Bayesian Retrieval of Thermodynamic Atmospheric Profiles from Ground-based Microwave Radiometer Data

Master Defensio - Christopher Polster - 15.09.2016

HATPRO

- Humidity And Temperature PROfiler
- Asset of the ACINN (i-Box)
- Microwave Radiometer
  - 7 + 7 channels
  - Elevation scanning
  - Temporal resolution of 1 s

https://forschungsinfrastruktur.bmwfw.gv.at/de/institution/universitat-innsbruck_3?id=2278

Thermodynamic Atmospheric Profiling During the 2010 Winter Olympics Using Ground-Based Microwave Radiometry

Cimini et al. 2011

Nowcasting severe convective activity over southeast India using ground-based microwave radiometer observations

Madhaluta et al. 2013

Application of brightness temperature data from a ground-based microwave radiometer to issue low-level windshear alert over Hong Kong International Airport

Chan and Lee 2013

A data assimilation experiment of temperature and humidity profiles from an international network of ground-based microwave radiometers

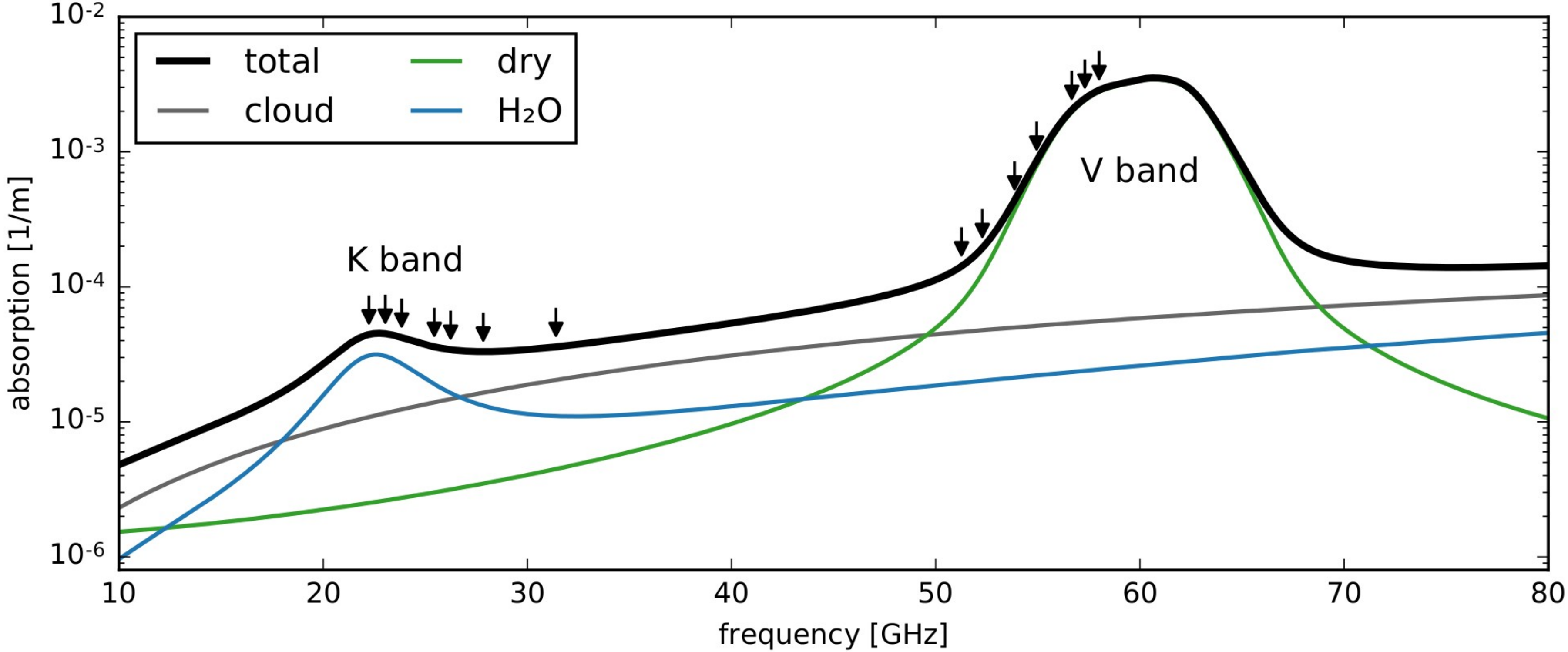
Cimini et al. 2014

Why Microwave Radiometers?

- Vertical sounding of the atmospheric state
  - Temperature
  - Humidity
  - Clouds

Why Microwave Radiometers?

- Atmospheric Microwave Absorption/Emission



Why Microwave Radiometers?

- Vertical sounding of the atmospheric state
  - Temperature
  - Humidity
  - Clouds
- Penetration of cloud layers
- Highest spatial resolution in the boundary layer
- Continuous measurement
- Alternatives: Balloon, Aircraft, Satellite, IR Radiometer

The Inversion (=Retrieval) Problem

Atmospheric State (true)

Pressure
Temperature
Humidity
Cloud Water
...

→

Microwave Radiometer

Brightness
Temperatures
at Different
Frequencies/Angles

→

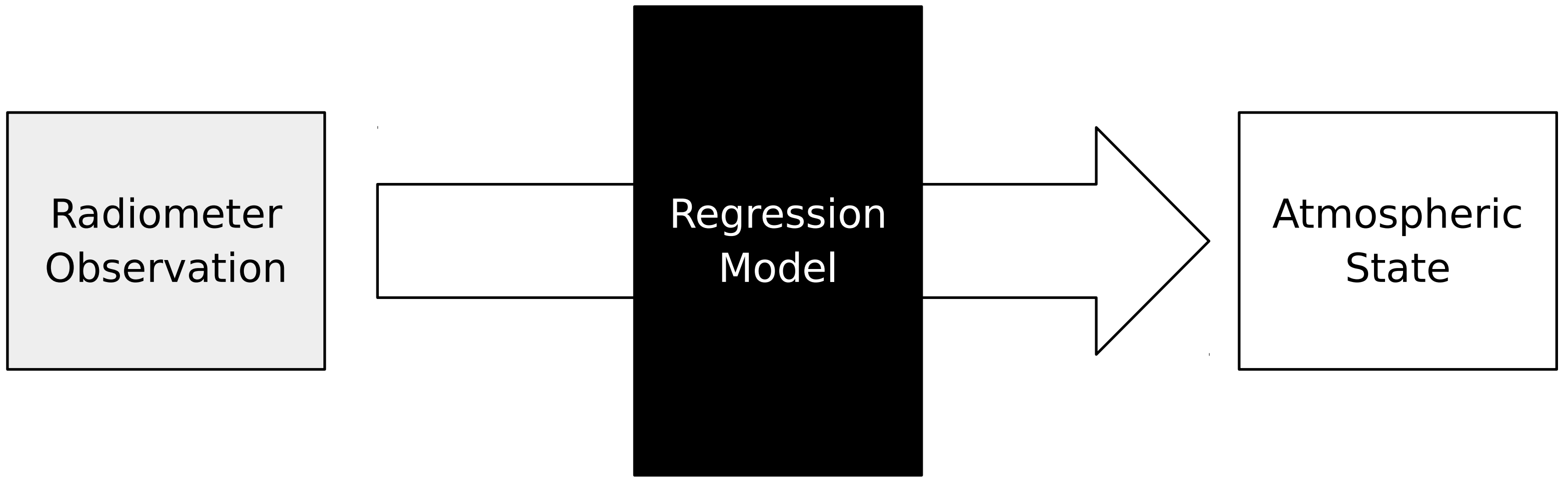
???

→

Atmospheric State (retrieved)

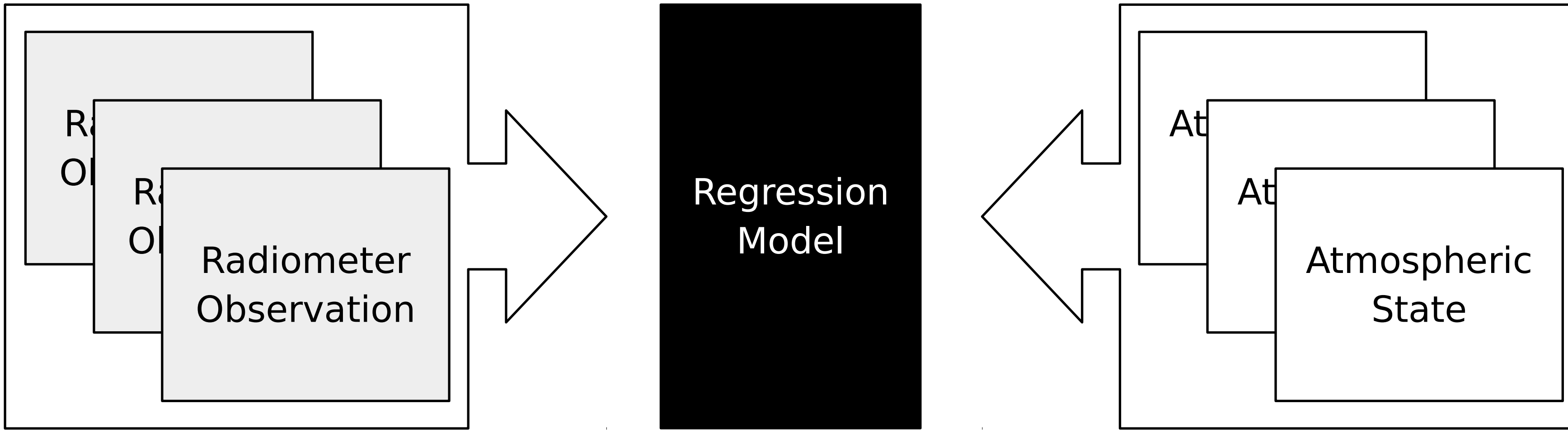
Temperature
Humidity
Cloud Water
....

Solving the Inversion Problem with Regression



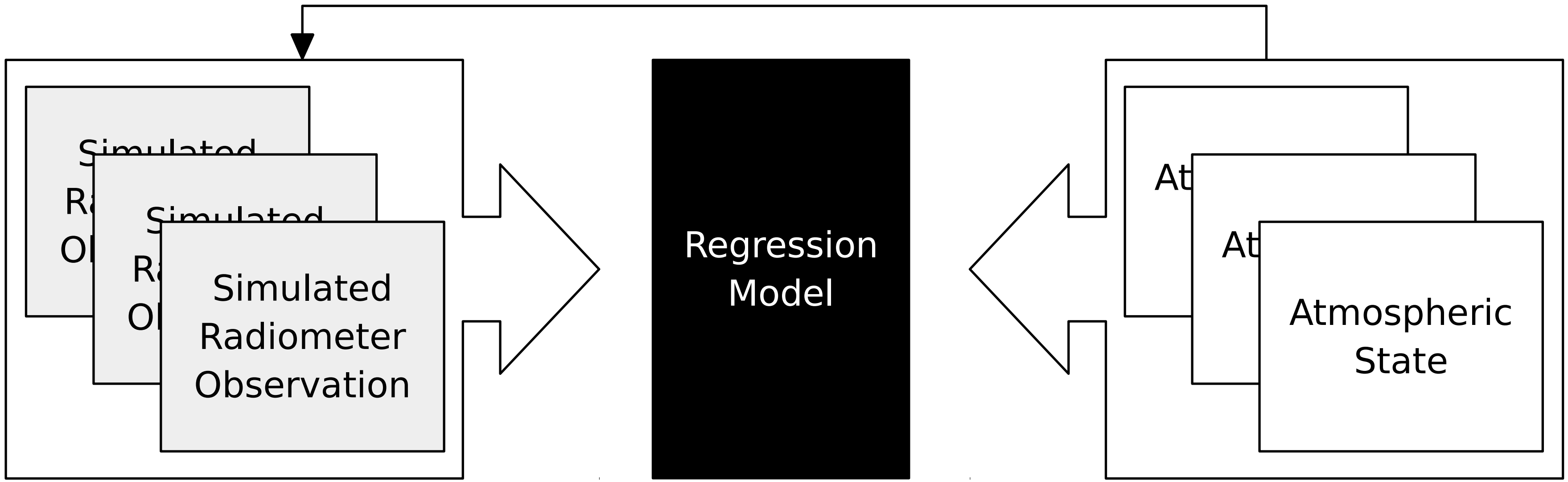
- Linear regression, neural networks, ...

Solving the Inversion Problem with Regression



- Quality of approximation determined by:
  - Training data
  - Choice of regression model

Solving the Inversion Problem with Regression



- Quality of approximation determined by:
  - Training data
  - Choice of regression model
  - Accuracy of radiative transfer model

Advantages of Regression Models

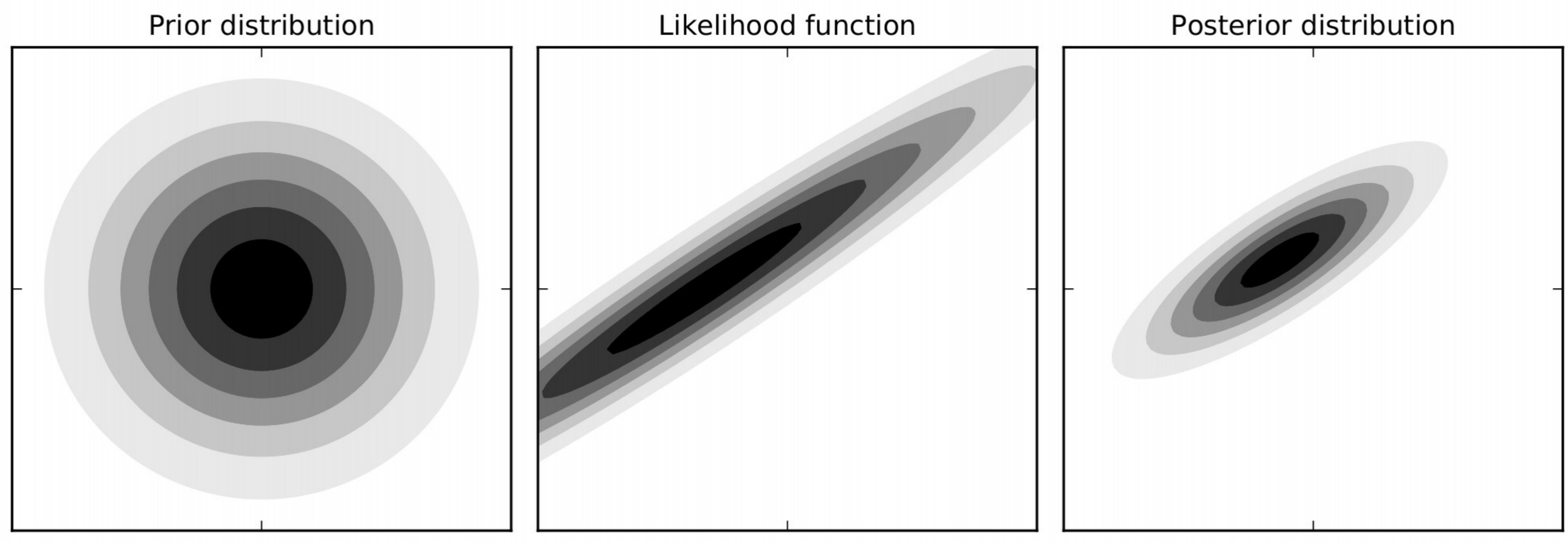
- Easy to use
- Variety of available models
- Trivial integration of additional data

Disadvantages of Regression Models

- No consideration of physical knowledge
- Unpredictable extrapolation behaviour
- Uncertainty assessment is hard

Bayes' Theorem

$$p(x) \qquad p(y\,|\,x) \qquad \sim \qquad p(x\,|\,y)$$



Bayes' Theorem → Optimal Estimation

$$p(x\,|\,y) \;\sim\; p(y\,|\,x)\,p(x)$$

- Prior: $p(x)$
  - What is known about the atmospheric state **before** the radiometer observation?
- Likelihood: $p(y\,|\,x)$ [read: y given x]
  - Can an observation be the result of a given state?
- Posterior: $p(x\,|\,y)$ [read: x given y]
  - What is known about the atmospheric state **after** the radiometer observation?

Bayes' Theorem → Optimal Estimation

- High dimensionality

  → Gaussian distributions

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- Likelihood function

  → Numerical radiative transfer model

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- Nonlinearity of radiative transfer

  → Linearization

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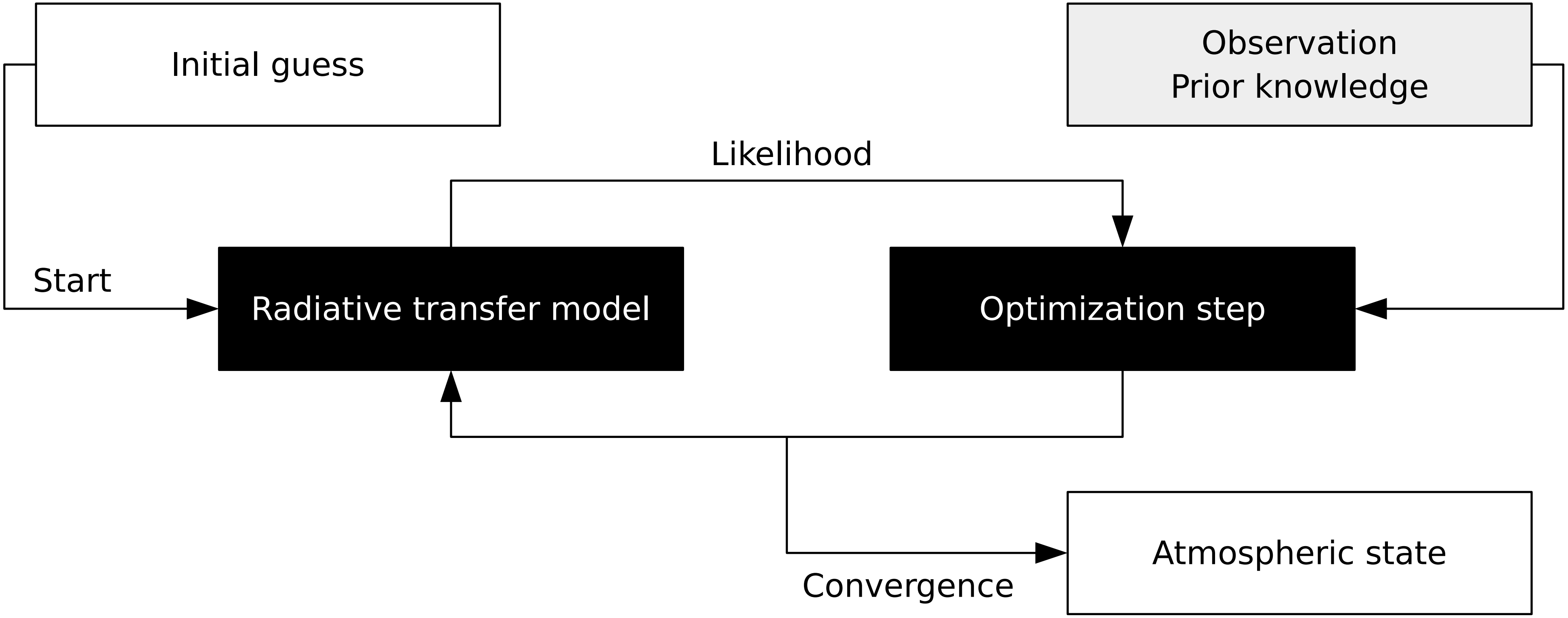
- Nonlinearity of radiative transfer

  → Linearization

- Optimum in linear case

  → Iterative search

Bayes' Theorem → Optimal Estimation



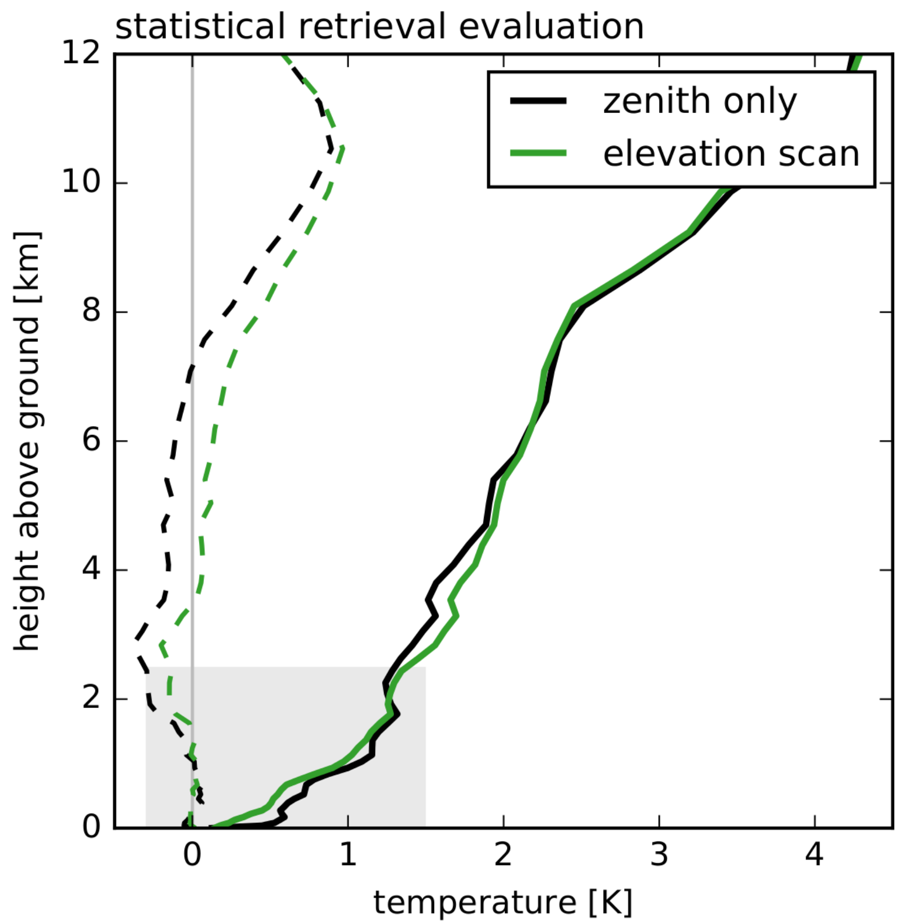
Advantages of Optimal Estimation

- Inclusion of additional information is natural
- Explicit inclusion of physical knowledge
- Uncertainty estimation

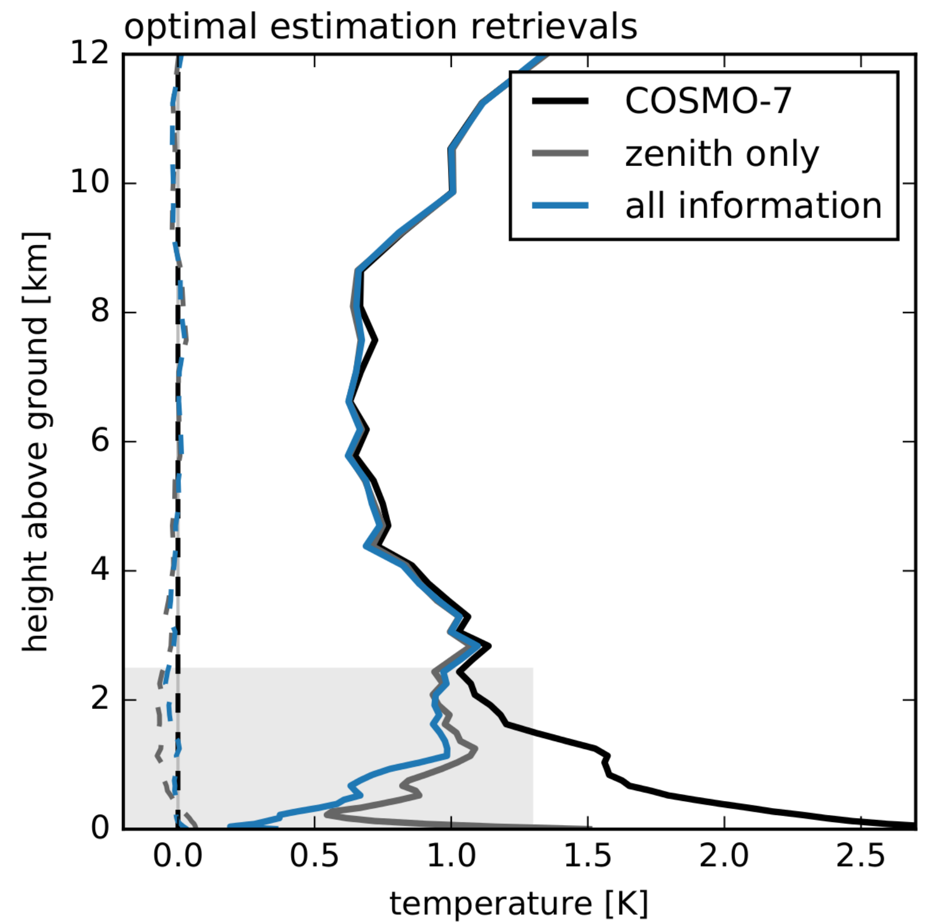
Disadvantages of Optimal Estimation

- Computational cost
- Data requirements
- Assembly of prior not trivial

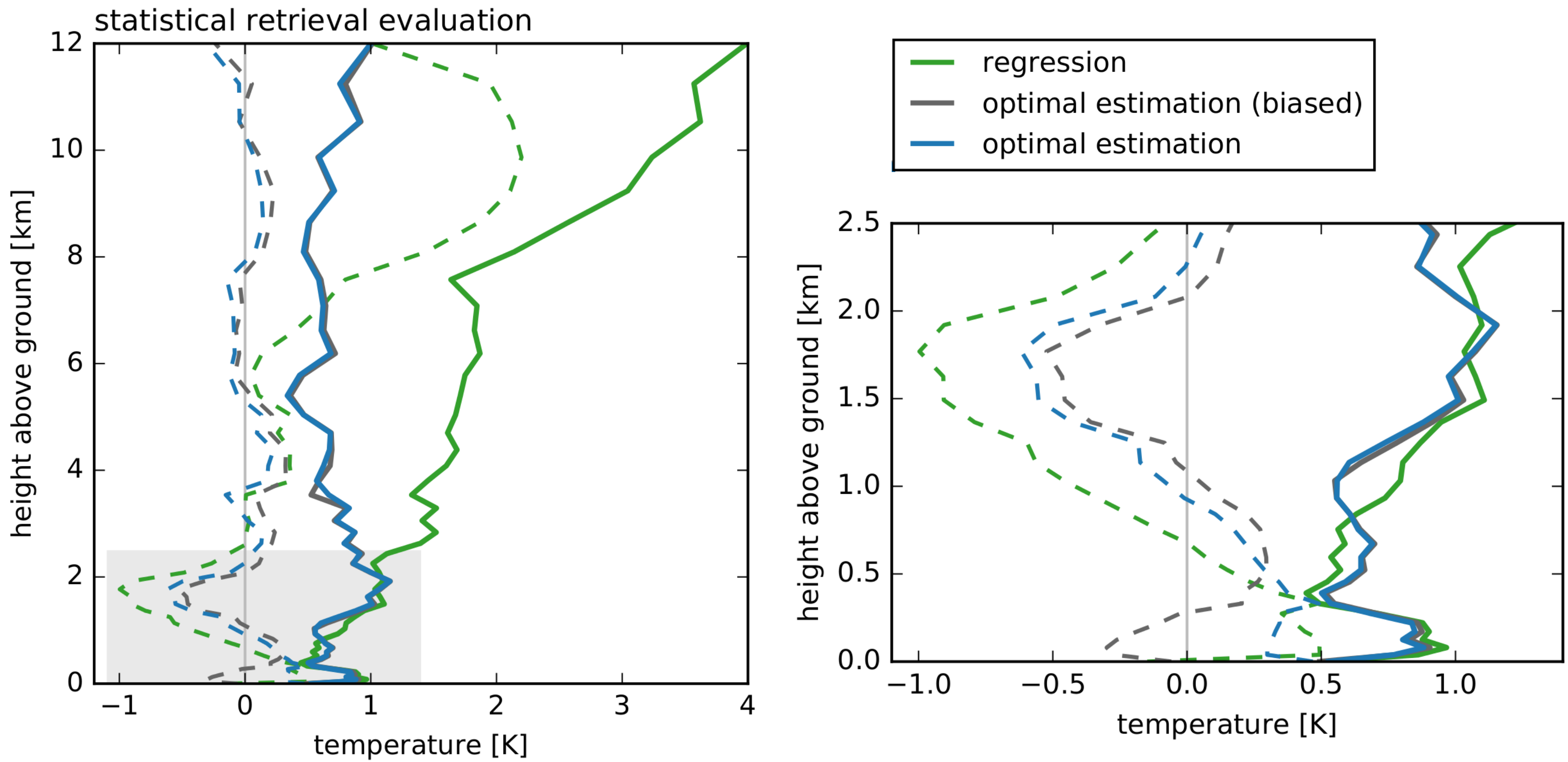
Regression



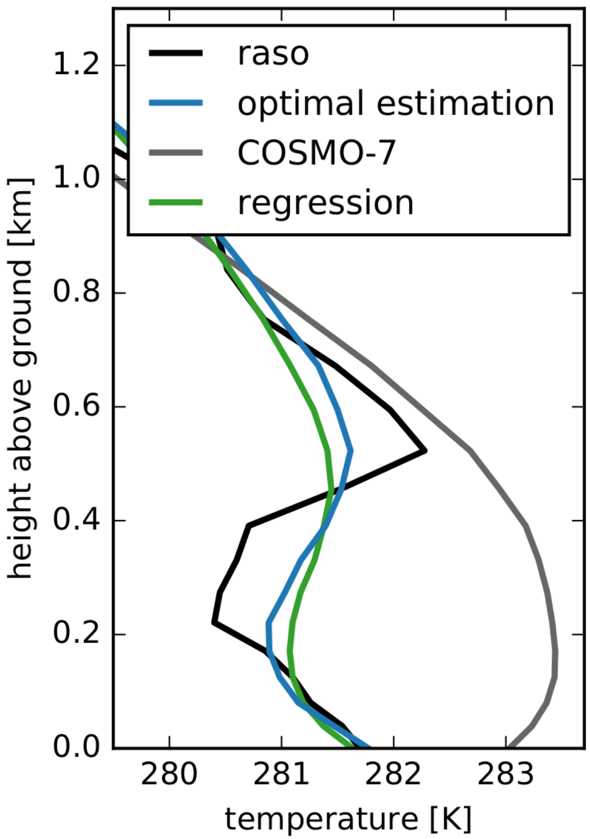
Optimal Estimation



Real HATPRO data



Case study with different prior distributions



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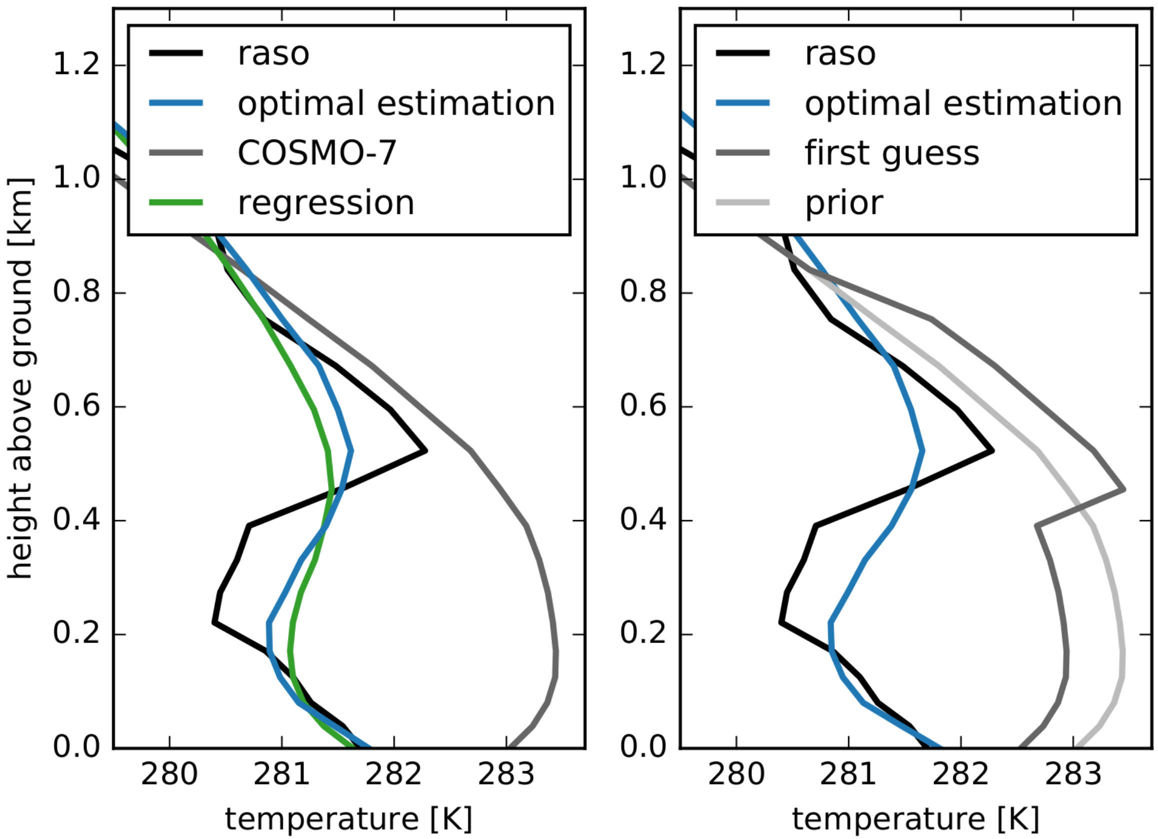

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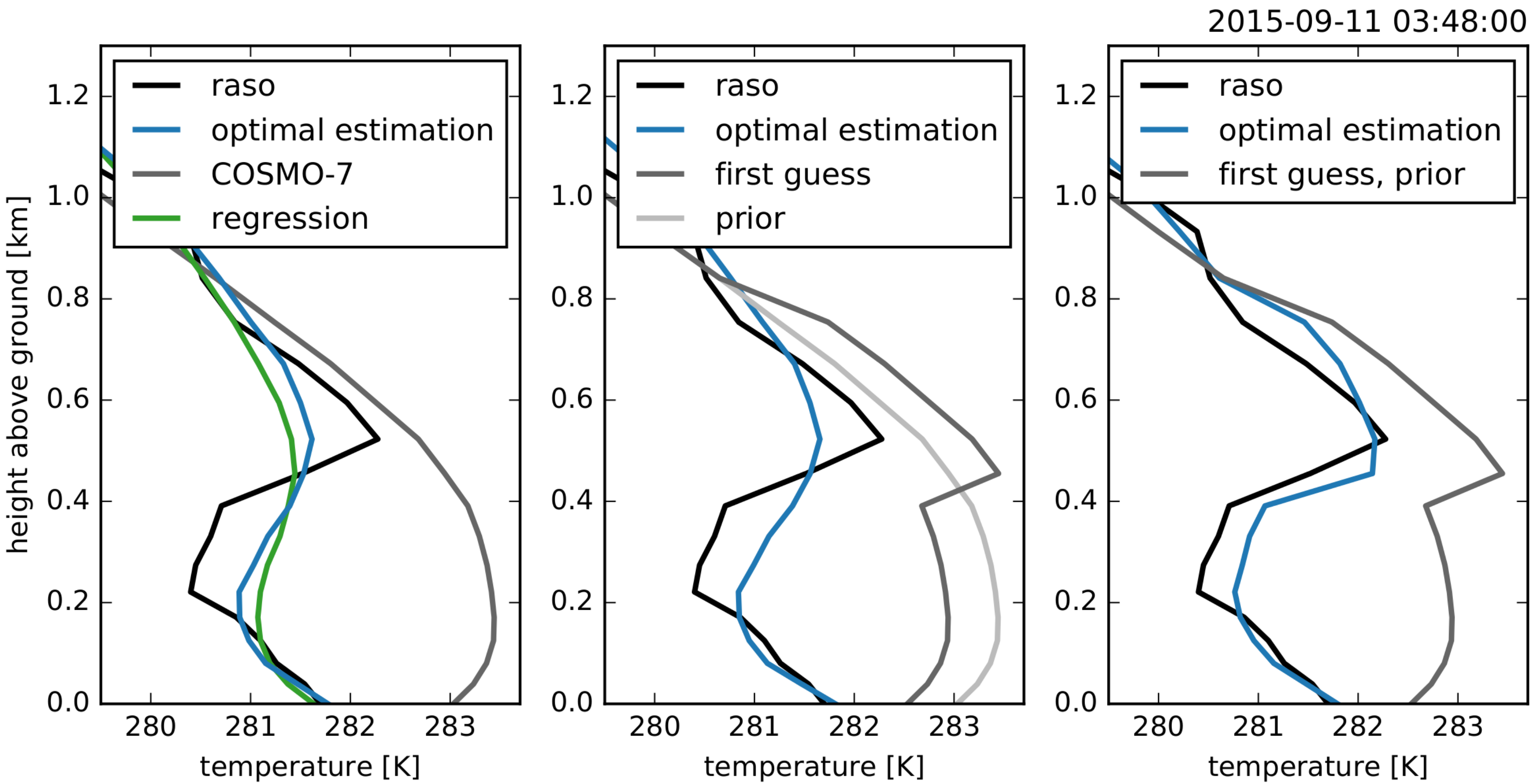

Conclusions

- Untuned optimal estimation is generally not better than a good regression model ... but also not worse
- Optimal estimation implementation is promising
  - Prior distribution appears to be the key component
- NWP model provides valuable information in upper atmosphere

Outlook

- Lack of sophisticated evaluation methods
- Assimilation of microwave radiometer data into NWP models on the horizon
- Next generation of radiative transfer models is being developed

References

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