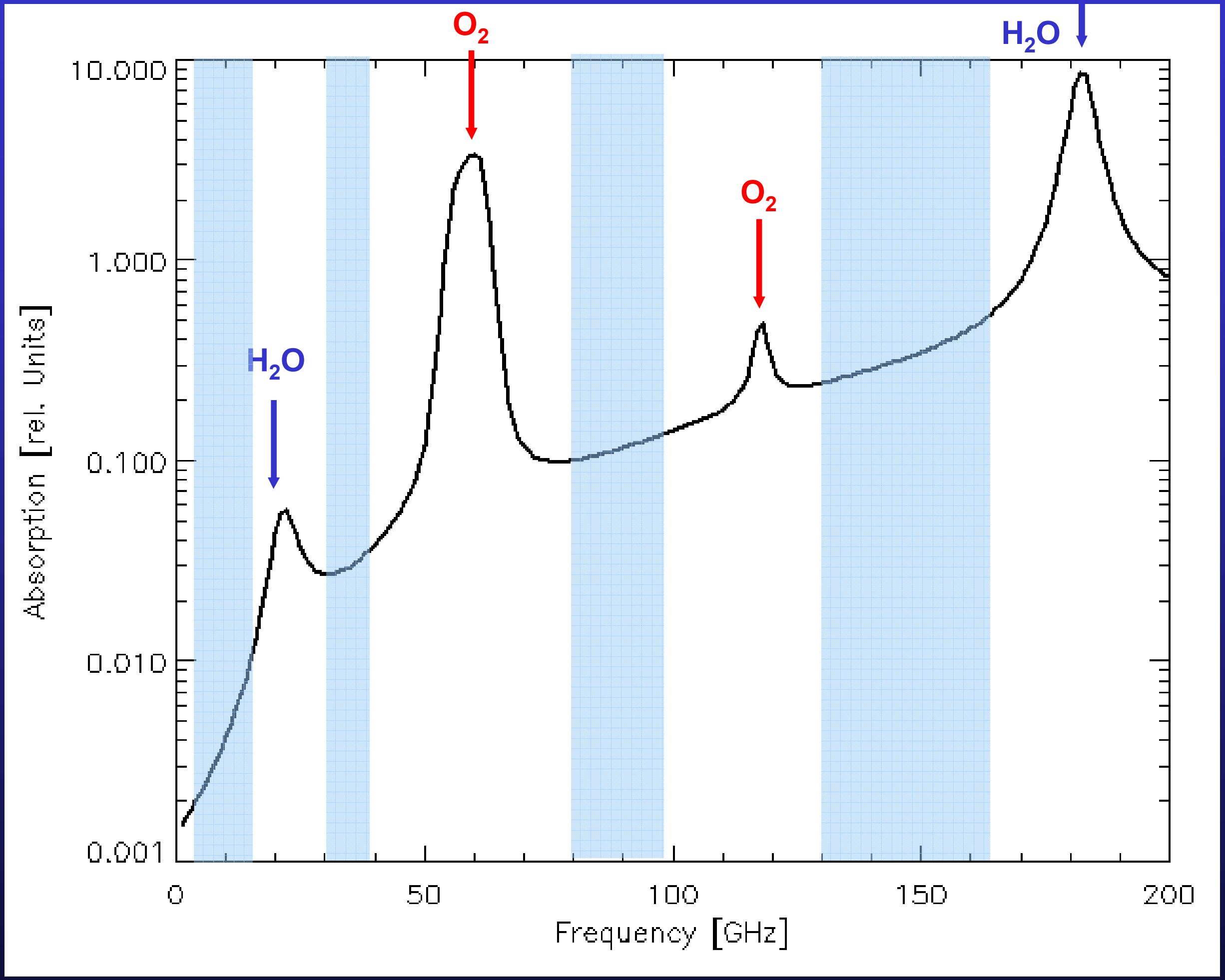
Microwave radiative transfer in support of cloud and precipitation assimilation

Ralf Bennartz
Atmospheric and Oceanic Sciences
University of Wisconsin - Madison

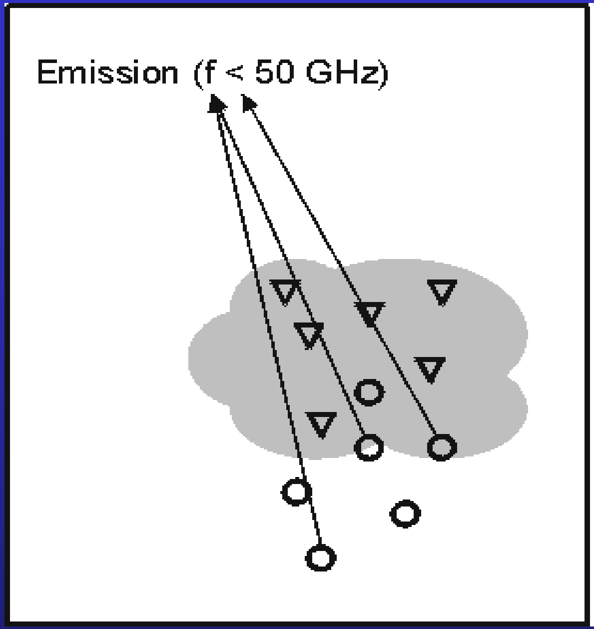
Outline

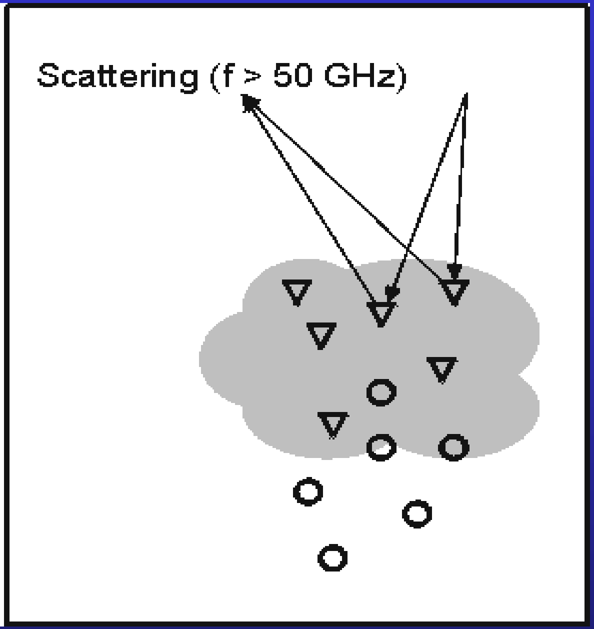
- Fundamentals
- Microwave RT for data assimilation
  - Microwave properties of clouds and precipitation
  - Radiative transfer solver
  - How important is scattering?
  - Integration with NWP models
- Status
- Recommendations

Fundamentals



Fundamentals

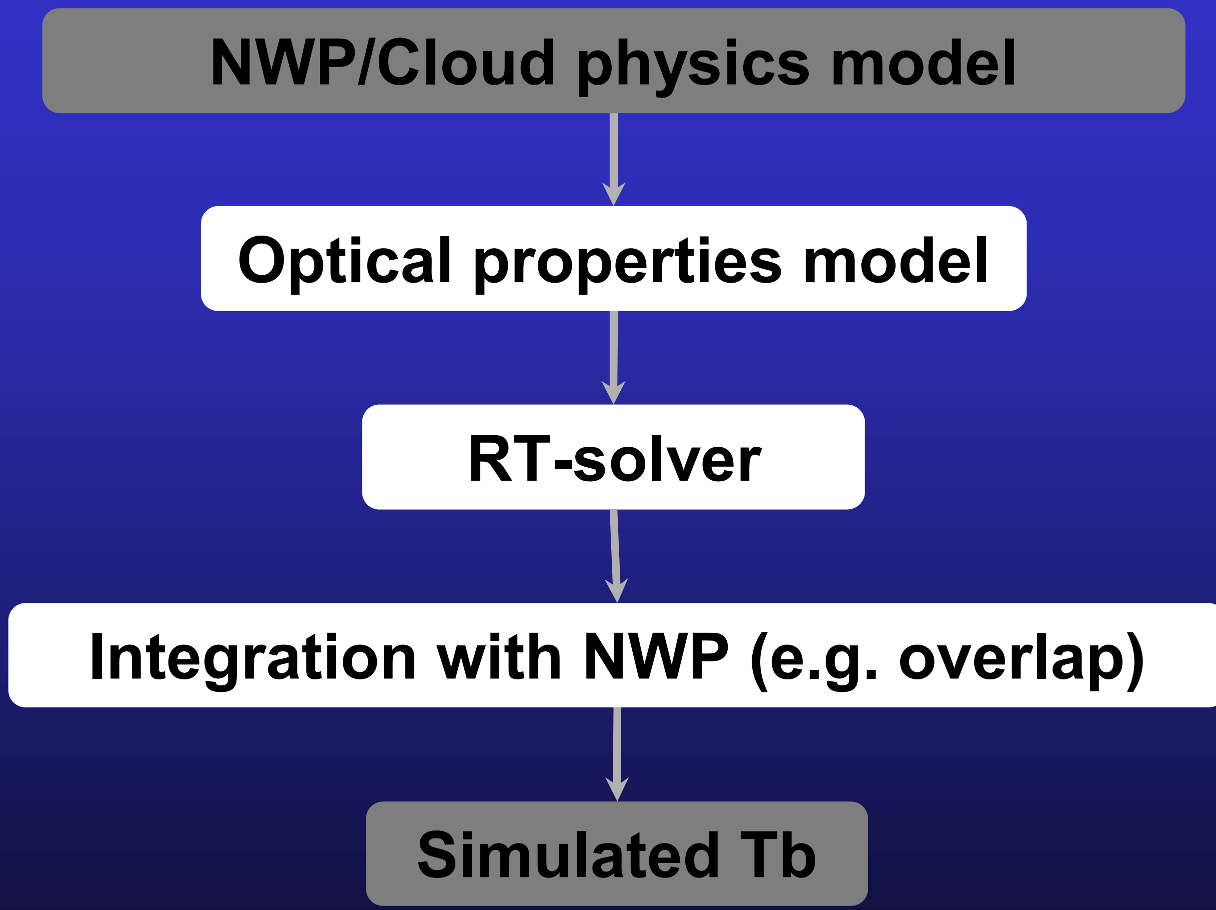




Fundamental observable: attenuation due to **liquid and rain column**

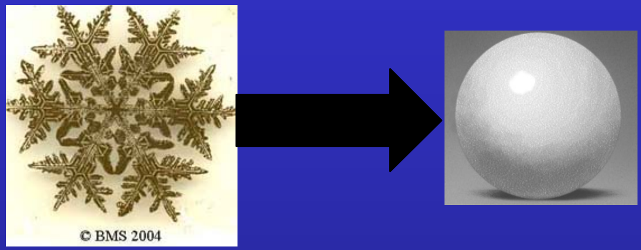
Precipitation ice scattering: Increasing effect at higher frequencies

Modeling Chain



Microwave Optical Properties Assessment

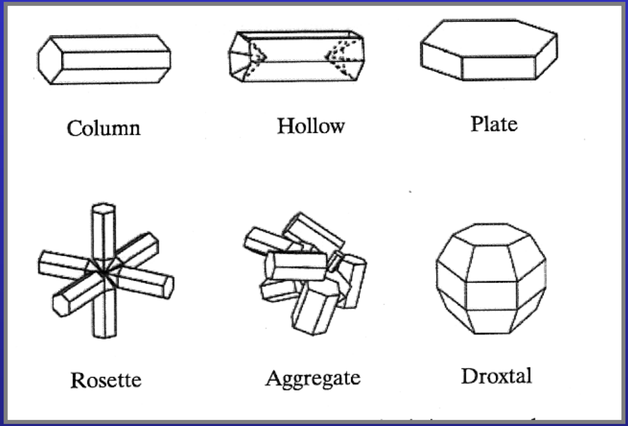
- Spheres (Mie theory)
  - JCSDA (snow, graupel, hail)
  - Surussavadee and Staelin (2006)
  - Dielectric mixing rules

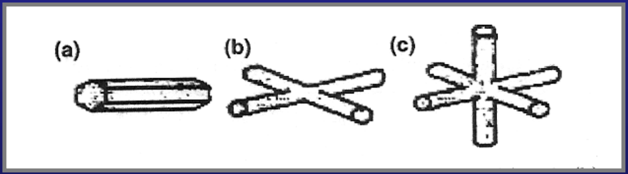


- Non-spherical (Discrete Dipole Approximation - DDA)
  - Liu (2004,2008)
  - Kim et al. (2007)
  - Hong (2007)

Microwave Optical Properties Assessment

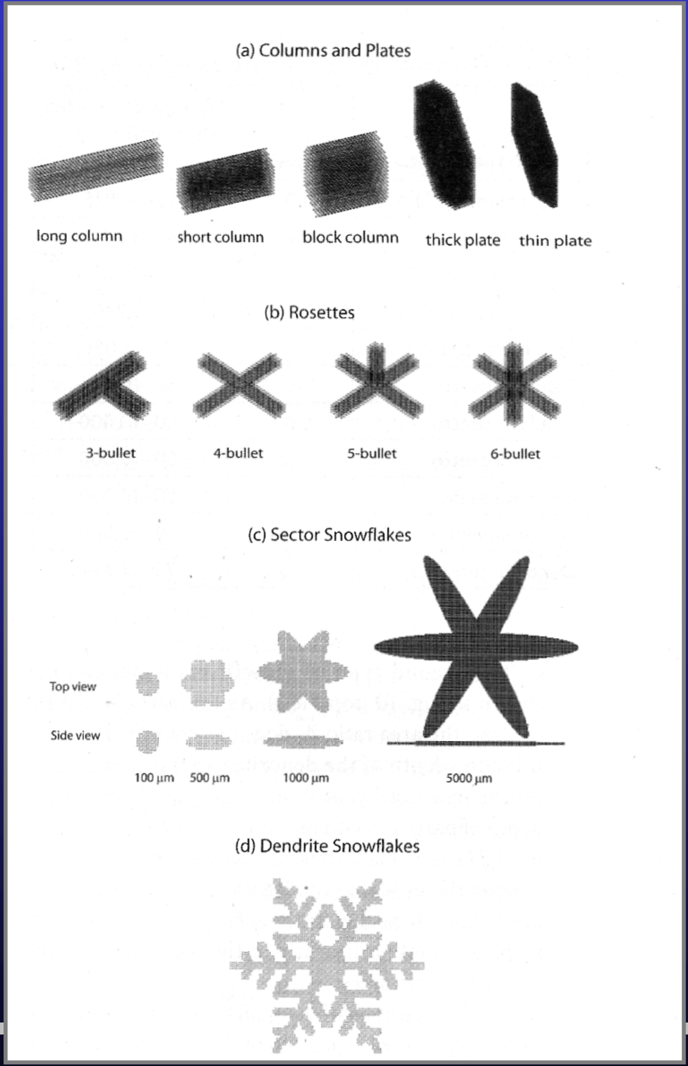
Hong (2007)

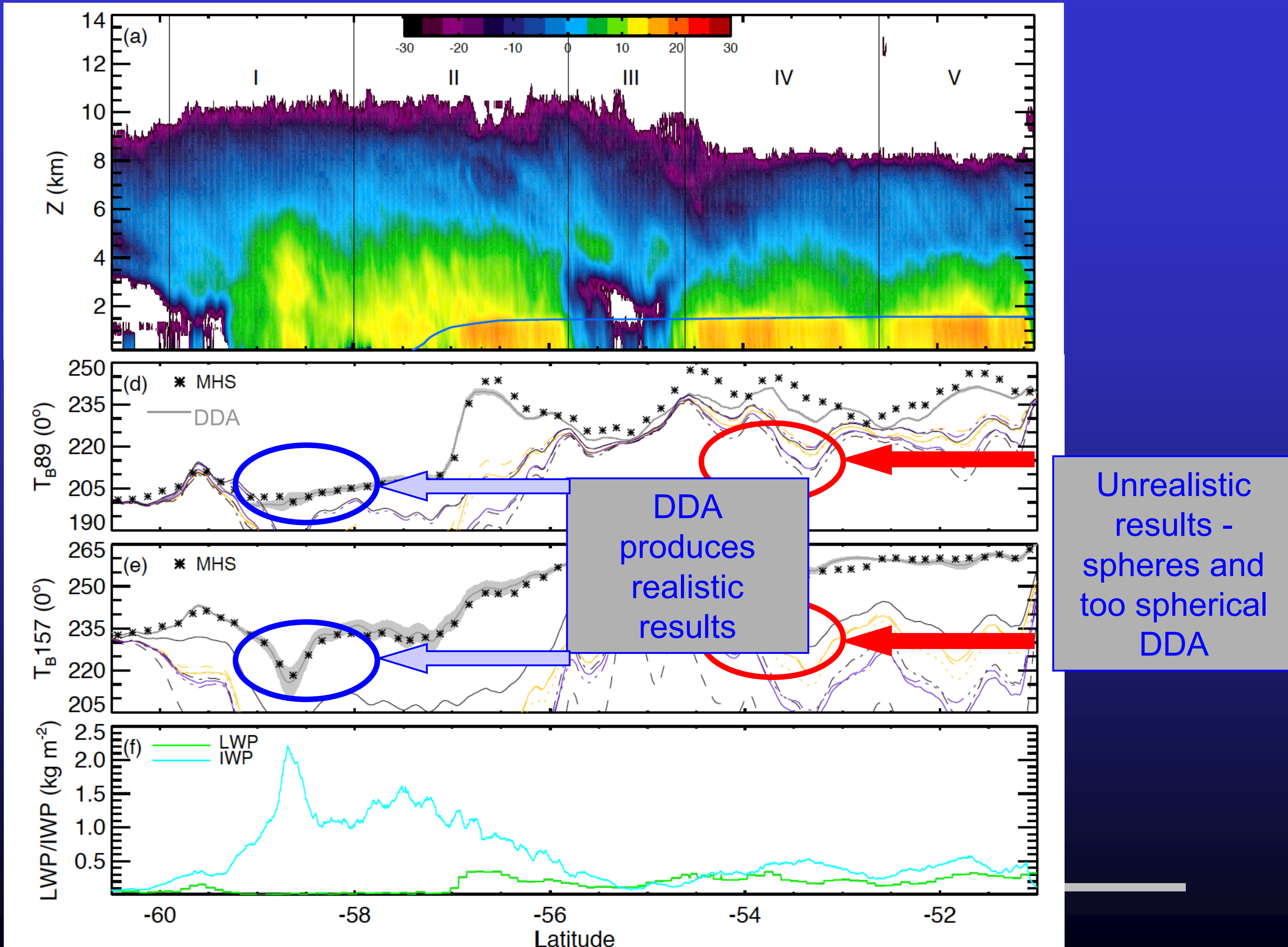




Kim et al. (2007)

Liu (2004,2008)

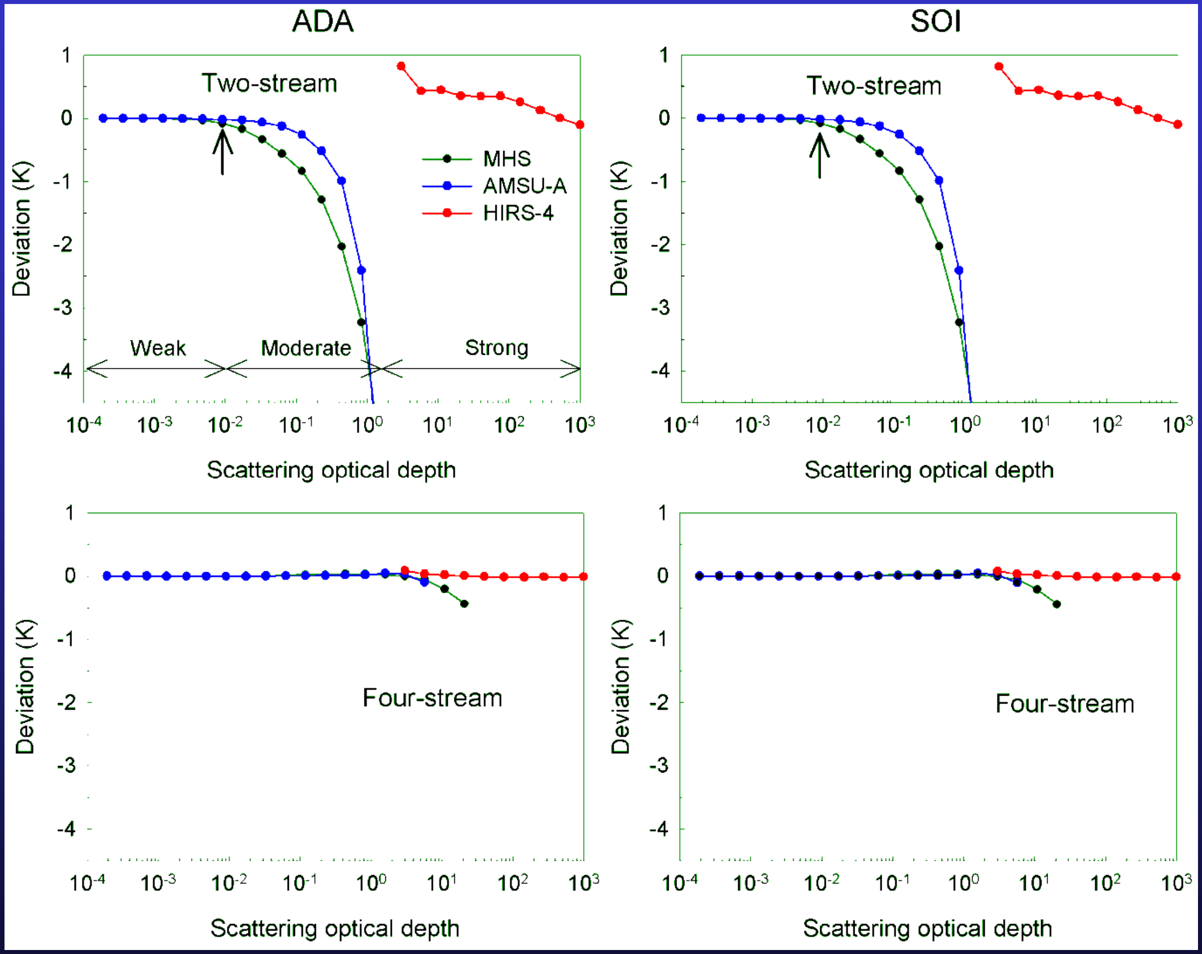



(a)
(d)
MHS
DDA
(e)
MHS
(f)
LWP
IWP
Z (km)
Latitude
DDA produces realistic results
Unrealistic results - spheres and too spherical DDA

RT Solvers:

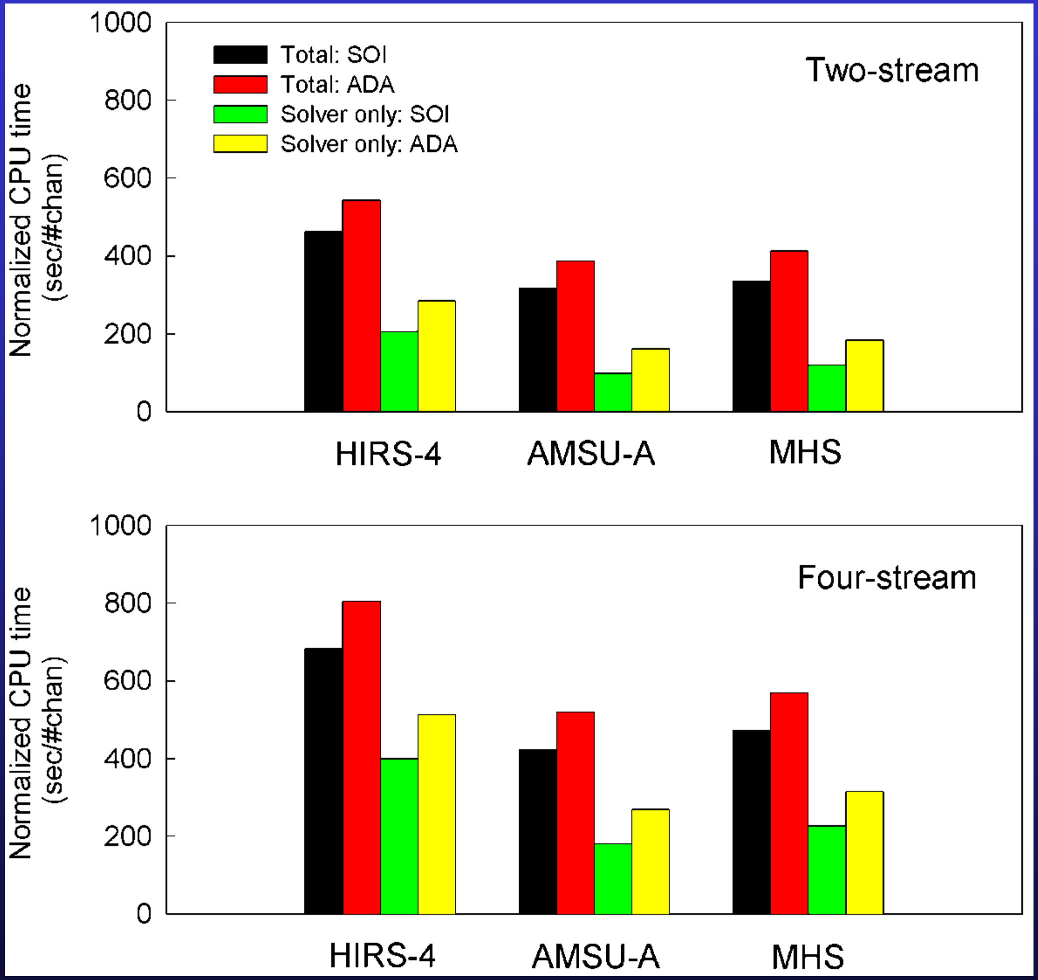
- Two community efforts:
  - RTTOV (Supported by EUMETSAT's NWP-SAF)
    - Non-scattering RT
    - Two-Stream Delta-Eddington
  - CRTM (Supported by JCSDA)
    - Non-scattering RT
    - ADA (Advanced Doubling and Adding)
    - SOI (Successive Order of Interaction)

RT solvers accuracy tests



Results from Greenwald

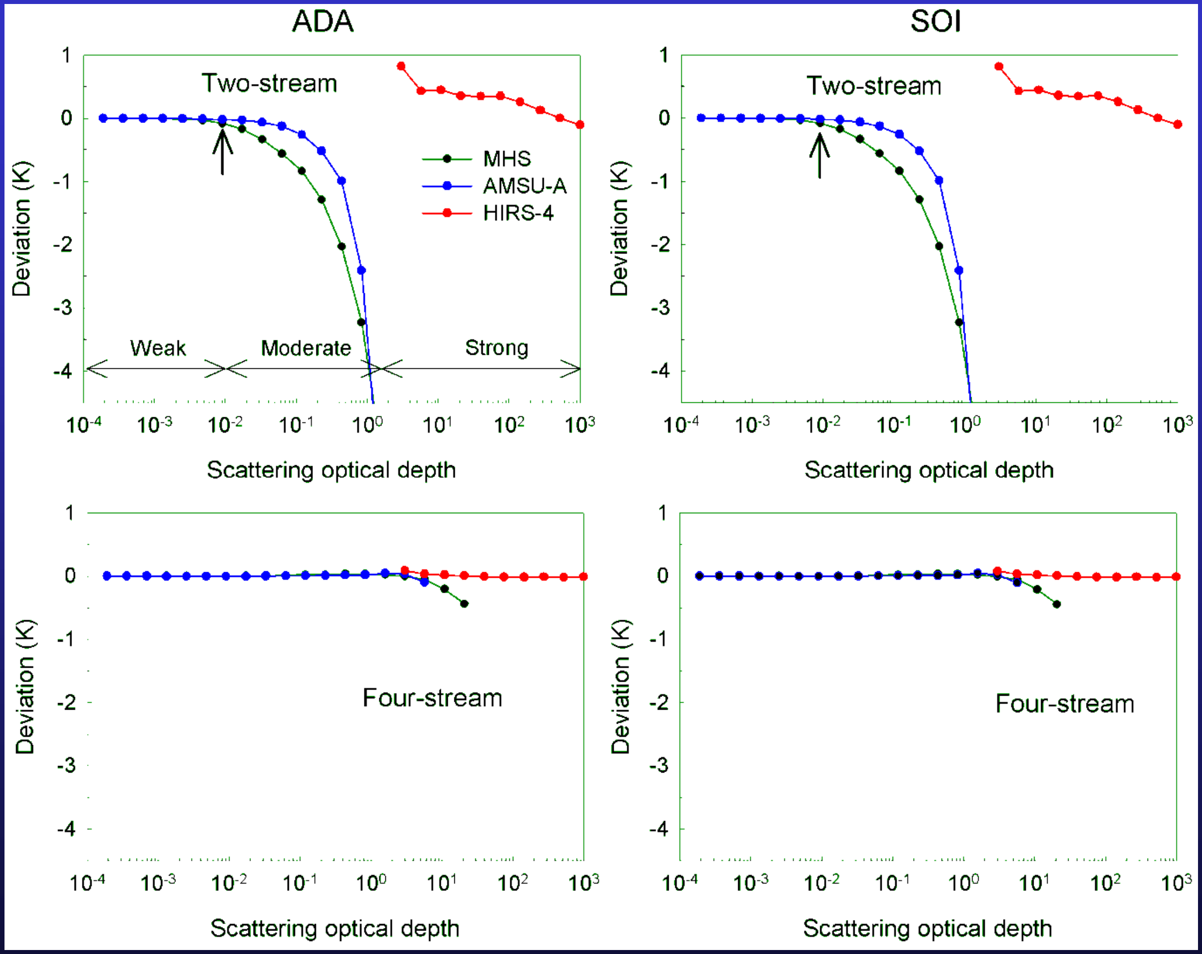
RT solvers speed tests



- ✓ Uses core CRTM routines
- ✓ About 10 - 20 % speed increase due to truncated doubling and iteration instead of adding

Results from Greenwald

RT solvers accuracy tests



Results from Greenwald

How important is scattering?

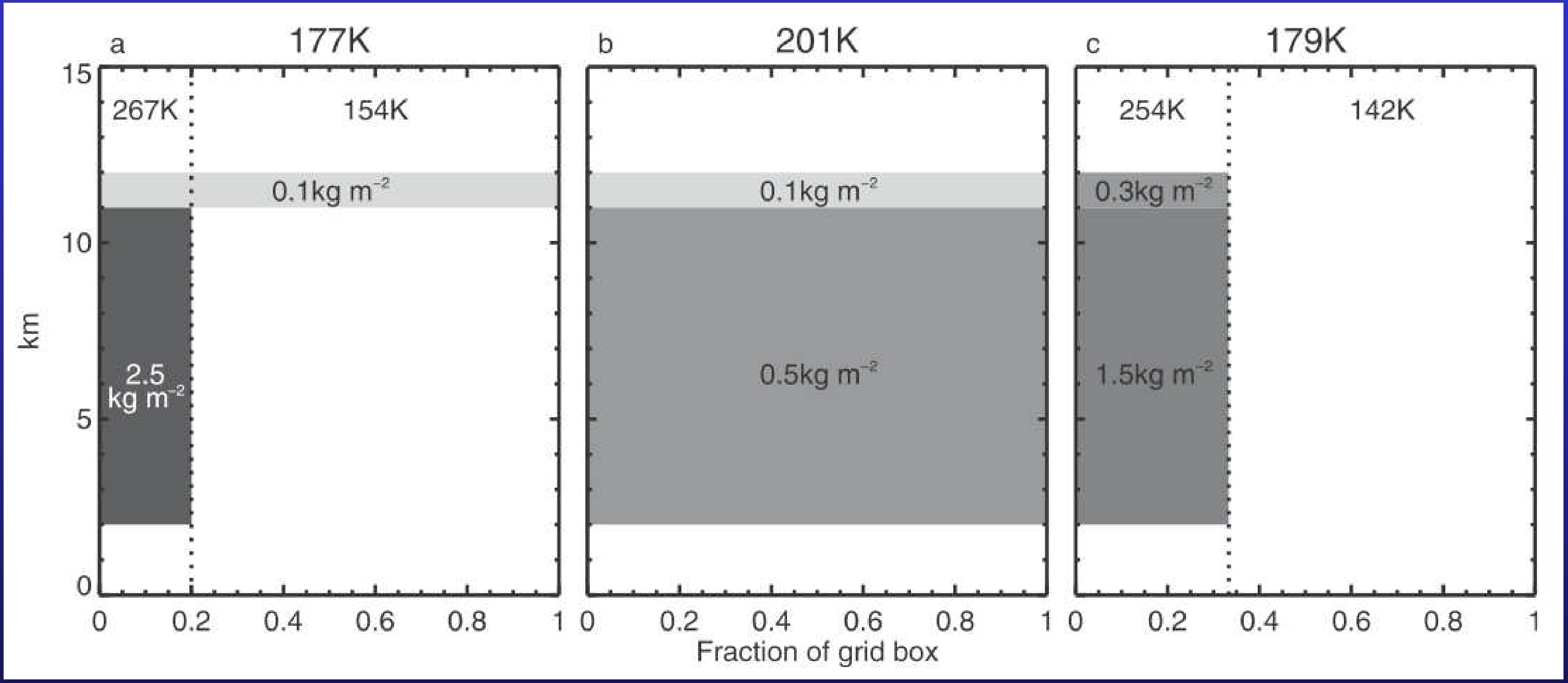
$$\delta_S(z) = \int_z^{TOA} k_S(z)dz$$

$$\delta_{S,Eff}(z) = \int_z^{TOA} k_S(z)e^{-\delta_A(z)}dz$$

Effective scattering optical depth gives an upper limit for the amount of scattering influencing the TOA radiance field

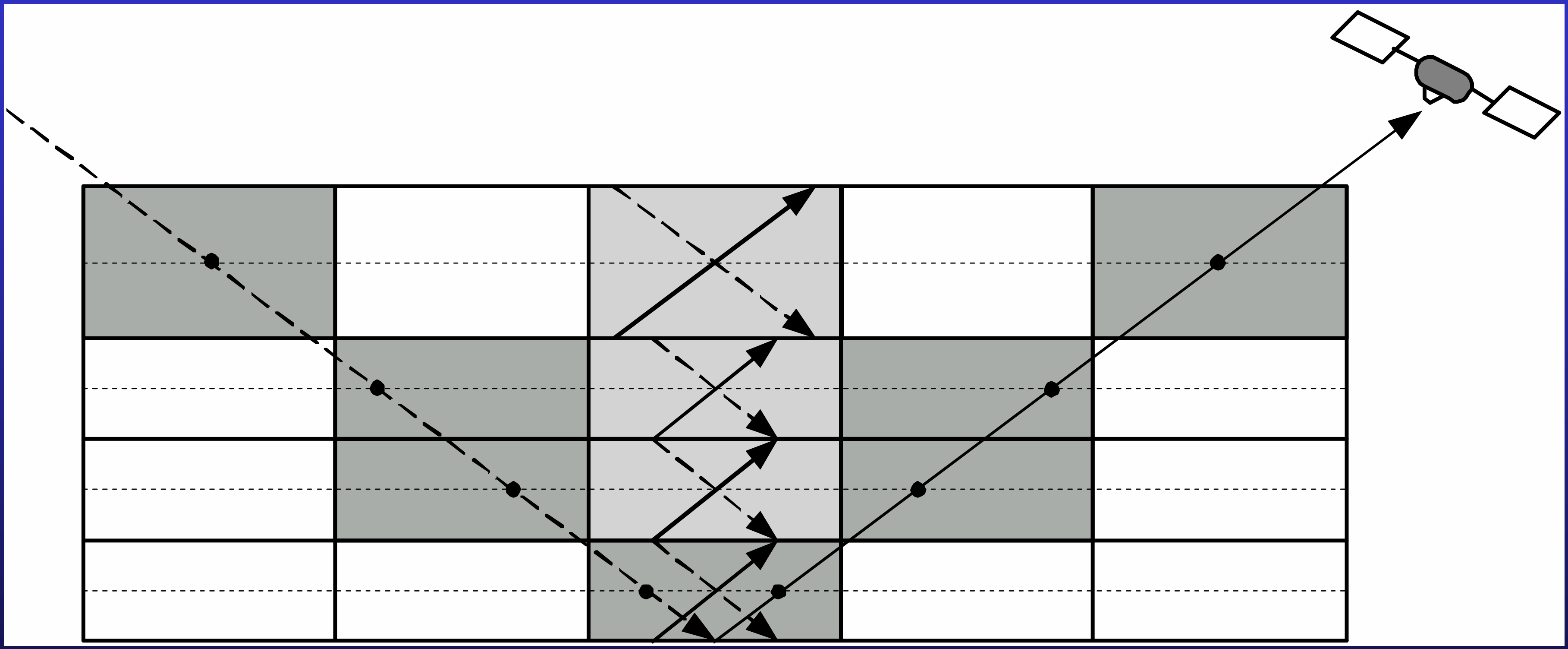
$$0 \le \frac{\delta_{S,eff}(z)}{\delta_S(z)} \le 1$$

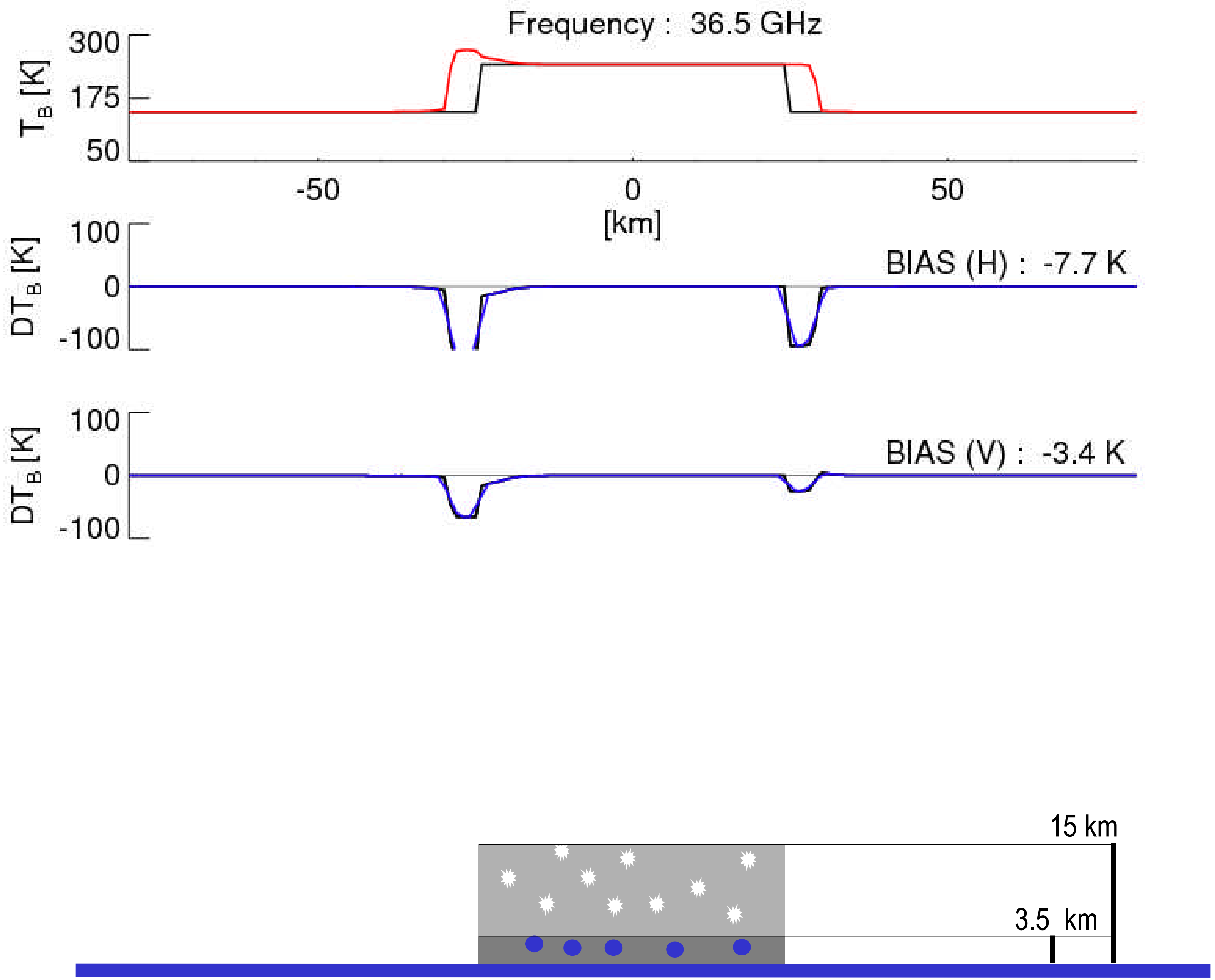
Integration with NWP models: Overlap

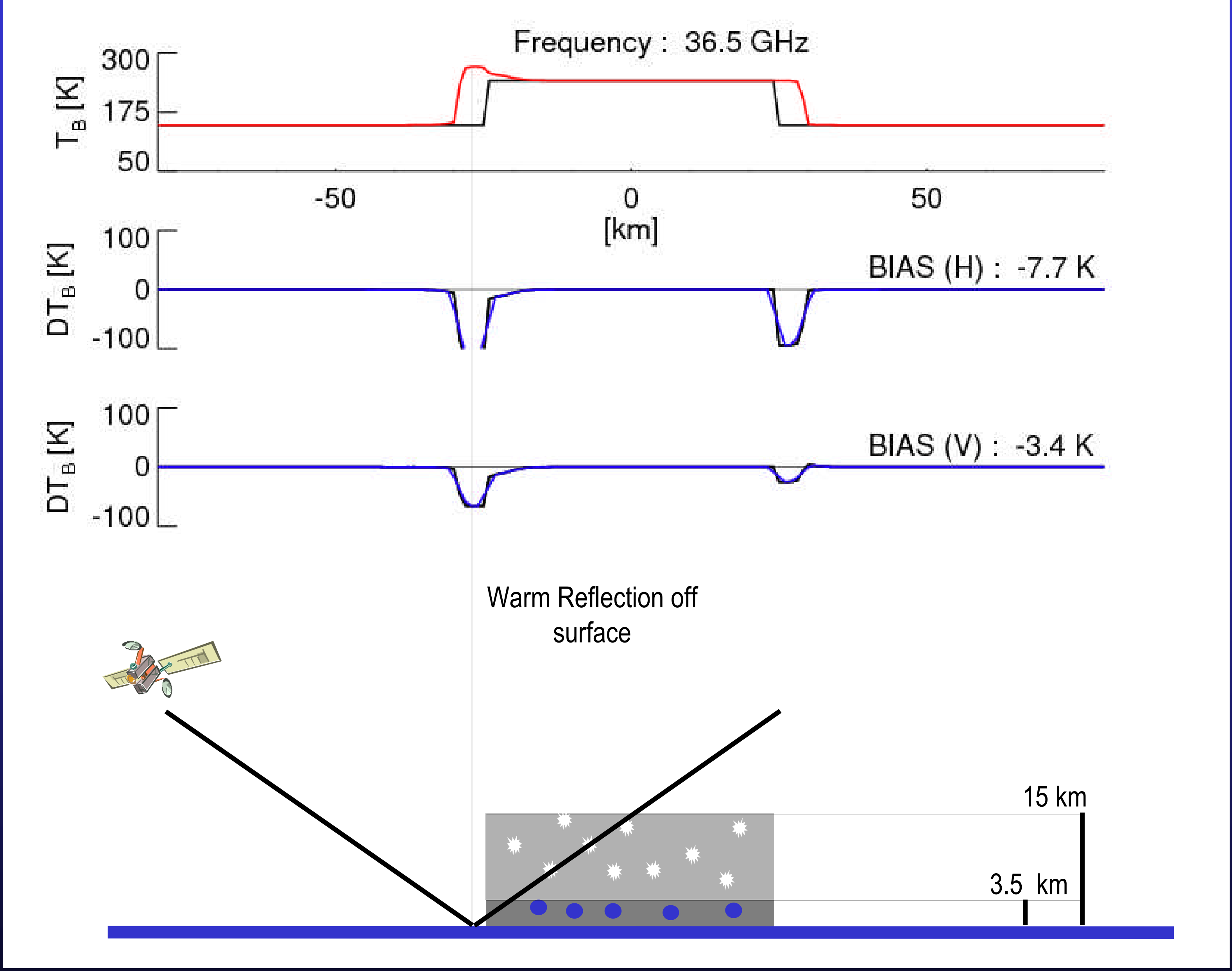


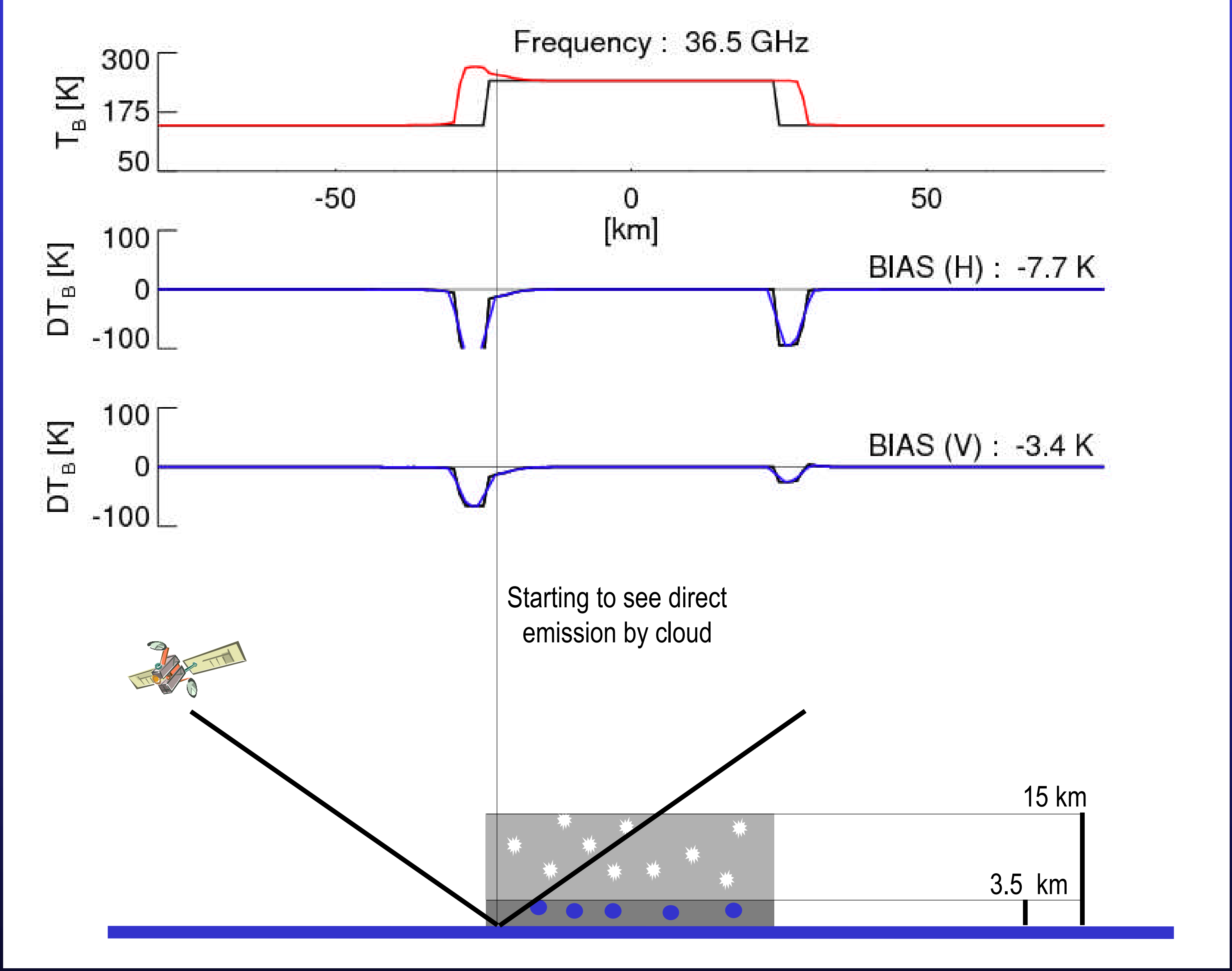
From Geer et al. (2009)

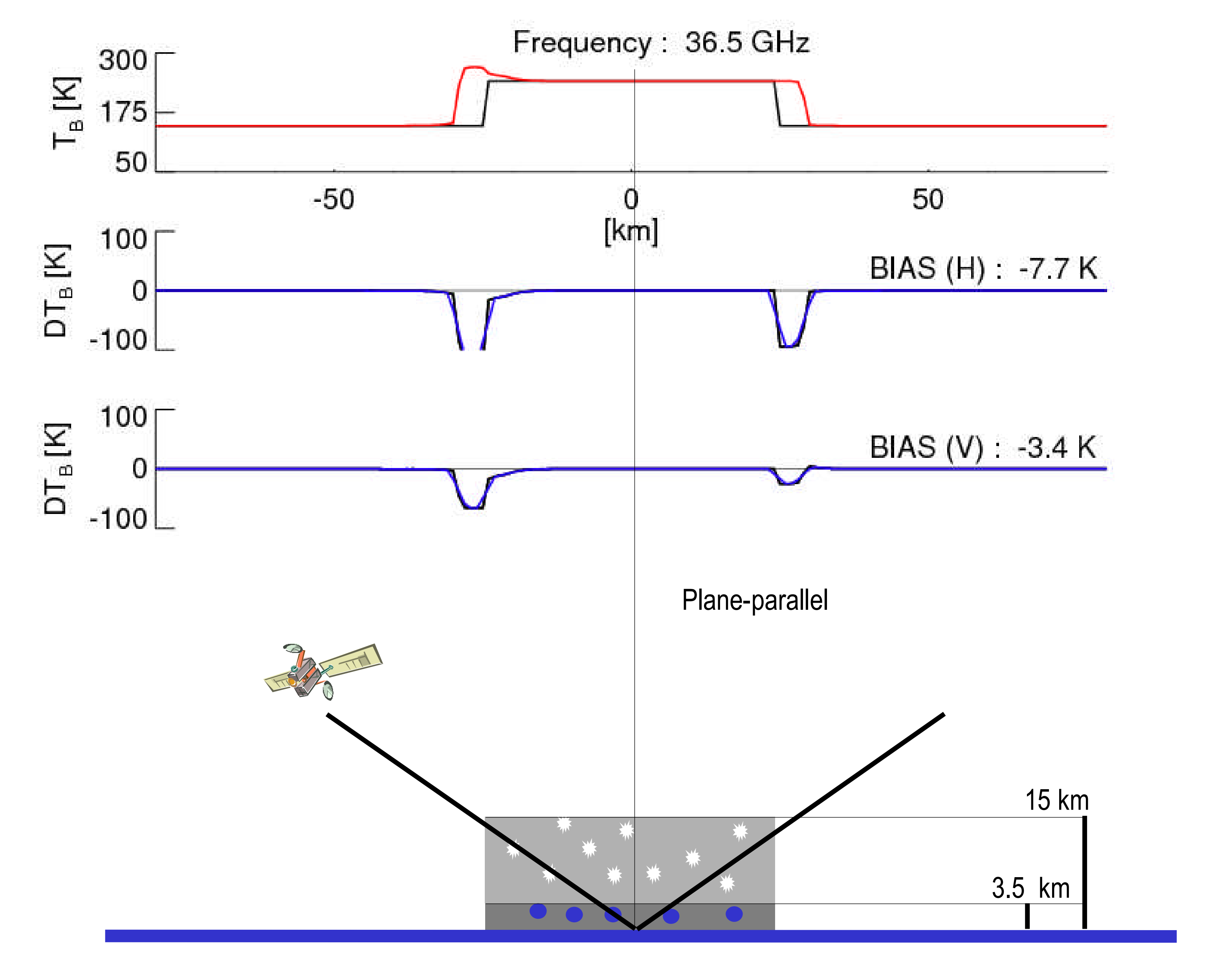
Going to higher spatial resolution

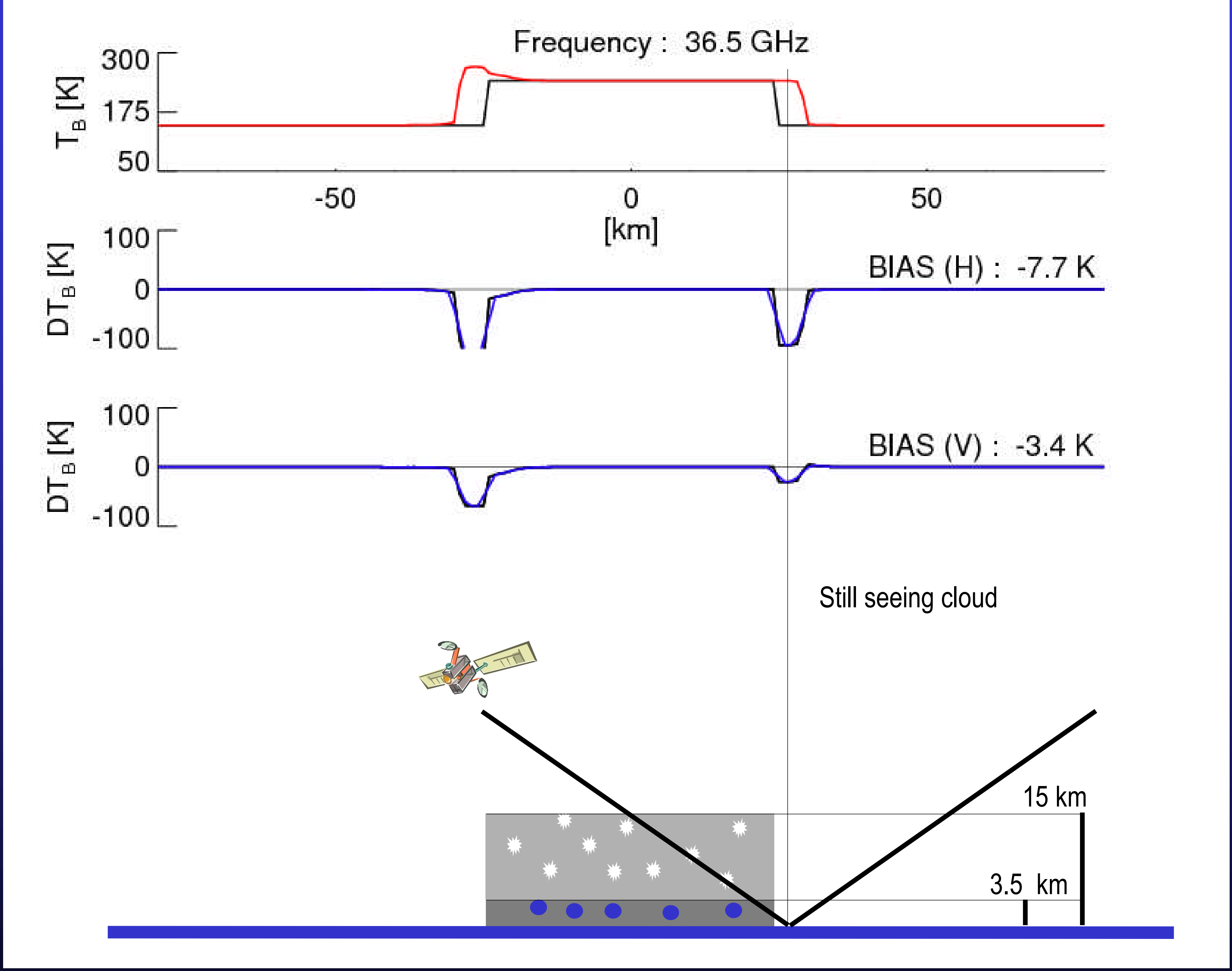



Frequency : 36.5 GHz
300
175
50
T_B [K]
-50
0
50
[km]
100
0
-100
DT_B [K]
BIAS (H) : -7.7 K
100
0
-100
DT_B [K]
BIAS (V) : -3.4 K
15 km
3.5 km


Frequency : 36.5 GHz
T_B [K]
300
175
50
-50
0
50
[km]
DT_B [K]
100
0
-100
BIAS (H) : -7.7 K
DT_B [K]
100
0
-100
BIAS (V) : -3.4 K
Warm Reflection off surface
15 km
3.5 km


Frequency : 36.5 GHz
300
175
50
T_B [K]
-50
0
50
[km]
100
0
-100
DT_B [K]
BIAS (H) : -7.7 K
100
0
-100
DT_B [K]
BIAS (V) : -3.4 K
Starting to see direct
emission by cloud
15 km
3.5 km


Frequency : 36.5 GHz
300
175
50
T_B [K]
-50
0
50
[km]
100
0
-100
DT_B [K]
BIAS (H) : -7.7 K
100
0
-100
DT_B [K]
BIAS (V) : -3.4 K
Plane-parallel
15 km
3.5 km



Frequency : 36.5 GHz
T_B [K]
300
175
50
-50
0
50
[km]
DT_B [K]
100
0
-100
BIAS (H) : -7.7 K
DT_B [K]
100
0
-100
BIAS (V) : -3.4 K
Still seeing cloud
15 km
3.5 km

Status

- RT Solvers
  - ✓ Various available and integrated into CRTM/RTTOV
  - ✓ Work to be done to find good compromise accuracy vs. speed

- Optical properties
  - ✓ Active/passive evaluation of various optical property models ongoing
  - ✓ Allows realistic estimate of observation error
  - ✓ Inclusion into RT LUTs still outstanding

- Observation error characteristics
  - ✓ Realistic estimates of observation error
  - ✓ What to do when global NWP models reach resolution of passive MW sensors or for mesoscale models in general? Abandon overlap for slant models?

Recommendations

- Short term
  - ✓ Various smaller improvements (e.g. assessment of effective scattering optical depth for model selection, optical properties databases)
  - ✓ Pave way for models with higher spatial resolution.
- Longer-tem
  - ✓ Treatment of higher frequencies, full use of scattering information (Requires significant advances in interface to cloud physics)
  - ✓ Error covariances