Problems and basic approaches for image reconstruction in aperture synthesis radiometry

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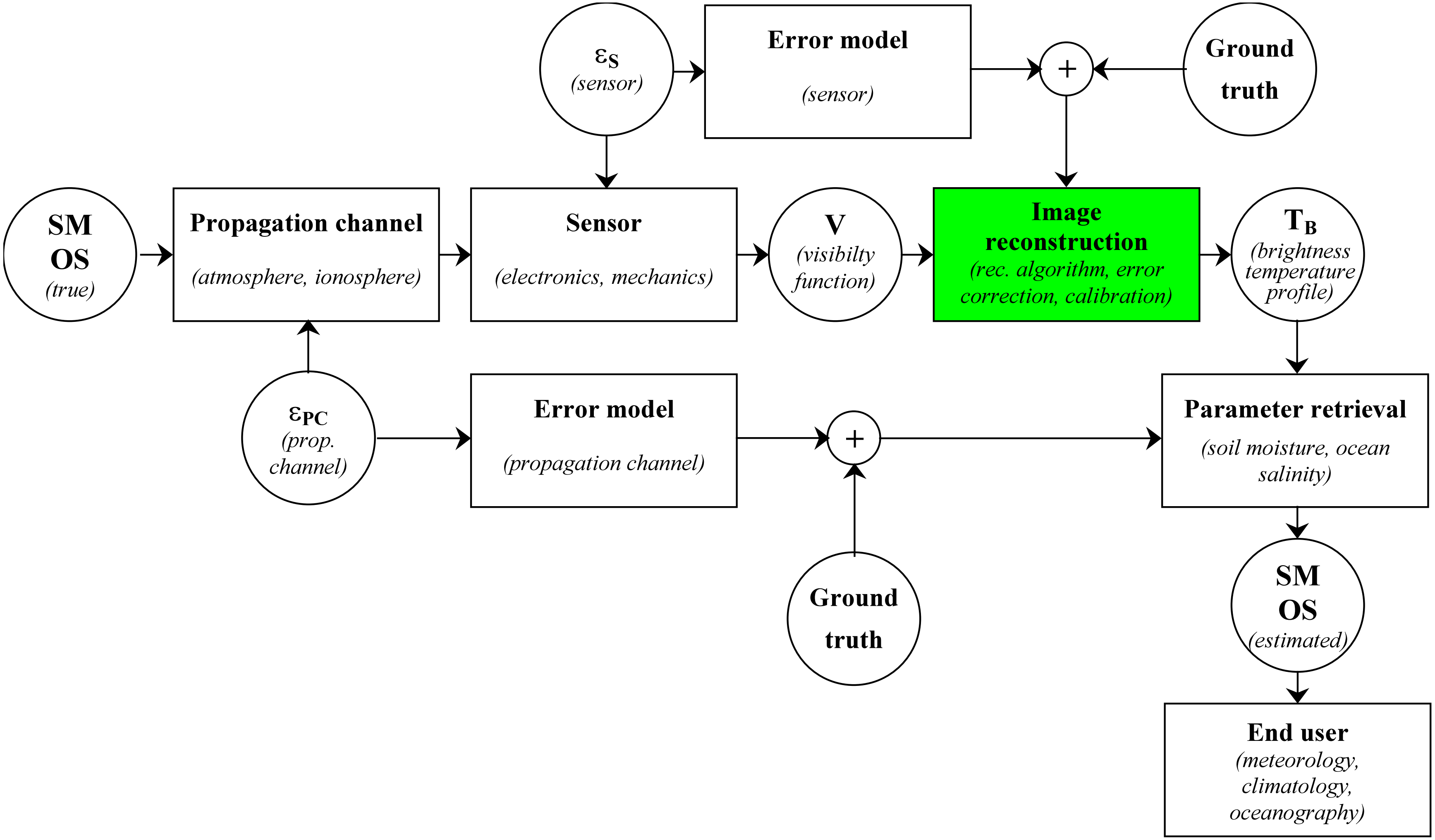
Structure of the presentation

- Definition of image reconstruction
- Error sources and their impact on image reconstruction
- Basic approaches for advanced image reconstruction
- First conclusions - stimulations for discussions

Overall system flow graph of the SMOS data processing



SMOS
(true)

Propagation channel
(atmosphere, ionosphere)

ε_S
(sensor)

Error model
(sensor)

Ground truth

Sensor
(electronics, mechanics)

V
(visibilty function)

Image reconstruction
(rec. algorithm, error correction, calibration)

T_B
(brightness temperature profile)

ε_{PC}
(prop. channel)

Error model
(propagation channel)

+

Ground truth

Parameter retrieval
(soil moisture, ocean salinity)

SMOS
(estimated)

End user
(meteorology, climatology, oceanography)

Definition of image reconstruction

1) Transformation of raw data into image data (basic algorithm)

2) Error correction (compensation/reduction algorithm)

3) Calibration (conversion algorithm: e.g. voltage to brightness temperature)

- Note: In general the application of the algorithms cannot be separated !

Basic equations of aperture synthesis imaging for the ideal case

Visibility function to be measured:

$$V\left(u_\lambda, v_\lambda\right) = \int_{-m_{\max}}^{m_{\max}} \int_{-l_{\max}}^{l_{\max}} \frac{P(l,m)\ T_B(l,m)}{\sqrt{1-l^2-m^2}} \exp\left[-2\pi\left(u_\lambda l + v_\lambda m\right)\right] dl\, dm$$

Constraints: sampling theorem (min. antenna distance), finite aperture size (resolution)

$$\Delta u_\lambda = 1/\left(2\, l_{\max}\right) \qquad \Delta l \geq 1/u_{\max}$$

$$\Delta v_\lambda = 1/\left(2\, m_{\max}\right) \qquad \Delta m \geq 1/v_{\max}$$

Image reconstruction rule: Inverse Fourier transform and pattern correction

$$T_B(l,m) = \frac{\sqrt{1-l^2-m^2}}{P(l,m)} \iint_{u-v\ plane} V\left(u_\lambda, v_\lambda\right) \exp\left[2\pi\left(u_\lambda l + v_\lambda m\right)\right] du_\lambda\, dv_\lambda$$

Modelling equation of the non-ideal case - potential instrumental error sources

Pattern imbalance
$f(u_\lambda, v_\lambda)$

Gain imbalance
$f(u_\lambda, v_\lambda)$

$$V(u_\lambda, v_\lambda) = \int\limits_{f} \int\limits_{-m_{\max}}^{m_{\max}} \int\limits_{-l_{\max}}^{l_{\max}} \frac{P_{ij}(l,m,f)\, T_B(l,m)}{\sqrt{1-l^2-m^2}} G_{ij}(f)$$

$$\times \quad \exp\left[-2\pi \frac{f}{f_0}\left(u_\lambda l + v_\lambda m + w_\lambda \sqrt{1-l^2-m^2}\right) + \Delta\varphi_{ij}(f)\right] dl\, dm\, df$$

$$+ \{\Delta V\}$$

Noise
$f(u_\lambda, v_\lambda)$

u-v plane imbalance
$f(u_\lambda, v_\lambda)$

Phase imbalance
$f(u_\lambda, v_\lambda)$

Image reconstruction methods to reduce errors due to system imperfections

- Direct method
- Method of closure phases / amplitudes
- Method of point source response adjustment
- CLEAN algorithm
- Maximum entropy method (MEM)

Conclusions 1

Identified problems:

There is a lack of knowledge about realistic magnitudes and their physical distributions of imperfections within the system.

Many methods to reduce imperfections exist. Which one are mostly adequate (combinations) for SMOS?

There is a lack in accuracy and performance estimation of the methods. There is no common comparison standard defined yet.

Conclusions 2

Recommendations:

Don‘t underestimate the significance of the adequate SMOS image reconstruction algorithm and the corresponding time and amount of research work.

Investigate the appearance shape of realistic imperfections. Provide a realistic estimate (definition).

Investigate the single methods isolated and combined for the SMOS situation. Search for alternative methods.

Define standards (scenarios, errors) for evaluation purposes.

Measure the errors as much and as good as possible.