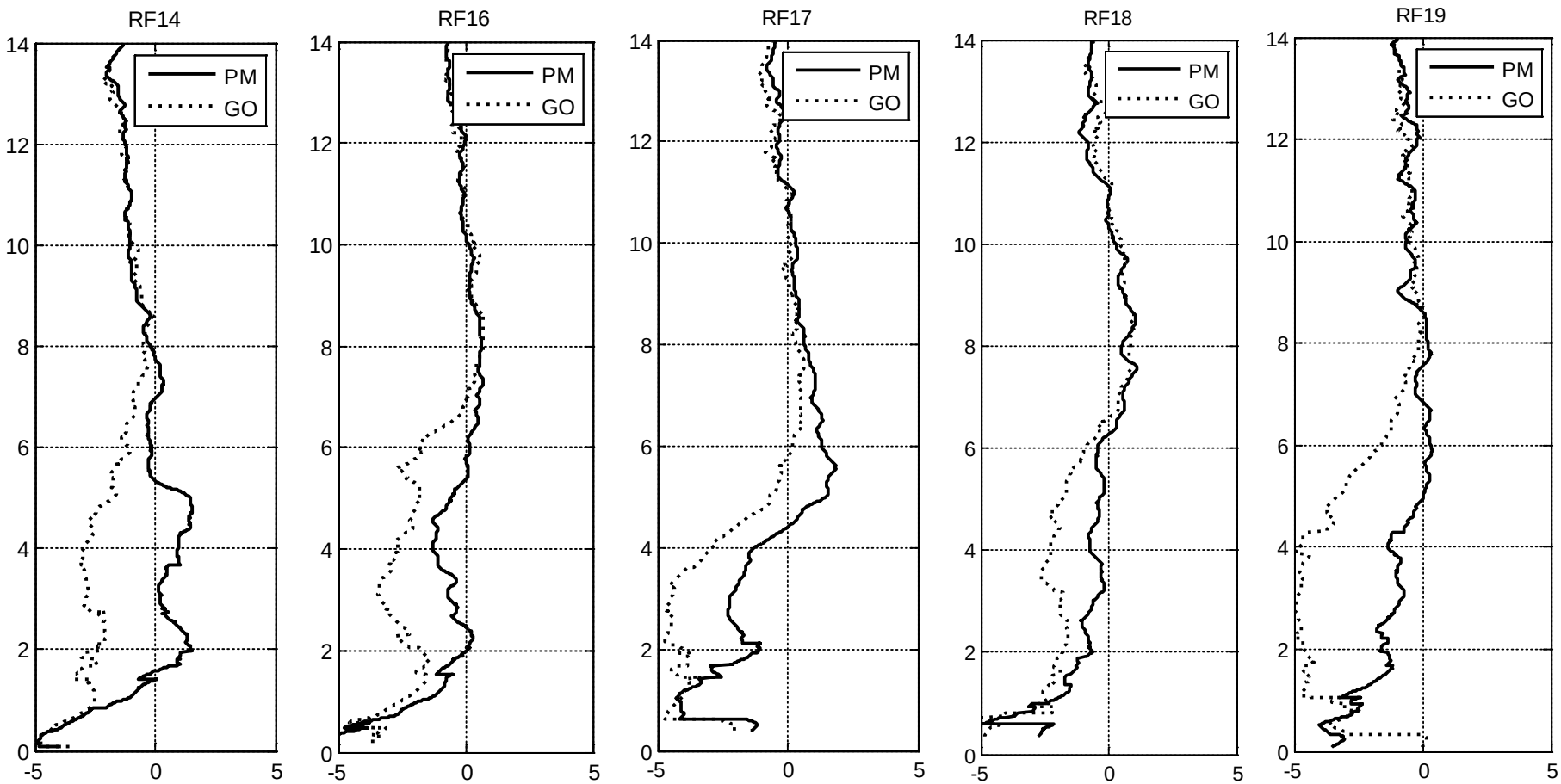




Phase Matching (PM)

Phase Matching

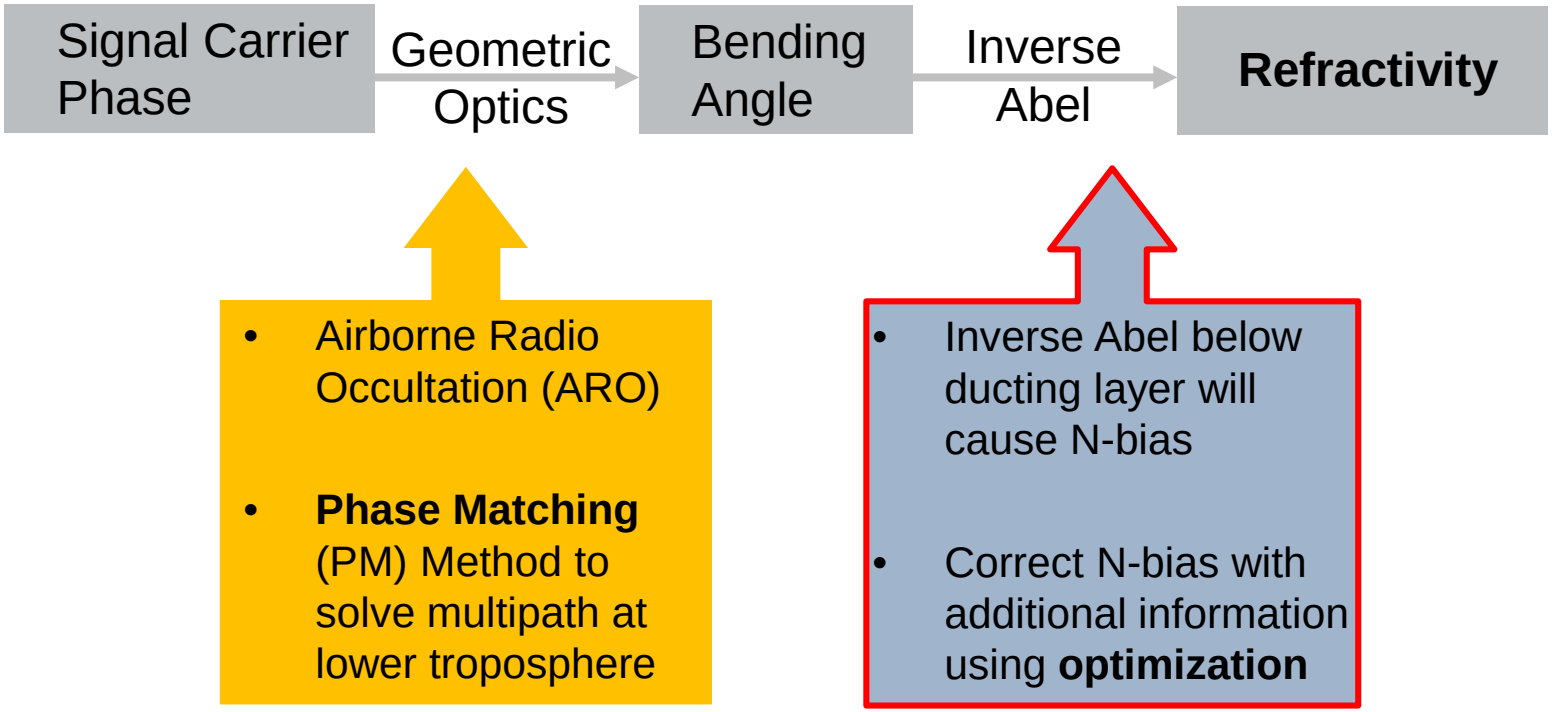
- Results



Retrieval Process

Bending angle and Refractivity

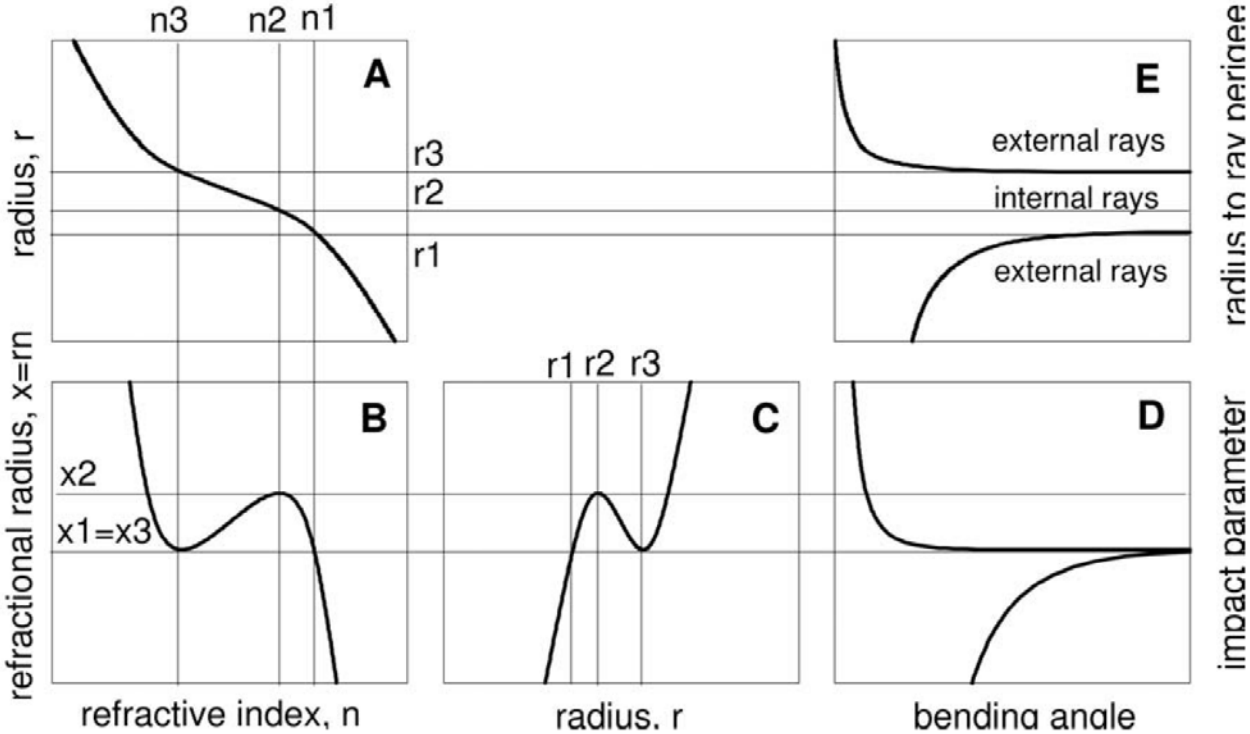
- Flow Chart



Optimization

Ducting Problem

- Super-refraction: N – x will becomes a multi-value function when dN/dz < -157 (N-unit / km^-1)

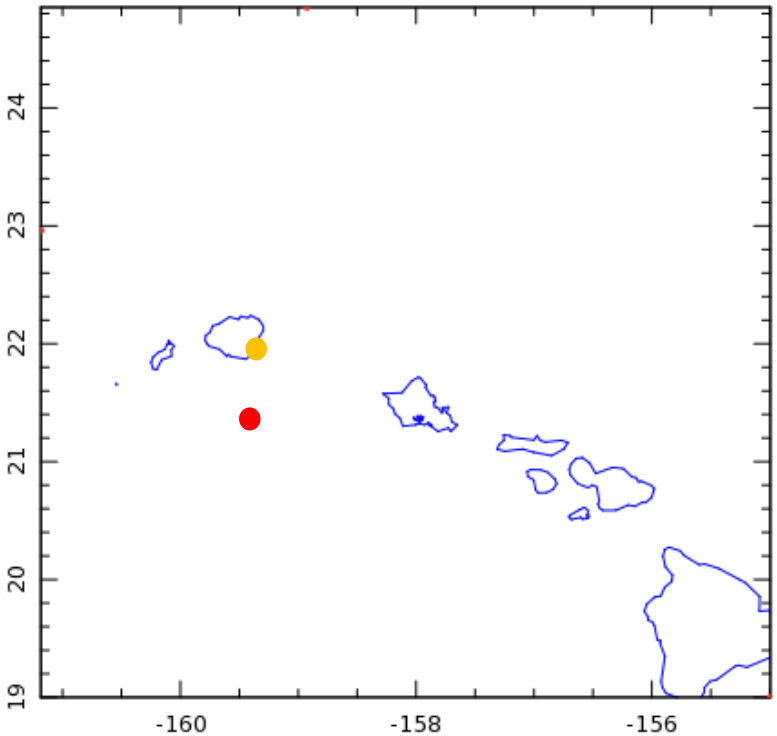


< Sokolovskiy, 2003 >

Optimization

Ducting Problem

- Example: Dec. 10, 2006 -- 1211UTC
- Radiosonde: 21.98 N, 159.35 W RO: 21.3 N, 159.37 W
- Distance: ~80 km Time difference: ~10 min



< Xie et al, 2010 >

Optimization

Ducting Problem

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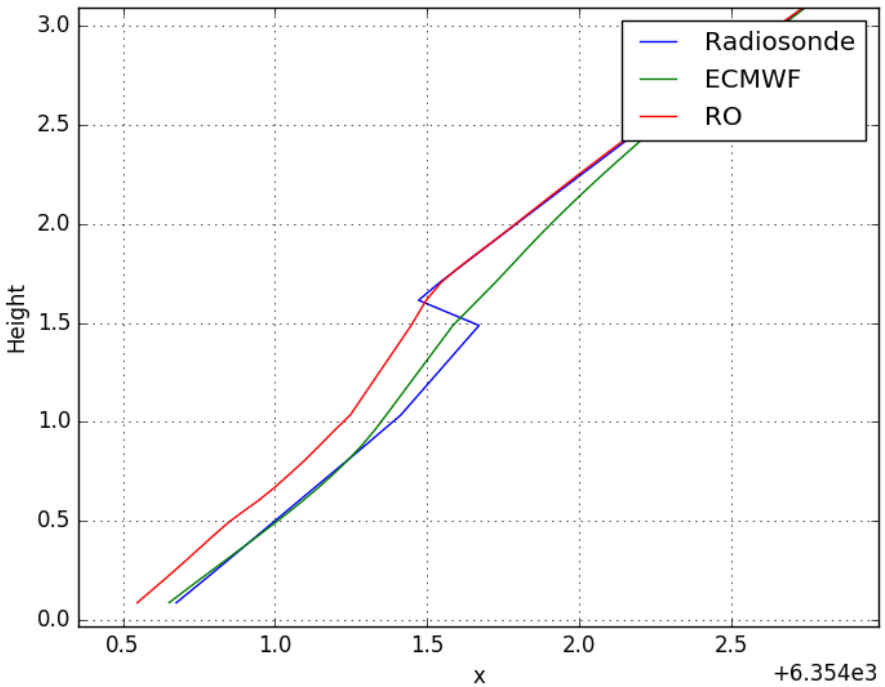
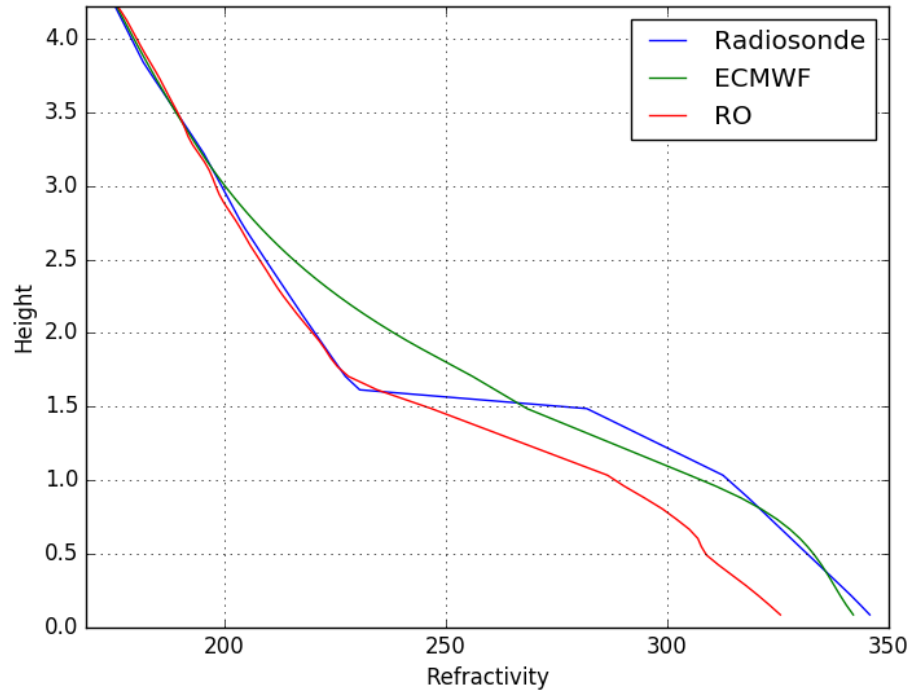
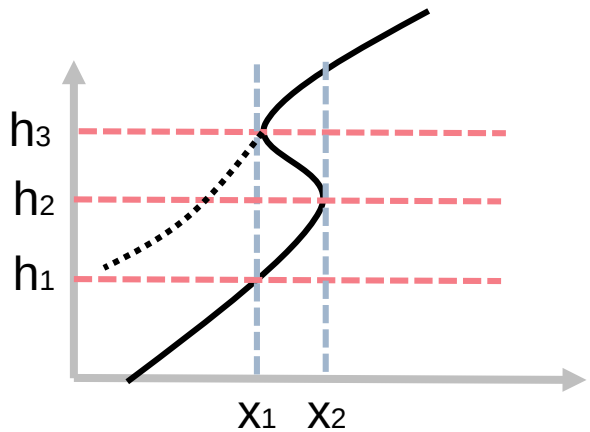




Optimization

Parametrization

- Assumption: The h-x curve in the ducting layer is bilinear



- Fei's equation:

$$h_A(x) = \tilde{h}(x) + \frac{2}{\pi}(h_3 - h_1)\left[z - (1 + z^2)tan^{-1}\left({}^{1}/_{z}\right)\right]$$

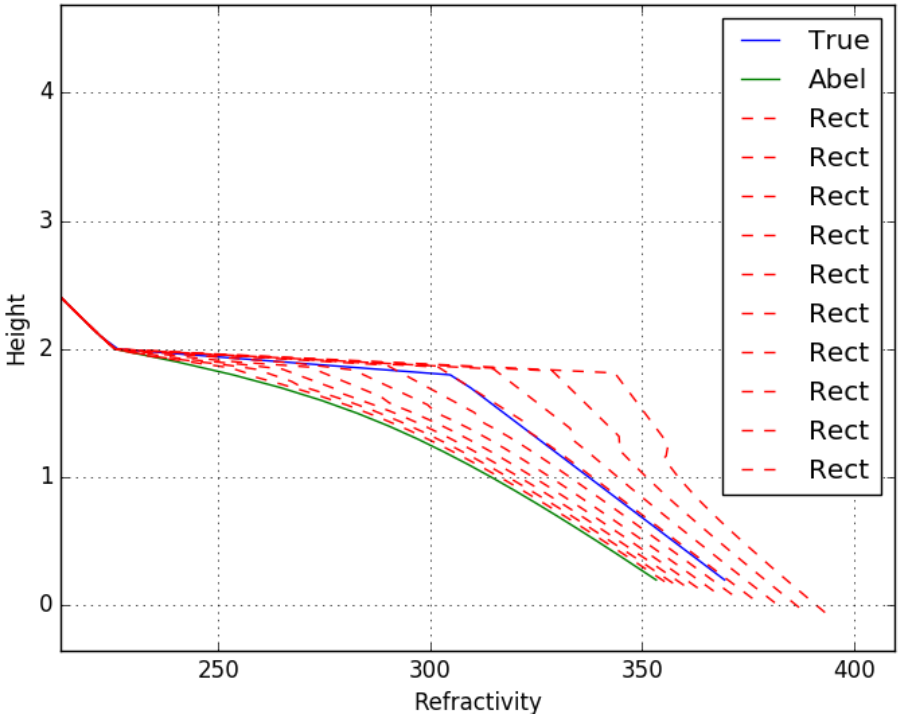
$$z = \sqrt{x_1 - x}/\sqrt{x_2 - x_1}$$

- With several constraints, families of refractivity solutions yield the same BA profile can be acquired.

Optimization

Parametrization

- However, to choose the correct profile among the whole family needs one additional constraint: <u>RO profile extends to the earth's surface!</u>

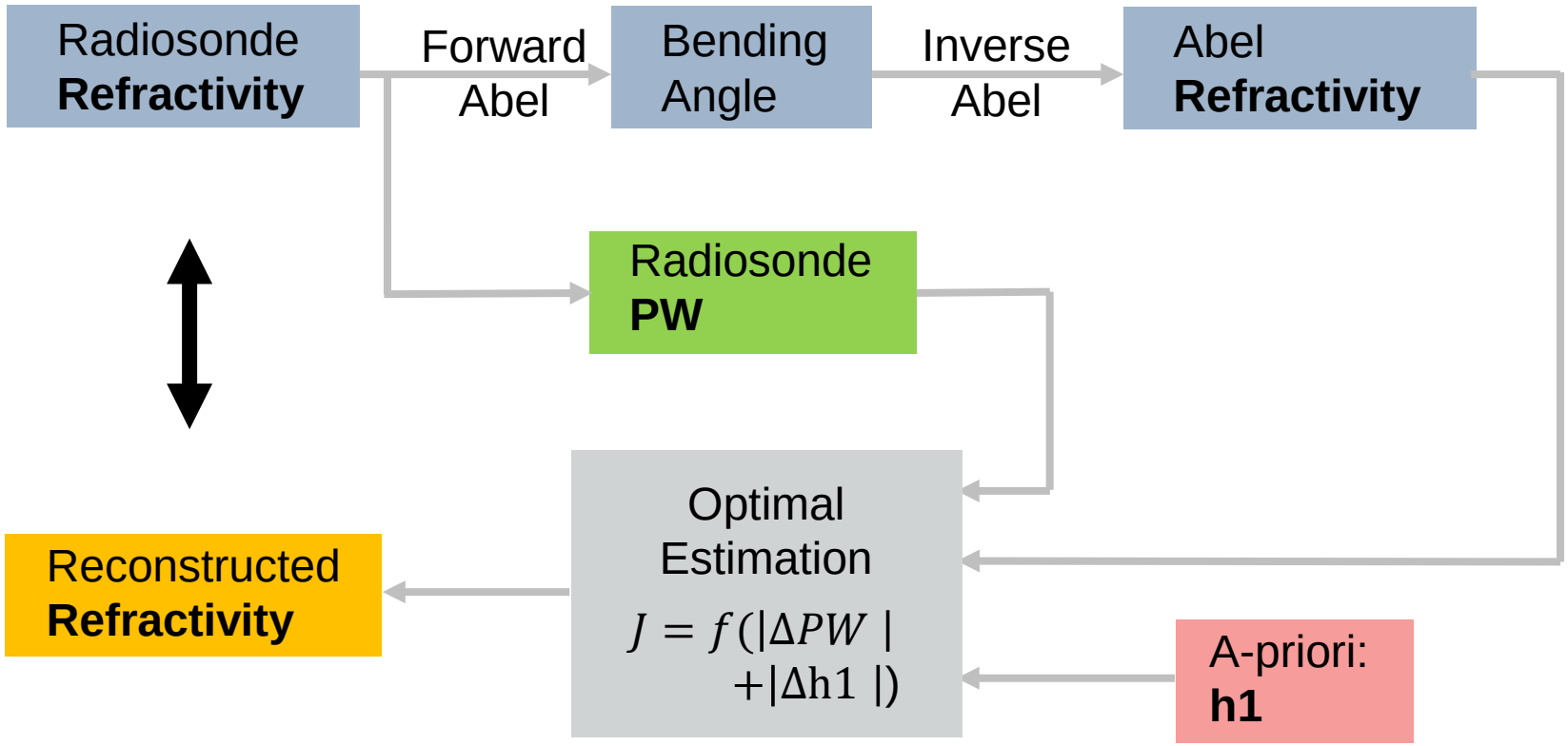


- Optimization with using of precipitable water (PW) as an external measurement can help us replace this constraint.

Optimization

Refractivity Reconstruction (Radiosonde PW)

- Flow Chart



Optimization

Refractivity Reconstruction (Radiosonde PW)

- 6 cases:

4.3

4.7

2.3

431

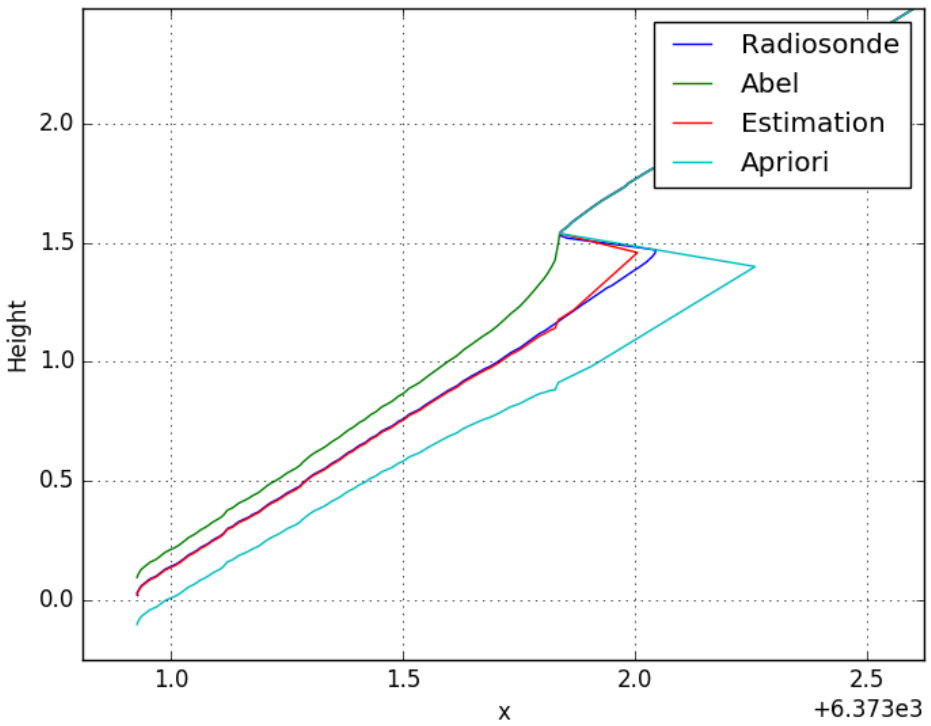
3.8

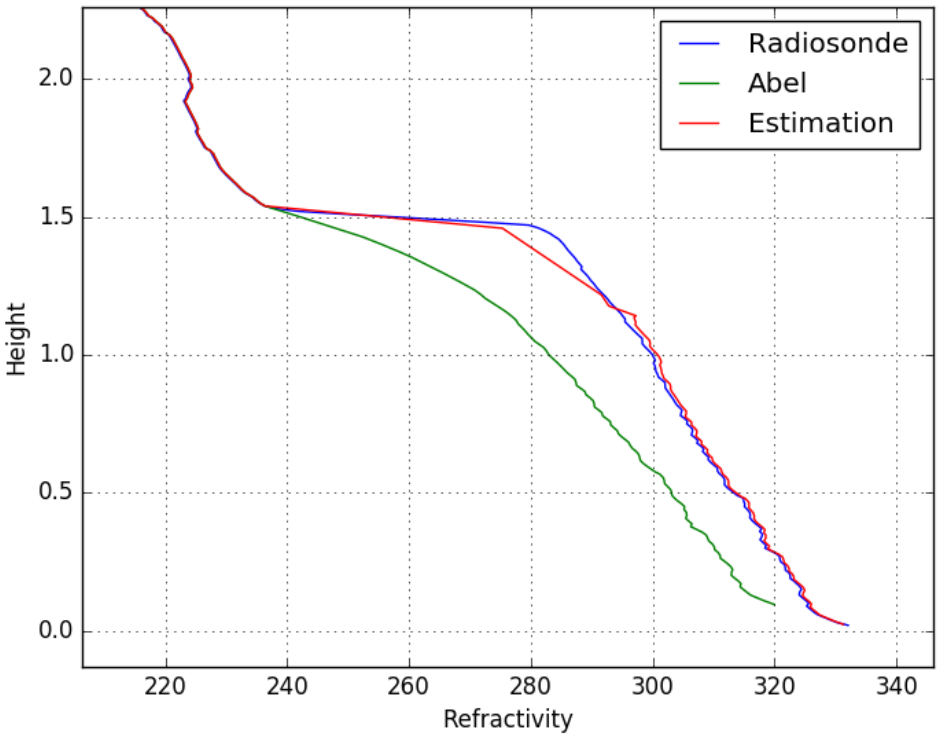
616

Optimization

Refractivity Reconstruction (Radiosonde PW)

- Radiosonde case 20081025_0723
- X-h and N-h reconstruction:

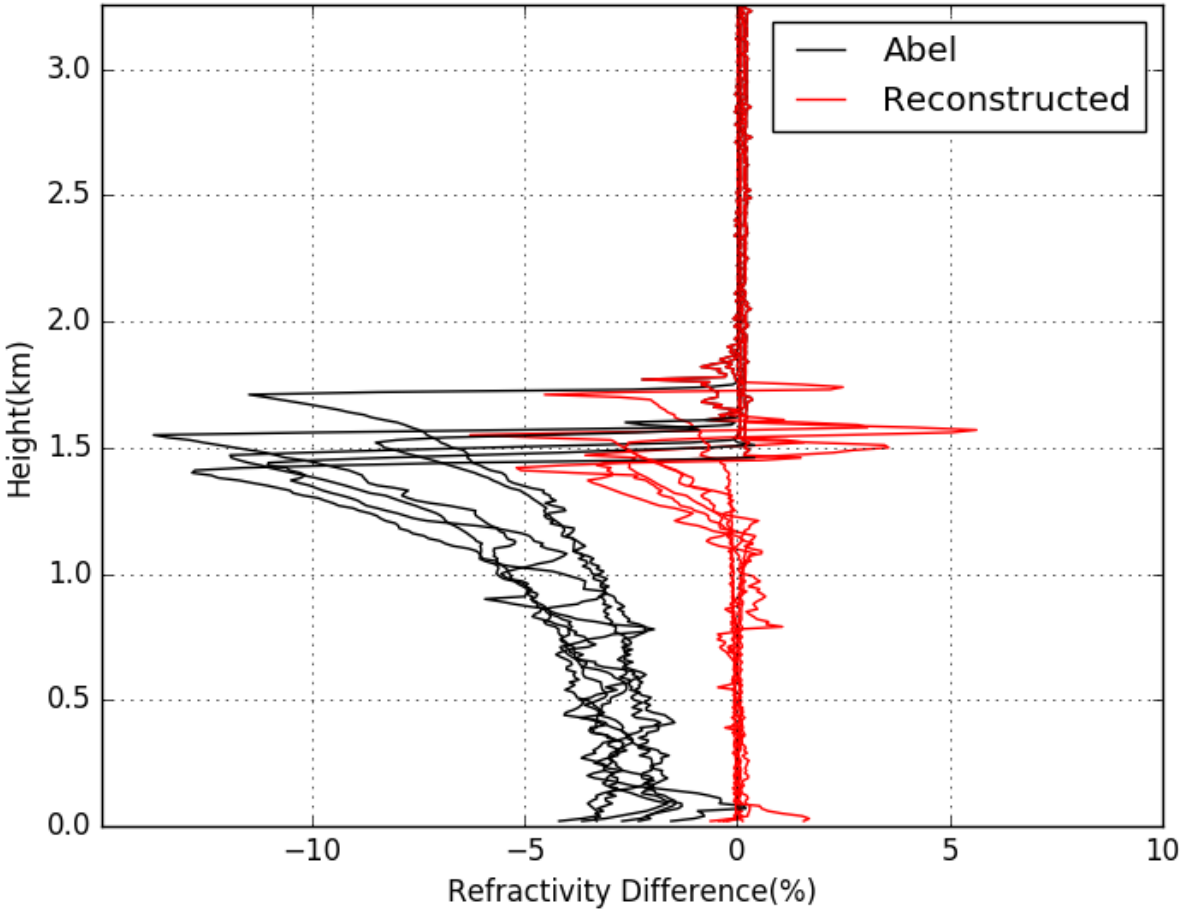




Optimization

Statistics

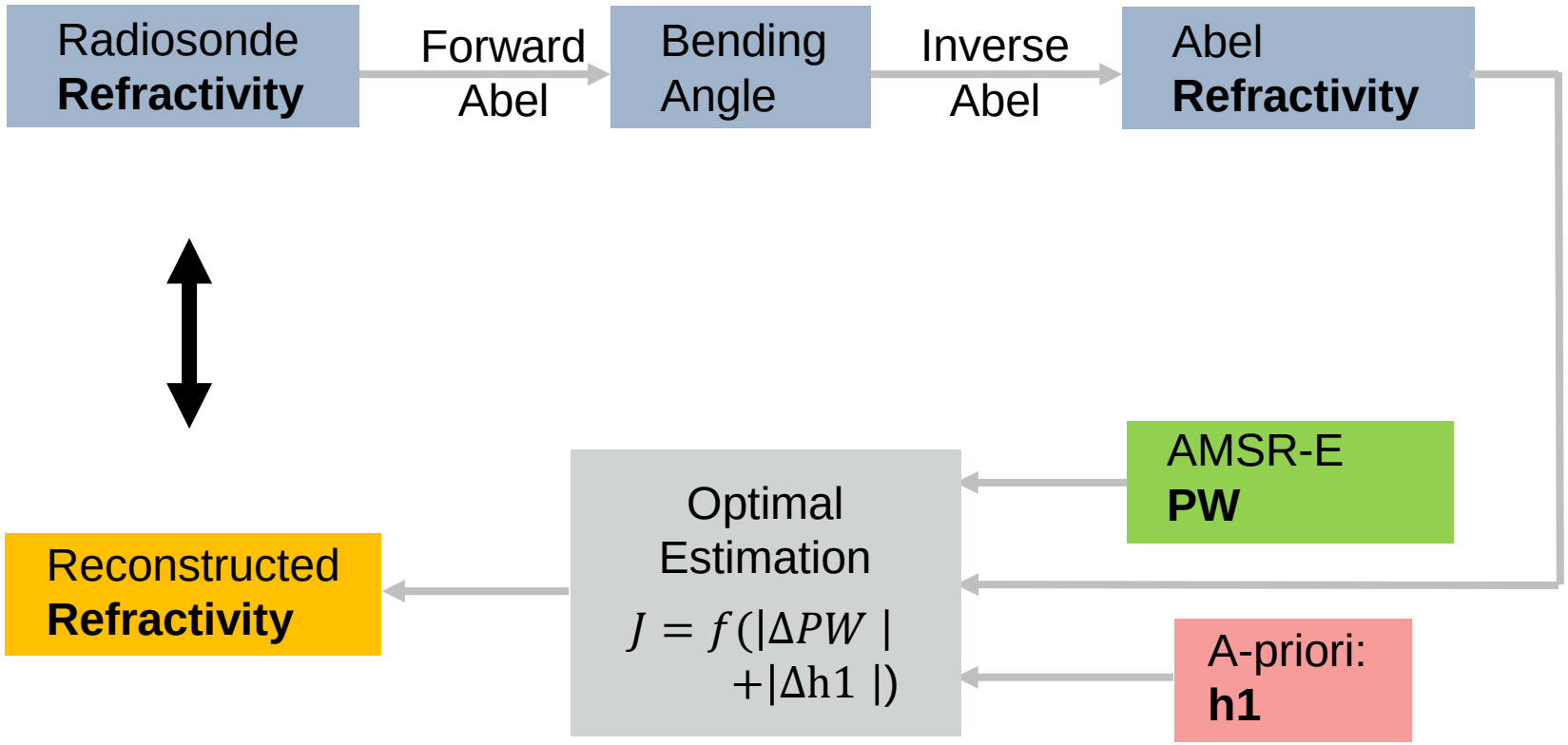
- 6 cases – Using PW from radiosonde



Optimization

Refractivity Reconstruction (AMSR-E PW)

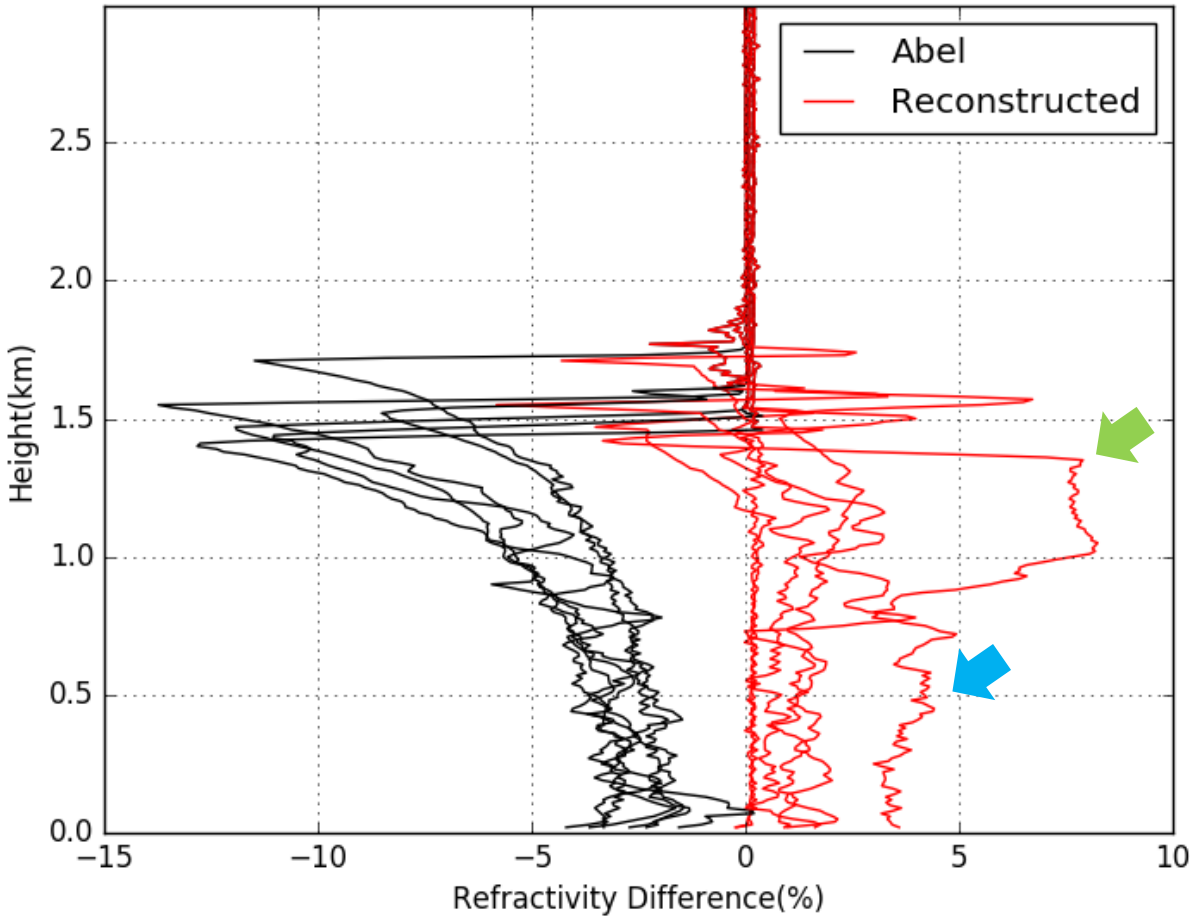
- Flow Chart



Optimization

Statistics

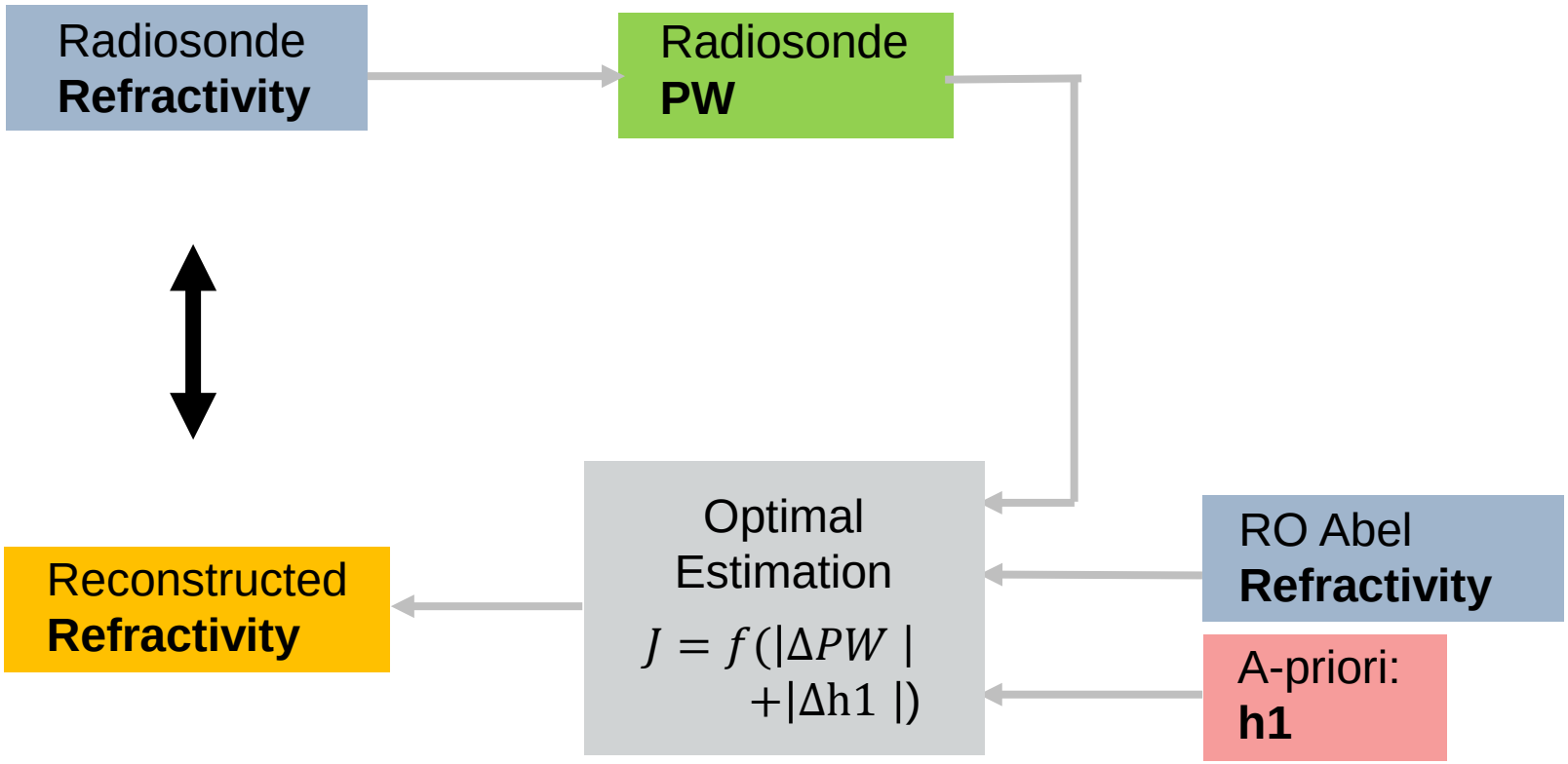
- 6 cases – Using PW from AMSR-E



Optimization

Refractivity Reconstruction (Radiosonde PW + RO Abel)

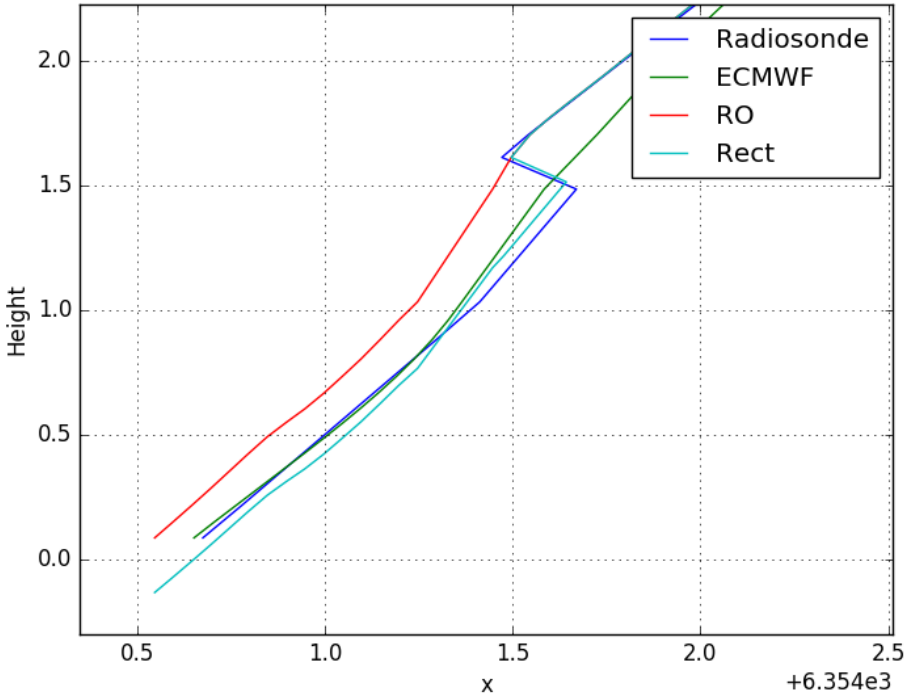
- Hawaii case

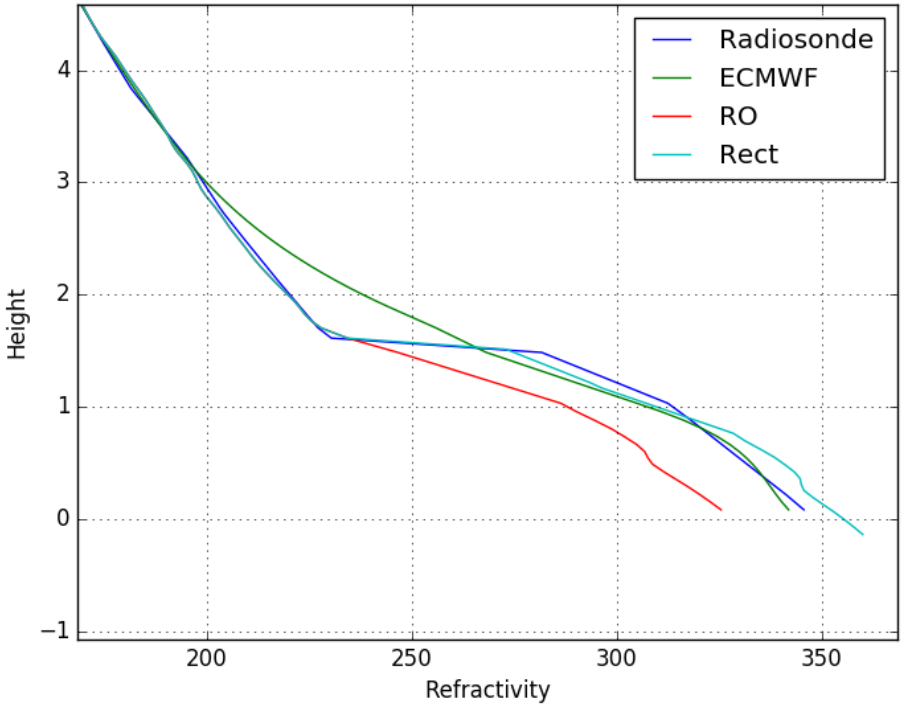


Optimization

RO case 20061210_1211

- X-h and N-h reconstruction:

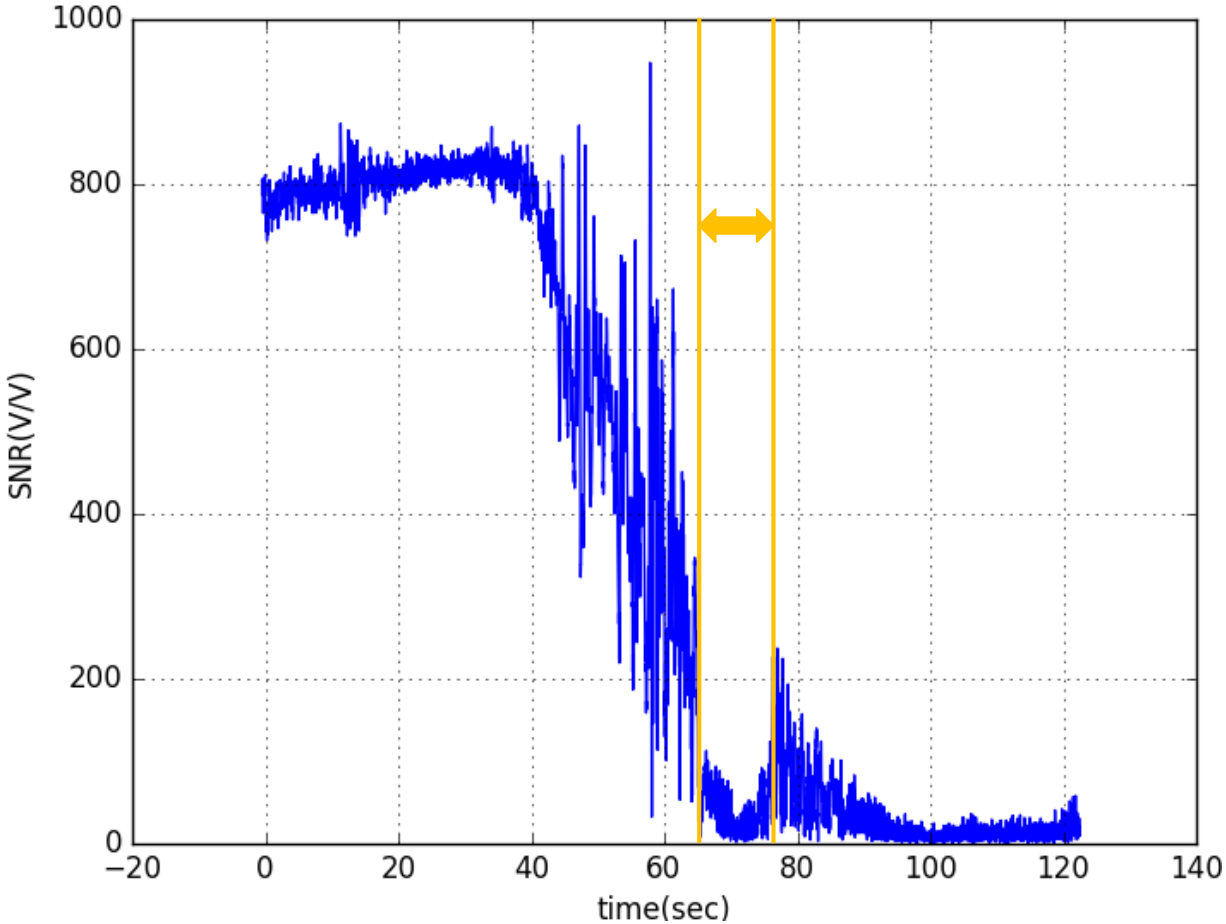




Optimization

Alternative constraint

- Signal Amplitude



Conclusion

- Phase Matching
  - PM is able to decrease negative bias caused by multipath effects due to rapidly changing refractivity gradient.
  - PM may also be useful to be applied on polarimetric RO data (both H and V) for bending angle retrieval.

- Optimization
  - In the application of ducting the combination of optimization and external (or internal, in the future) measurements can effectively decrease the N-bias in refractivity profile.
  - It can also be applied in the polarimetric RO data to estimate the refractivity bias based on the rain rate.

Jet Propulsion Laboratory
California Institute of Technology

jpl.nasa.gov

Progress

AMSR-E

- Direct Method:
  - Hydrostatic gas law: $P_{i-1} = P_i \left(\frac{T_i}{T_{i-1}}\right)^{\frac{m_i g_i}{R\left(dT/dz\right)}}$

    m: mean molecular mass
    g: gravitational acceleration
  - Refractivity: $N = 77.6\frac{P}{T} + 64.8\frac{e}{T} + 3.776e5\frac{e}{T^2}$
  - Step:
    - (1) Initial guess for e_{i-1} and initial P_i from RO profile
    - (2) Update m_{i-1} by using e_{i-1}
    - (3) Calculating P_{i-1} with the hydrostatic law
    - (4) Update e_{i-1} using P_{i-1} and T_{i-1}
    - Repeat (2) to (4) until convergence
  - Result: P (hPa) and e (hPa)

Progress

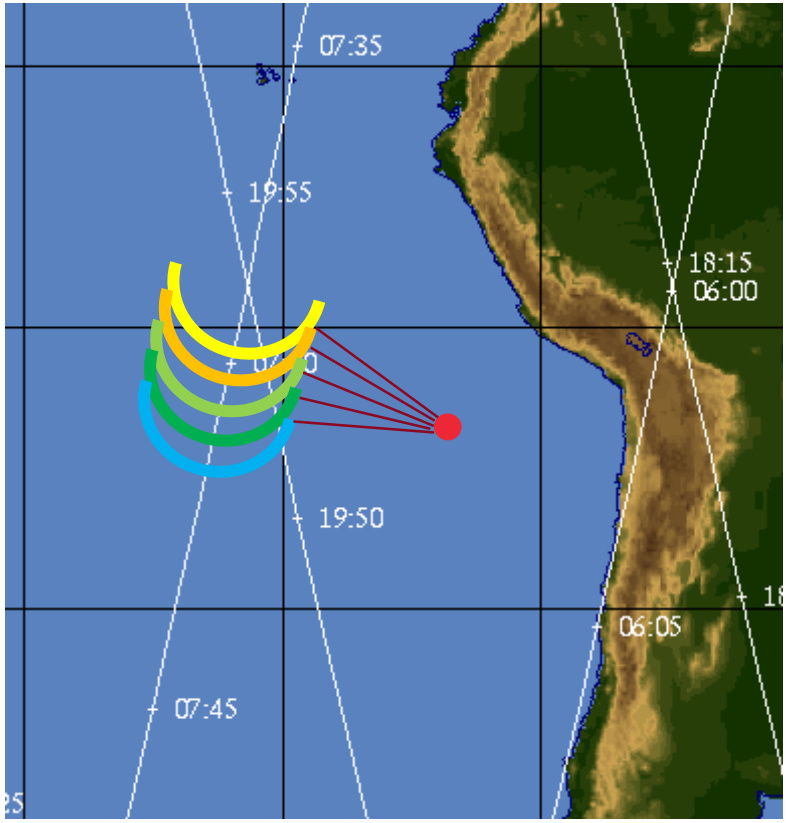
AMSR-E

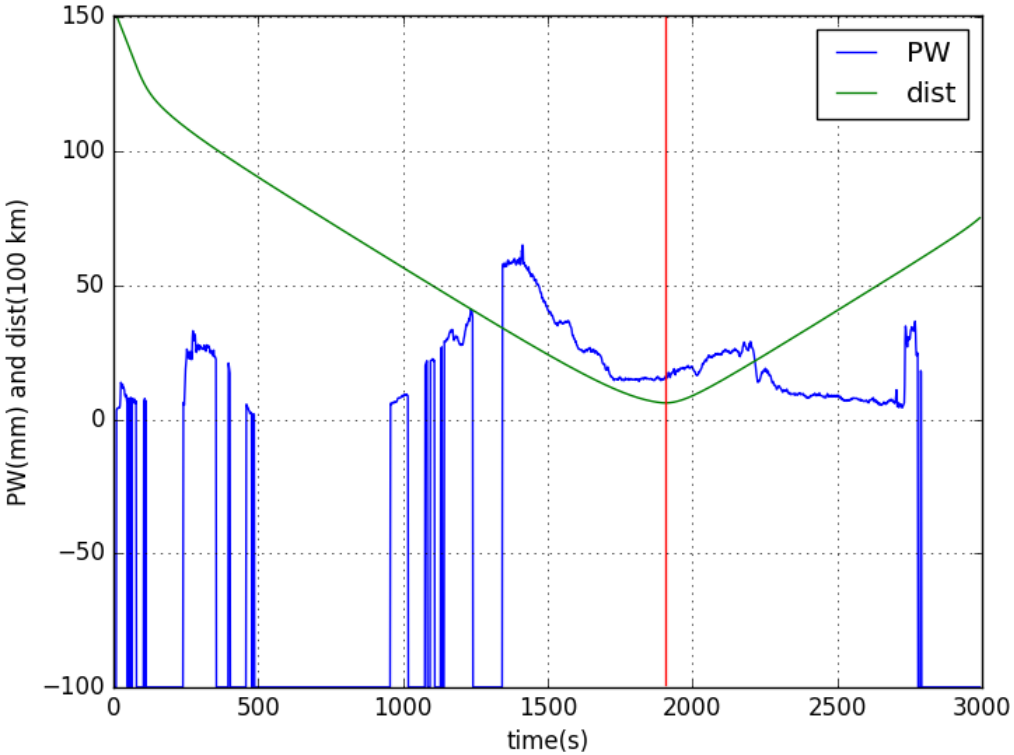
- Precipitable Water:
  - Specific Humidity: $\mathrm{q} \cong 622\frac{e}{P}$ (g/kg)
  - Column Water Vapor(CWV): $W = \frac{1}{g}\int_{P_0}^{P_T} q dp$ (g/m^2)
    - However, we don't have P and q profile at bottom
    - Extrapolate the curve to the surface by fitting the P-z curve exponentially
    - Assume q is constant from surface to the lowest height of the profile
  - Precipitable Water: $PW = \rho W$ (mm)

Progress

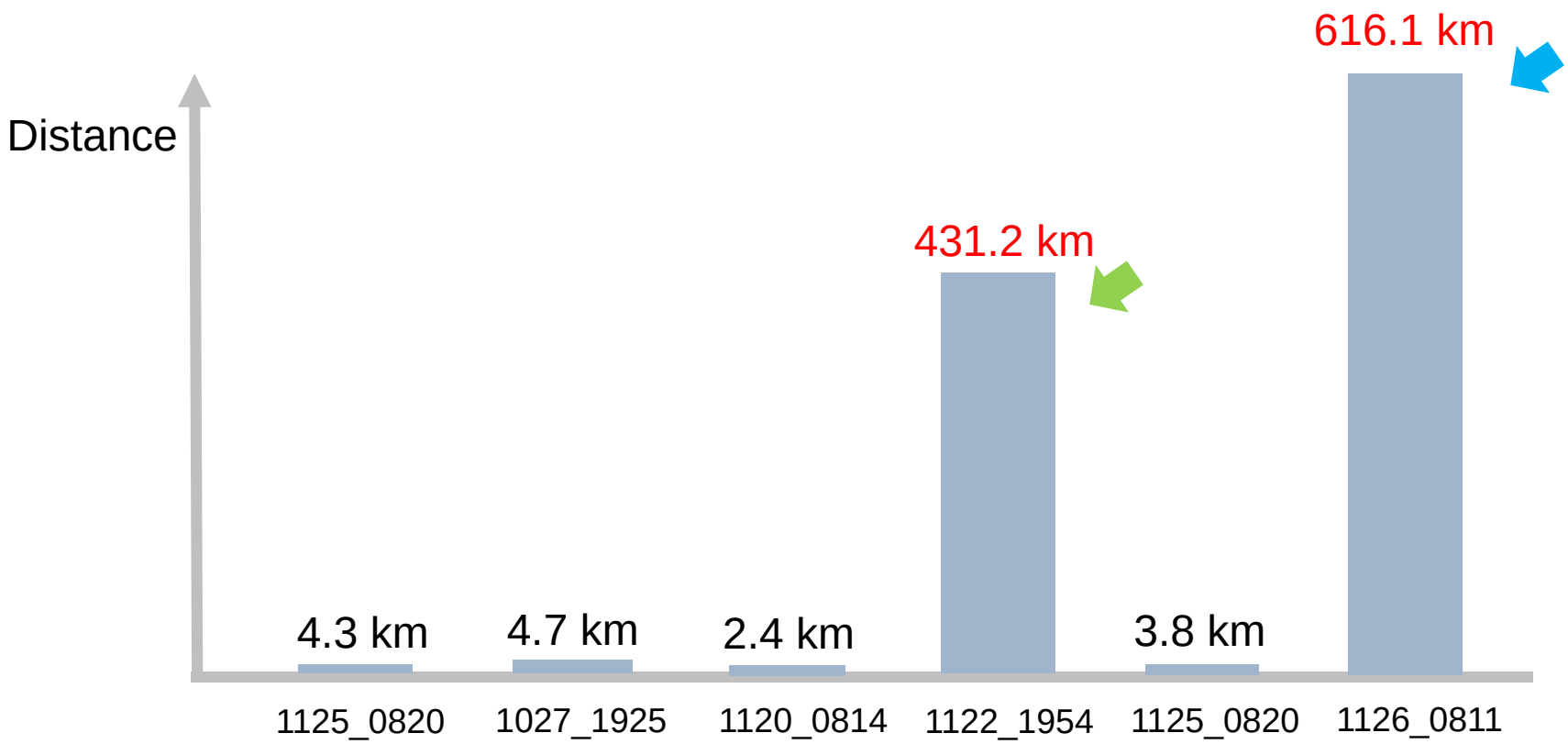
AMSR-E Measurement

- Choose the point with the shortest distance





Results

Outliers

- Outliers: when AMSR-E measurement is too far from radiosonde measurement: