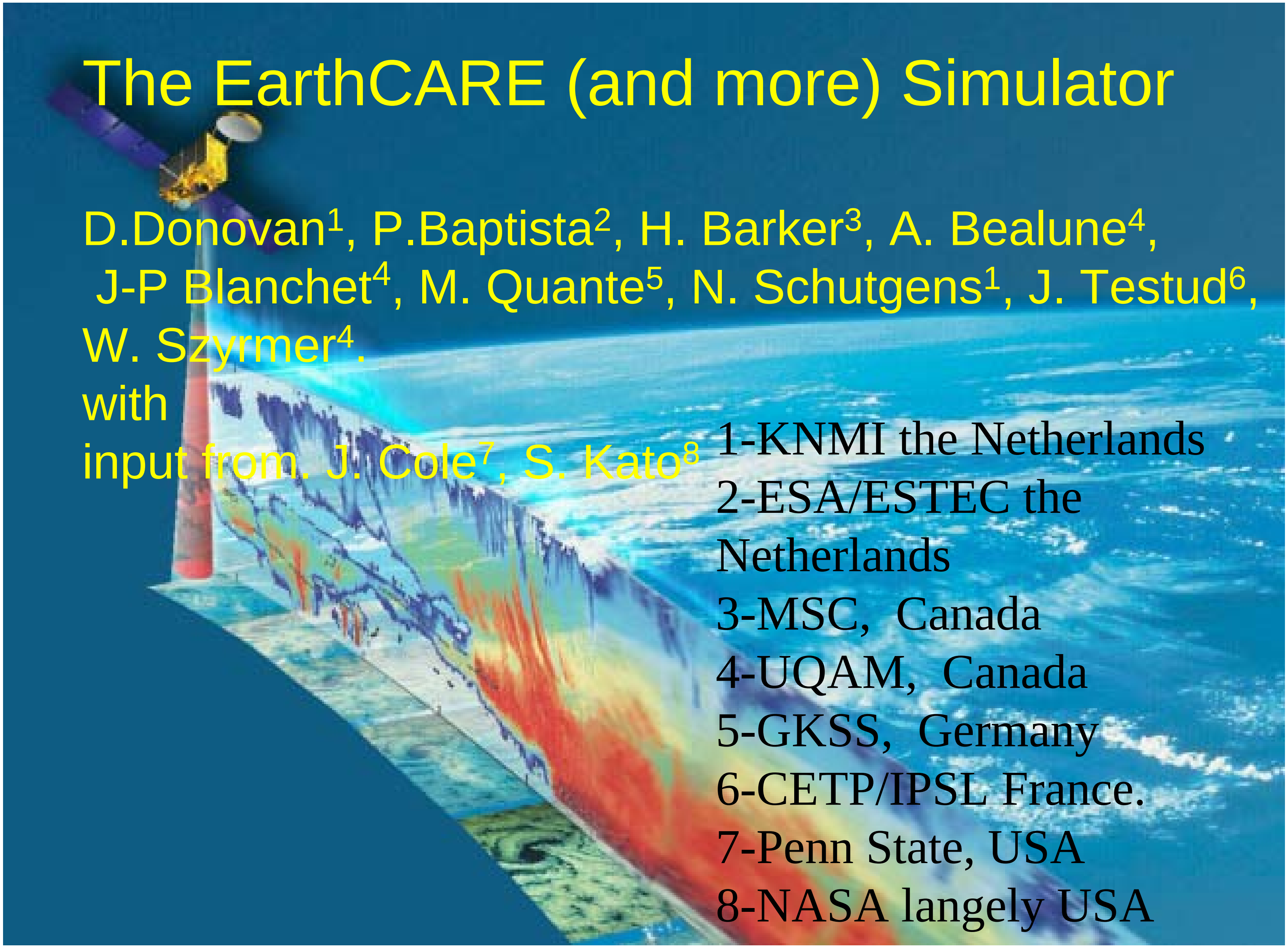
The EarthCARE (and more) Simulator



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with

input from. J. Cole[7], S. Kato[8]

1-KNMI the Netherlands
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3-MSC, Canada
4-UQAM, Canada
5-GKSS, Germany
6-CETP/IPSL France.
7-Penn State, USA
8-NASA langely USA

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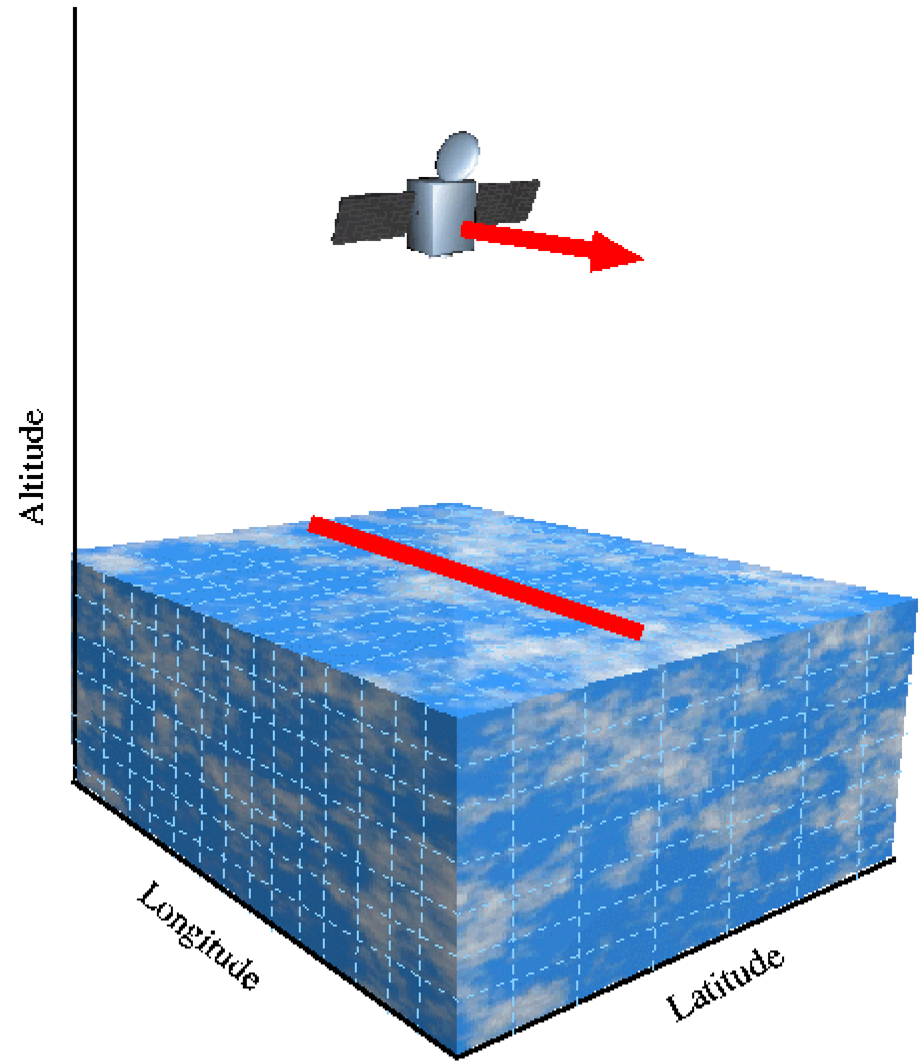
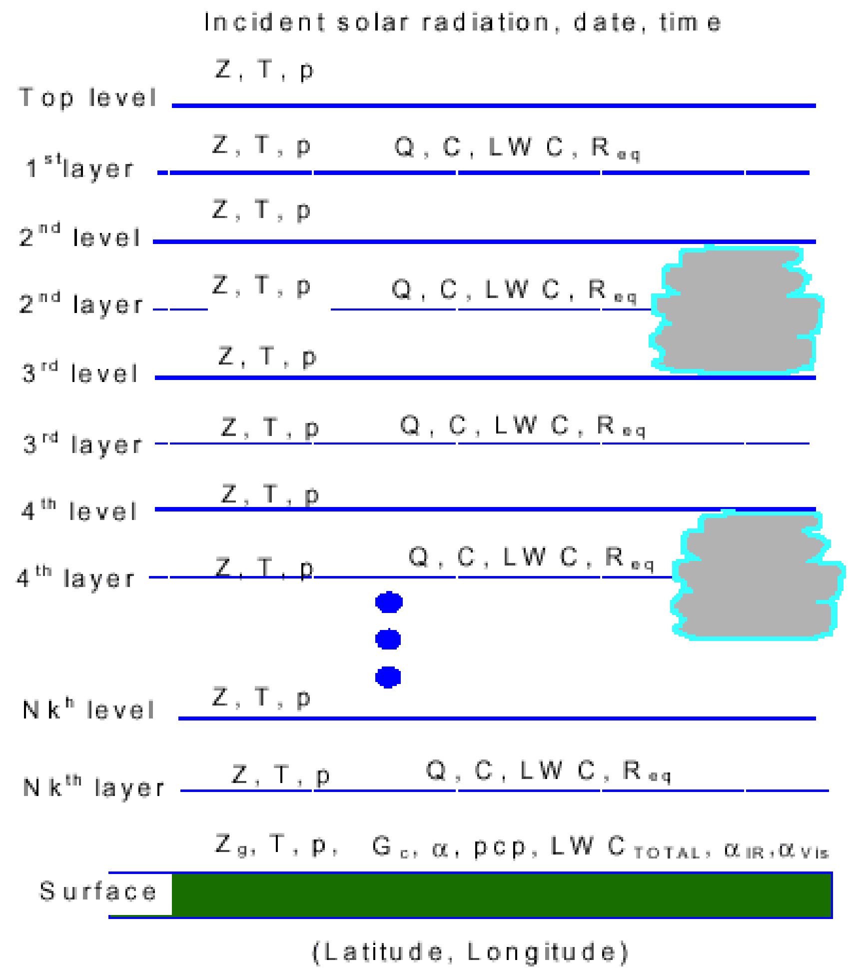
Basic Idea



Altitude
Longitude
Latitude

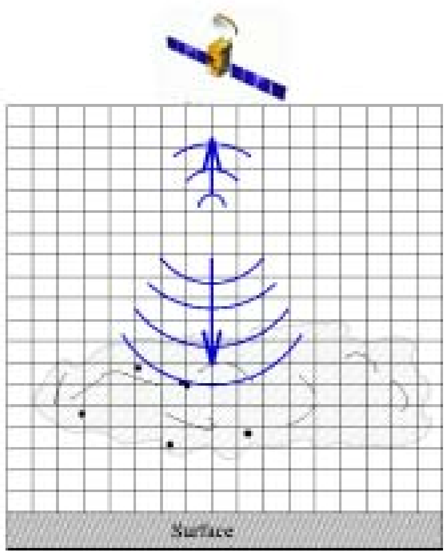


Incident solar radiation, date, time
Top level
Z, T, p
1st layer
Z, T, p
Q, C, LWC, R_{eq}
2nd level
Z, T, p
2nd layer
Z, T, p
Q, C, LWC, R_{eq}
3rd level
Z, T, p
3rd layer
Z, T, p
Q, C, LWC, R_{eq}
4th level
Z, T, p
4th layer
Z, T, p
Q, C, LWC, R_{eq}
Nkh level
Z, T, p
Nkth layer
Z, T, p
Q, C, LWC, R_{eq}
Z_g, T, p, G_c, α, pcp, LWC_{TOTAL}, α_{IR}, α_{VIS}
Surface
(Latitude, Longitude)

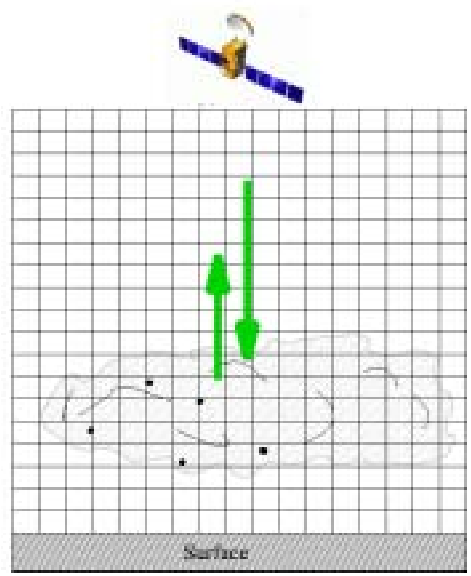
Features

- 3-D Monte Carlo Radiative transfer codes used for Passive instrument simulations.
- 3-D Monte Carlo simulation of Lidar returns.
- Realistic Noise levels calculated via instrument parameters
- All instrument treated in a consistent fashion. Crude instrument specific parameterization have been avoided.
- Both simple user defined scenes can be treated as well as complex scenes derived from cloud resolving model data.

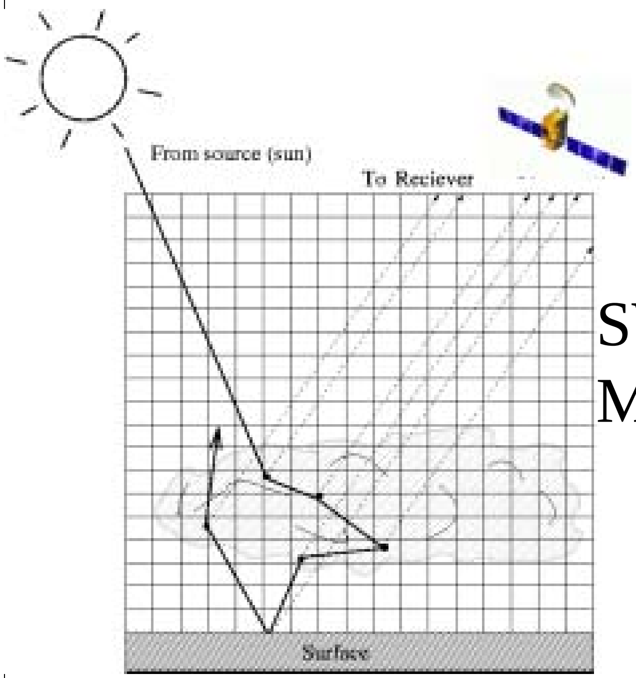
Built primarily for Ecare but is being adapted for aspects of the A-train !



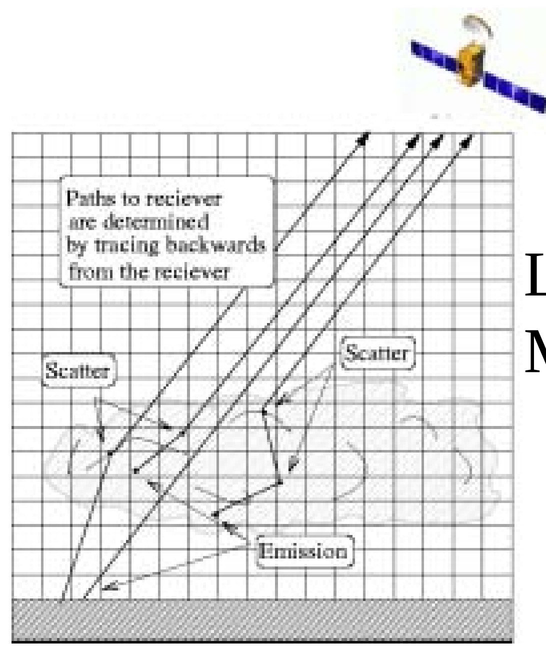
Radar
simulator



Lidar
MC code



SW
MC code



LW
MC code

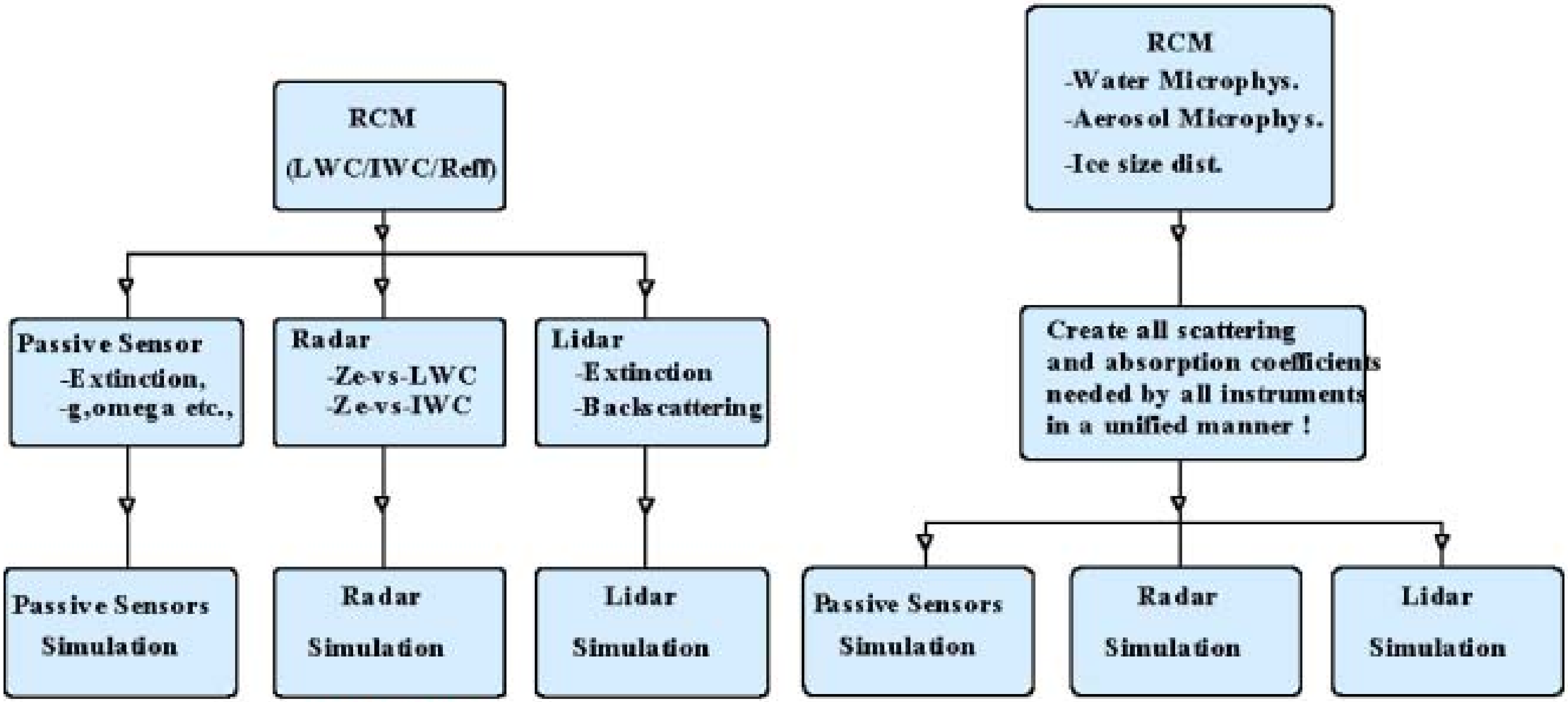
In order that the results be truly useful

- **All the instruments must see the `same' atmosphere and surface**
- Crude instrument specific parameterizations/relationships are being avoided
- Atmosphere/clouds/aerosols must be defined at a `low-level' (i.e. All instrument modules must ultimately draw on the same microphysical cloud and aerosol properties)

- **A flexible input strategy is needed**
- A common `Universal File Format' has been defined and a tool to create simple scenes in this format has been developed
- Model data is translated into this format

••••

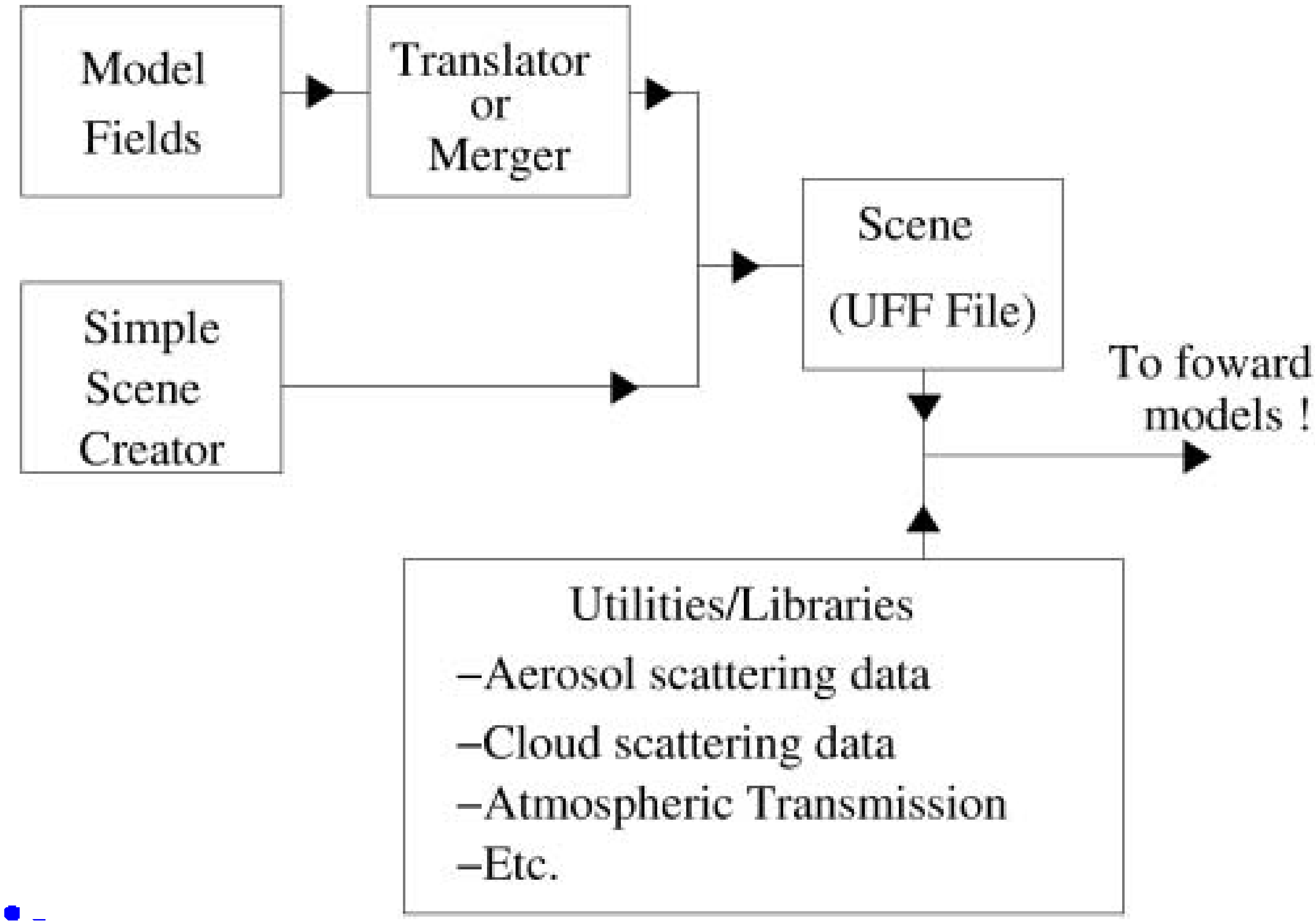
Fragmented Approach -Vs- Unified Approach



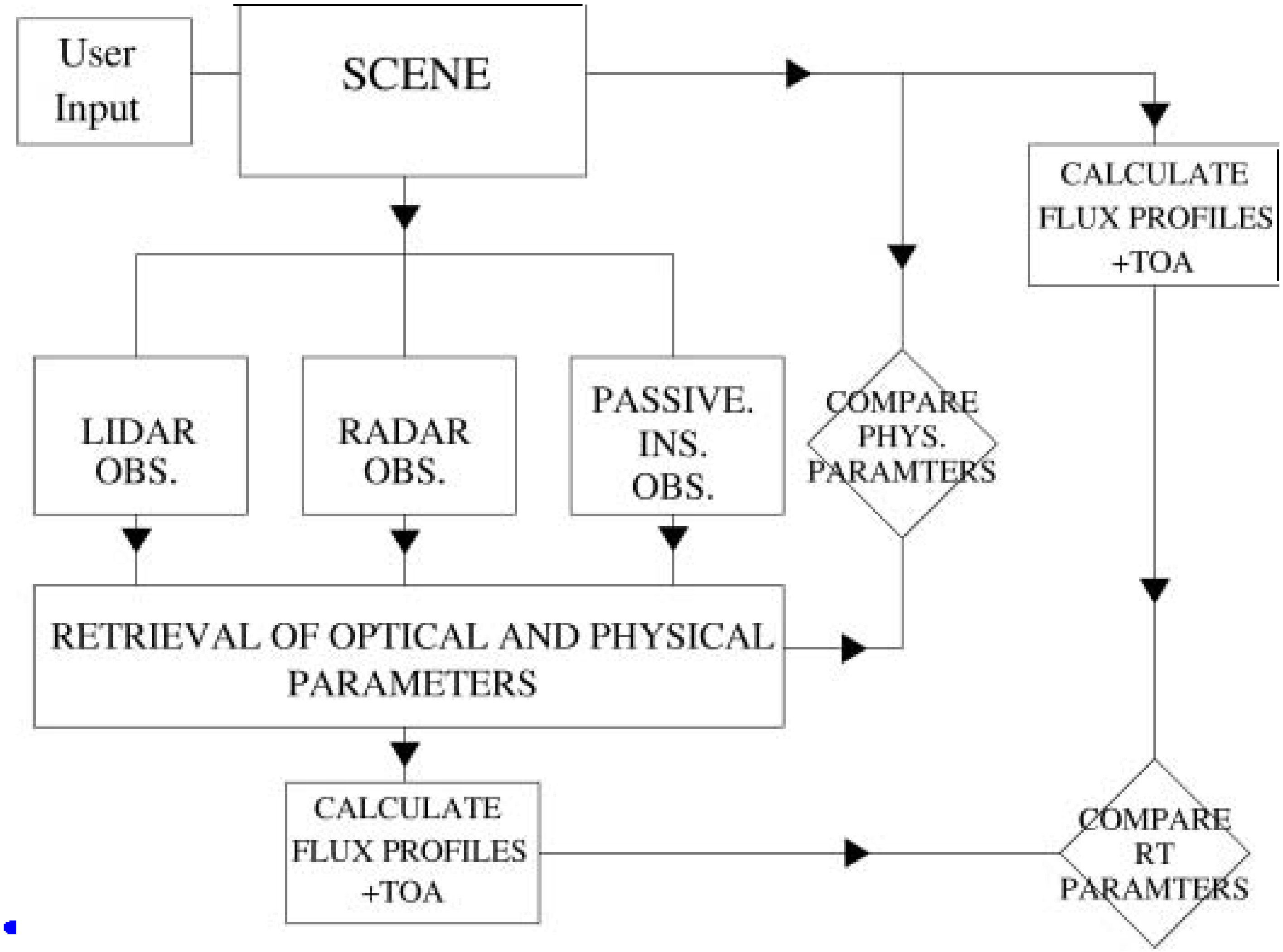
SYPAI
(ERM Simulator)

EarthCARE
Simulator

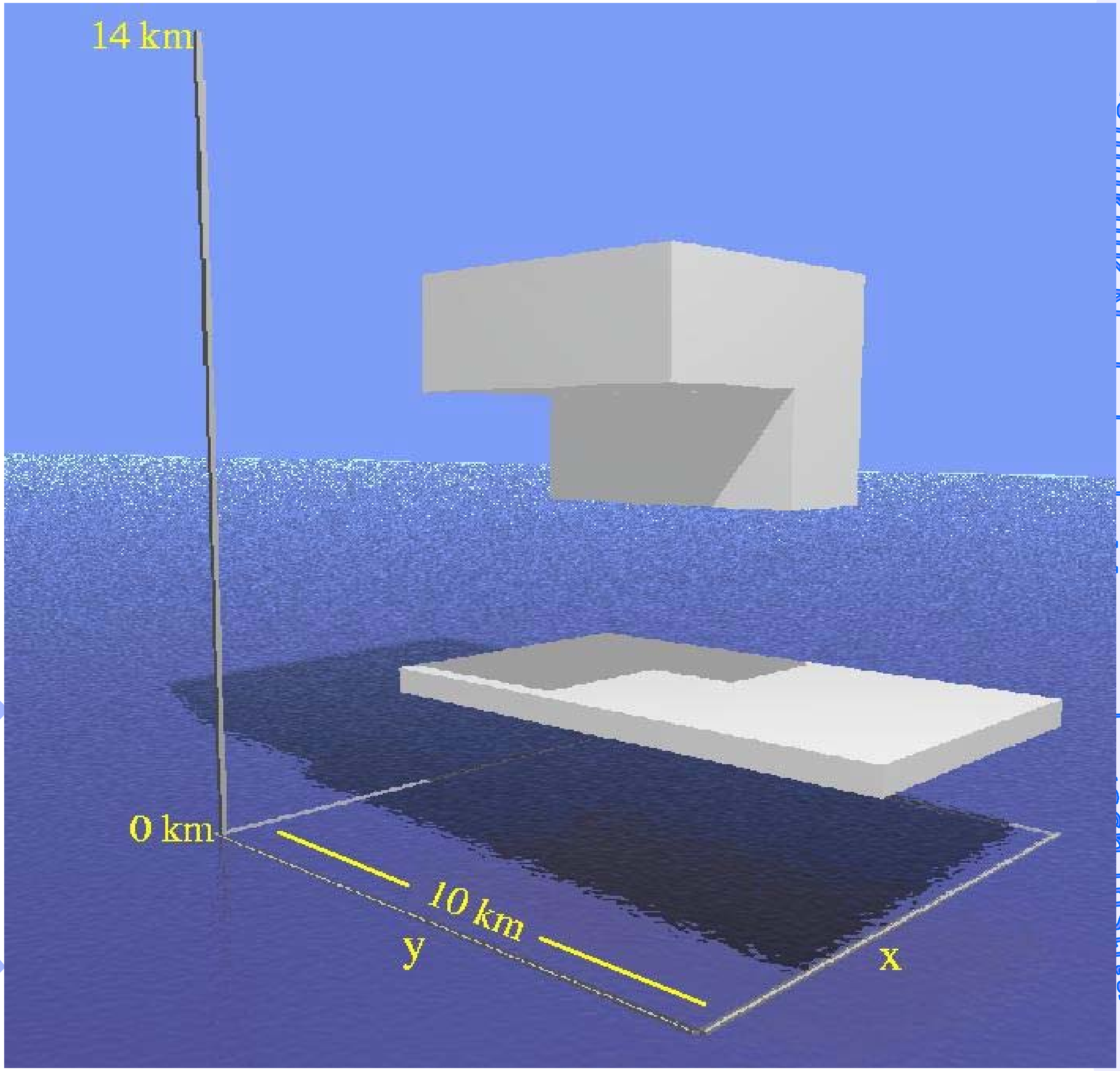
Modular unified approach



End-to-End collection of tools

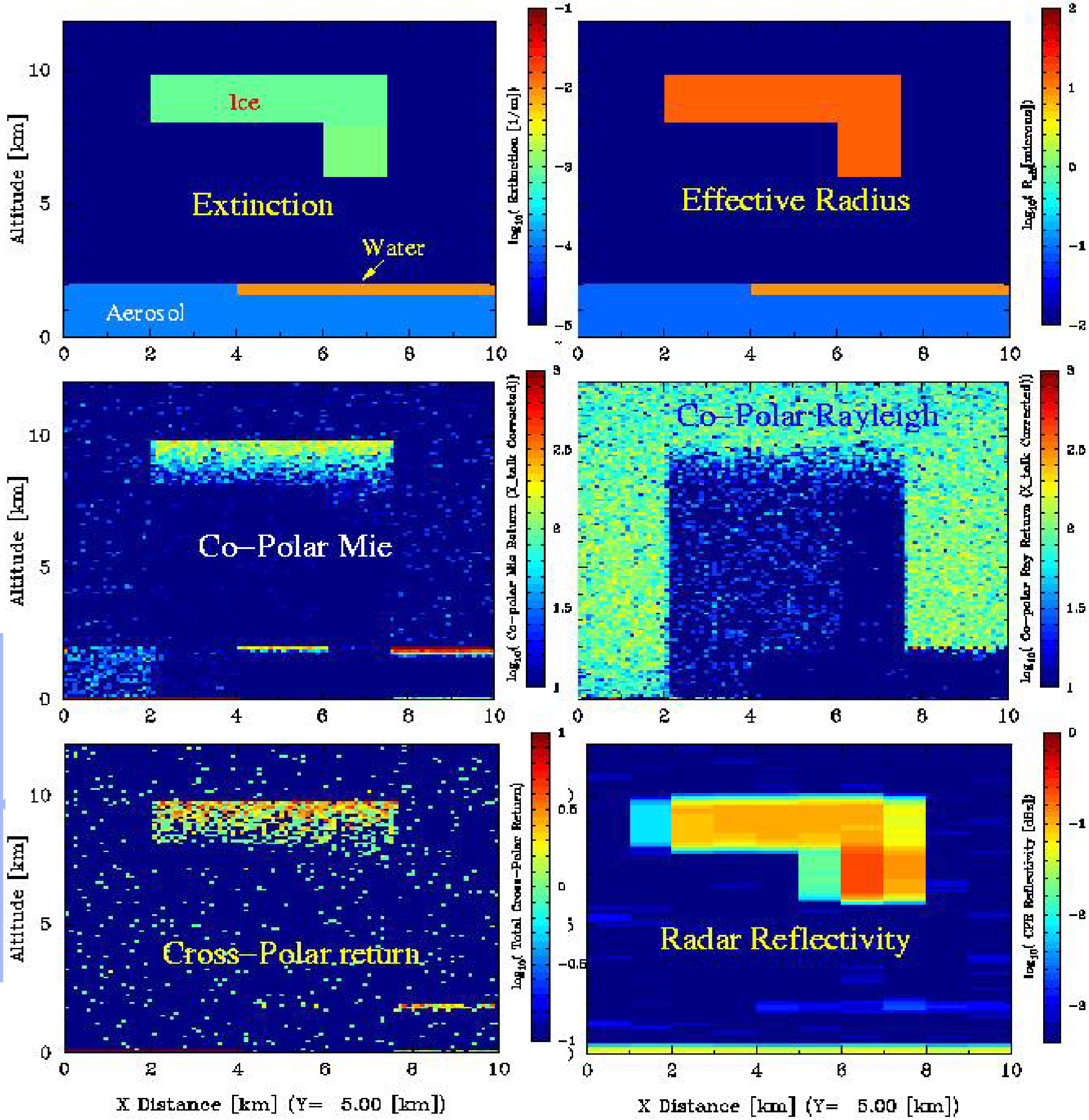


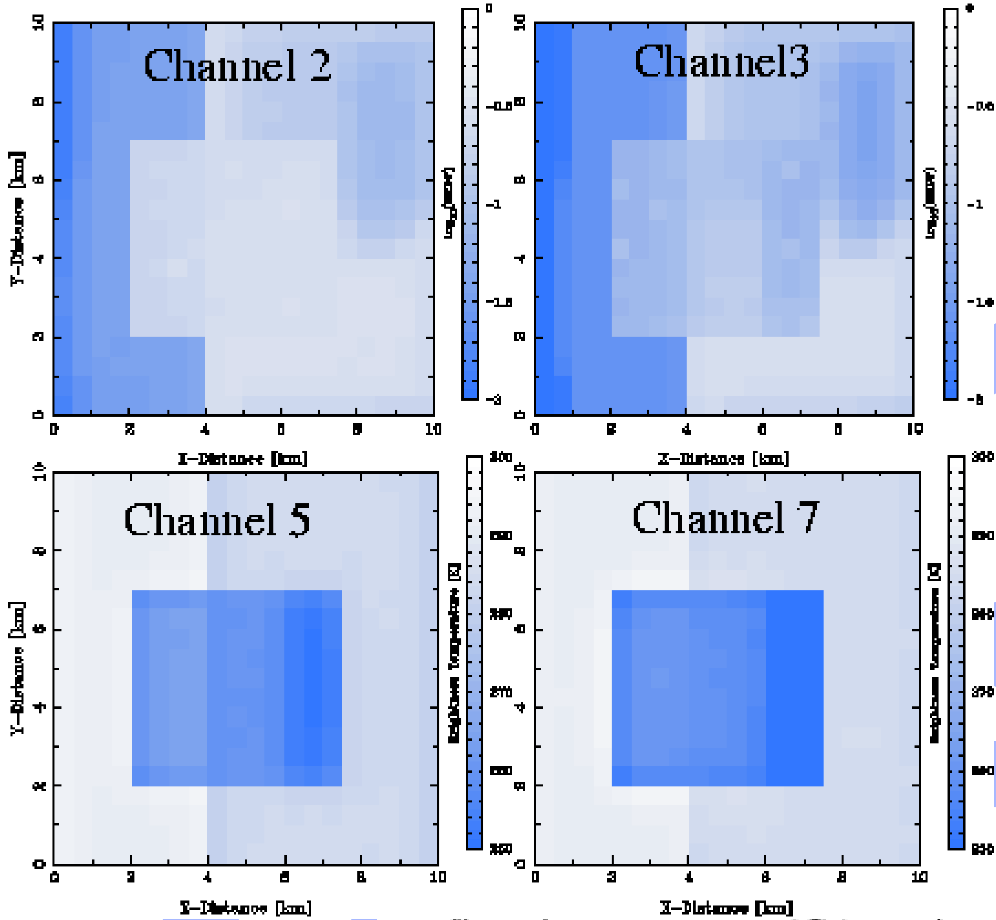
A Sample*
`Simple' scene

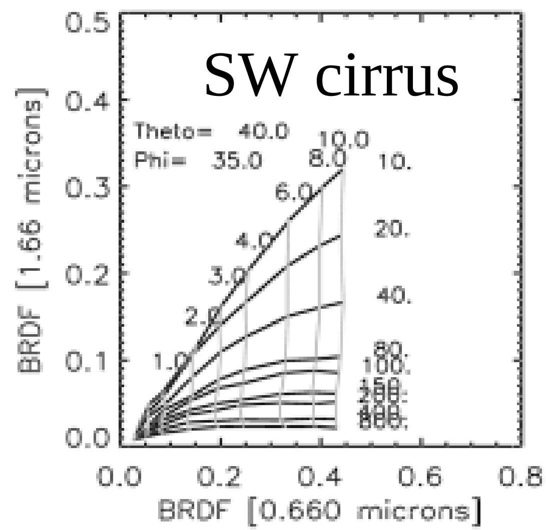


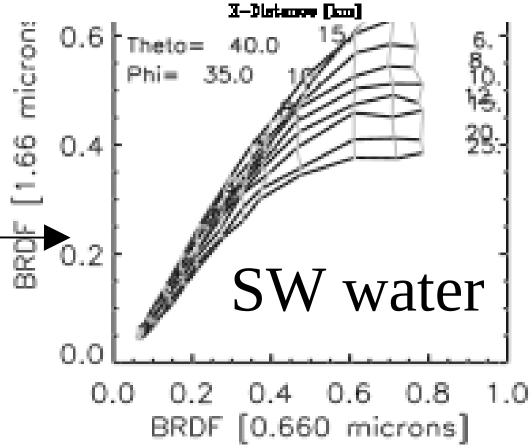
*Artistic impression only

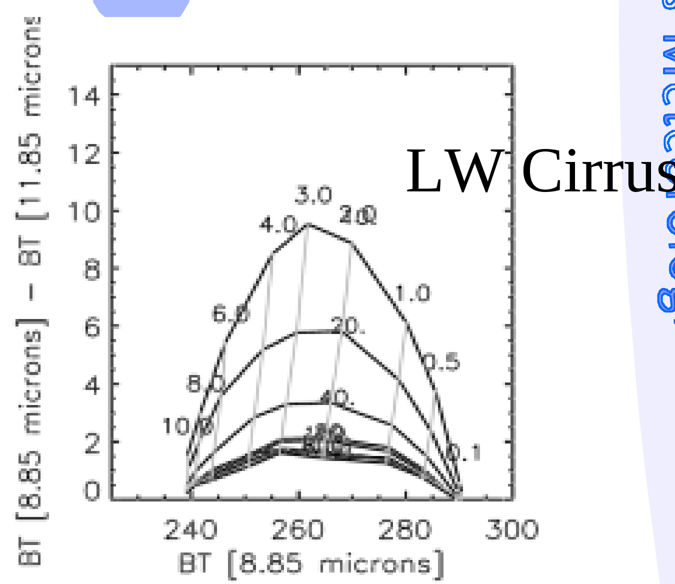
Simple Scene











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How to combine things......

- How to put things together in a useful (optimal) fashion. ?
- Lots of room for new ideas.
- Optimal estimation combination of separate products ?
- Neural networks ?
- Model to observation approaches ?

- Can only hope to find a range of possible atmospheric states that fit your observations which are likely not `complete'

- Treat the problem explicitly as a optimization problem using an underlying model !!.

Putting it all Together (end-to-end)

- Use lidar+radar + IR MSI channels.
- Model with free-parameters related to height resolved mode radii and scattering type+temperature+smoothness+`expectations'
- Use ICA to calculate brightness temperatures
- Solve for direct nadir columns using simulated annealing optimization procedure
- Use off nadir MSI radiances to expand the nadir information outwards.
- Compute BBR rdaiances and compare to BBR measurements.
- Do you get closure ?

Model:
For each z_i where $Mask(z_i) = 1$

$$
\begin{aligned}
N_{is}(R) &= \frac{N_{s,is}}{R_{ms,is}} \frac{1}{\Gamma(\gamma_{s,is})} \left(\frac{R}{Rm_{s,is}} \right)^{(\gamma_{s,is}-1)} exp[-R/Rm_{s,is}] \\
&= \frac{N_{l,is}}{R_{ml,is}} \frac{1}{\Gamma(\gamma_{l,is})} \left(\frac{R}{Rm_{l,is}} \right)^{(\gamma_{l,is}-1)} exp[-R/Rm_{l,is}]
\end{aligned}
$$

where is is the scattering type (water,plates,columns etc..)
(**water and ice are assigned before hand via masks.**)

Free Parameters:
For each z_i where $Mask(z_i) = 1$

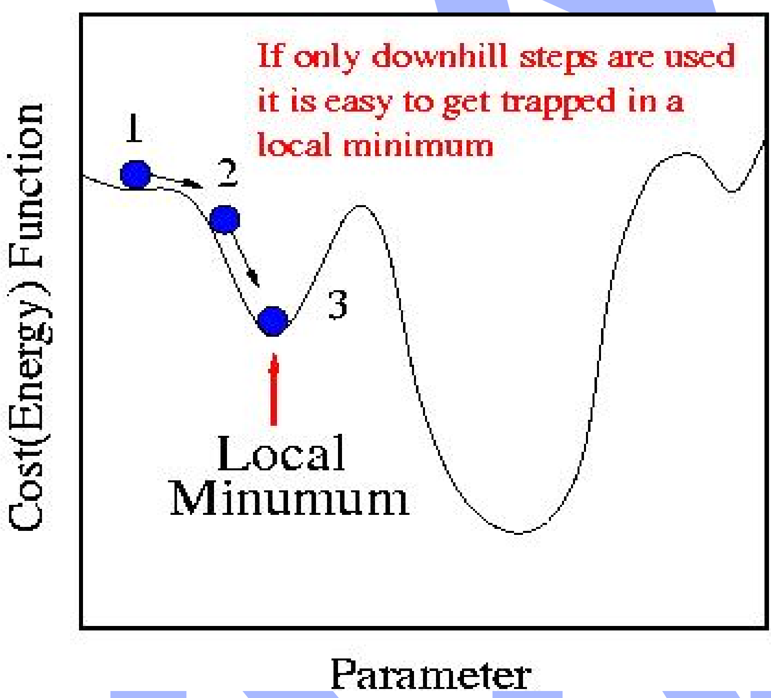
1. $\alpha_{is,l}, \alpha_{is,s}$, ($is = 0$ for water, $is = 1$ for ice)
2. $Rm_{s,is}, Rm_{l,is}$
3. γ's are fixed

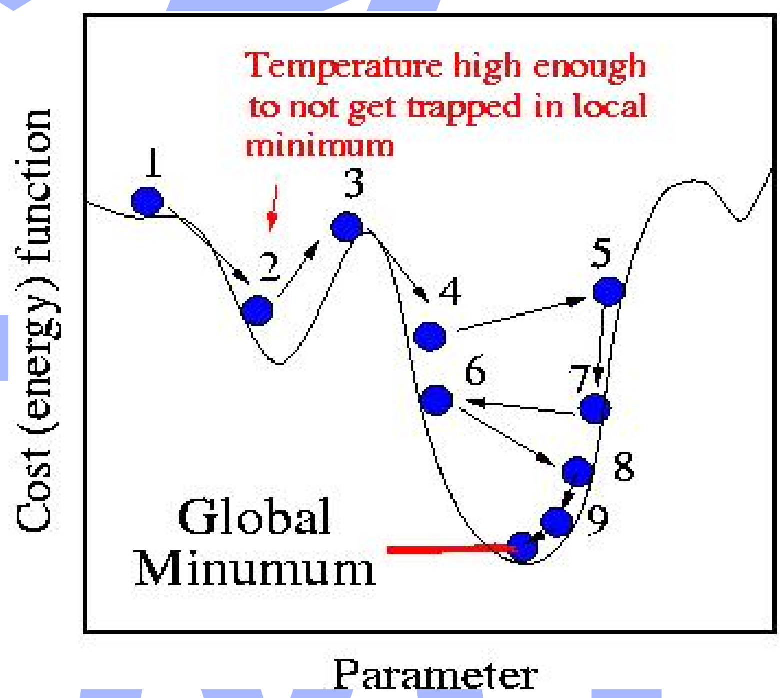
Cost function:

$$C(N_{is}, R_{m,is}) = \sum_{iz} \left(\frac{(Z_{obs}(iz) - Z_{calc}(iz))}{\delta Z_{obs}(iz)} \right)^2 + $$
$$+ \sum_{iz} \left(\frac{(\beta_{lid,obs}(iz) - \beta_{lid,calc}(iz))}{\delta \beta_{lid,obs}(iz)} \right)^2$$
$$+ \sum_{iz} \left(\frac{(\alpha_{lid,obs}(iz) - \alpha_{lid,calc}(iz))}{\delta \alpha_{lid,obs}(iz)} \right)^2$$
$$+ \sum_{is} \sum_{iz} \left(\frac{Rm_{l(s),is}(iz) - Rm^*_{l(s),is}(iz)}{\delta Rm^*_{l(s),is}(iz)} \right)^2$$
$$+ \sum_{is} \sum_{iz} \left(\frac{d \log(Rm_{l(s),is}(iz))}{dz} \right)^2$$
$$+ \sum_{is} \sum_{iz} \left(\frac{d \log(ext_{l(s),is}(iz))}{dz} \right)^2$$
$$+ \sum_{ic=5}^{7} \left(\frac{Bt_{obs,ic} - Bt_{calc,ic}}{\delta Bt_{obs,ic}} \right)^2$$

Complicated
with many local minima

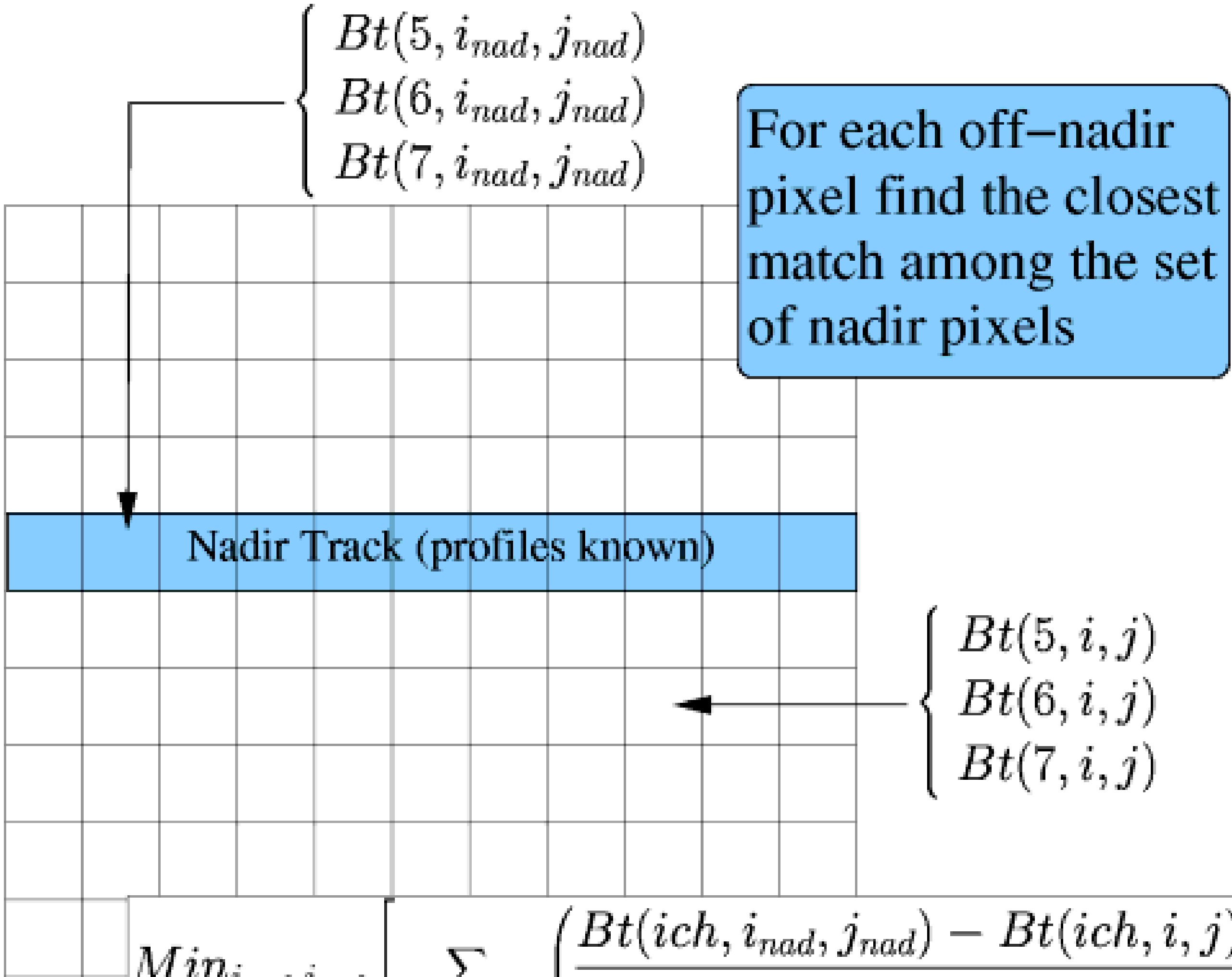
Use a Simulated Annealing approach





2D track to 3D domain

KNMI



$$Min_{i_{nad}, j_{nad}} \left[\sum_{ich=5,6,7} \left(\frac{Bt(ich, i_{nad}, j_{nad}) - Bt(ich, i, j)}{Bt(ich, i, j)} \right)^2 \right]$$

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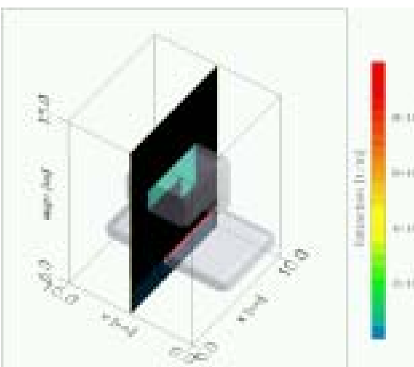
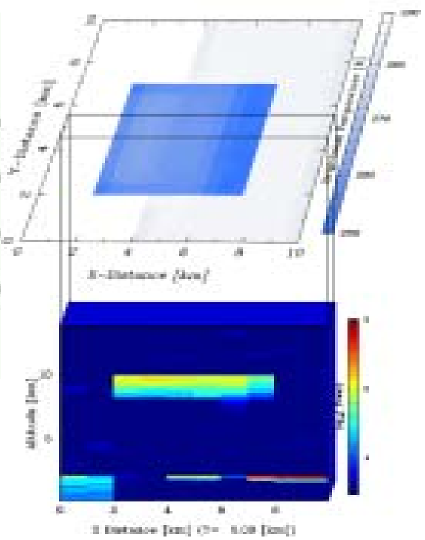
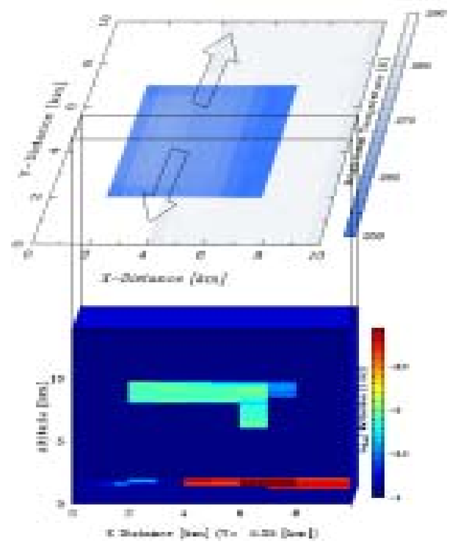
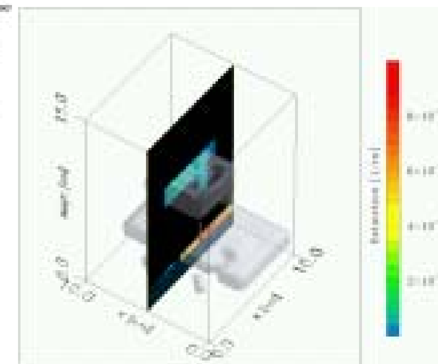
MSI images

synthetic 3D scene	simulated measurements	Retrieval profiles	reconstructed 3D scene
extinction	co-polar Mie	extinction	extinction







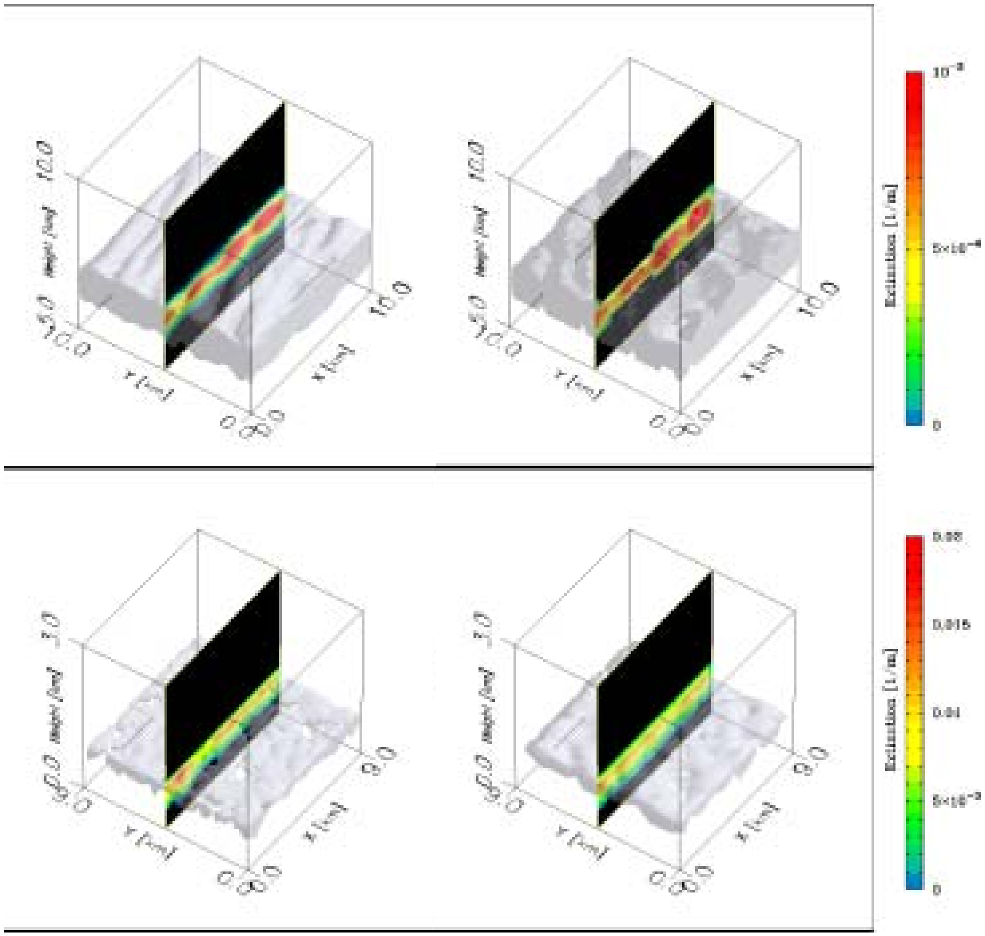


TOA FLUX
SW: 244 W/m²
LW: 238.6 W/m²

Difference :
SW: 5 W/m²
LW:2.3 W / m²

TOA Flux
SW: 249 W/m²
LW: 236.3 W/m²

model 3D scene   Reconstructed scene



Thin cirrus case

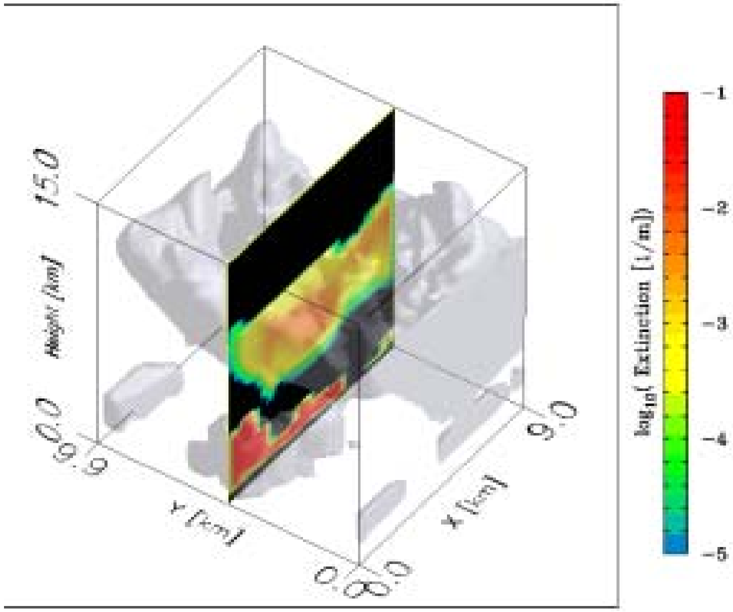
	True	Retrieved
SW TOA (W/m^2)	*116*	*121*
LW TOA (W/m^2)	*206.5*	*213.0*

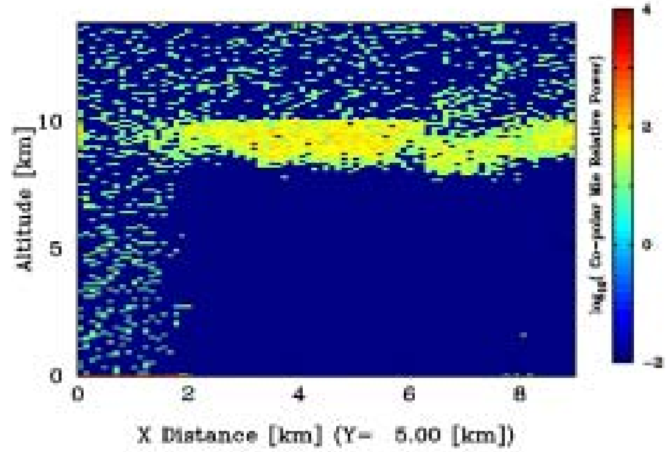
Differences: SW TOA **5 W/m^2**
LW TOA **6.5 W/m^2**

Stratus case

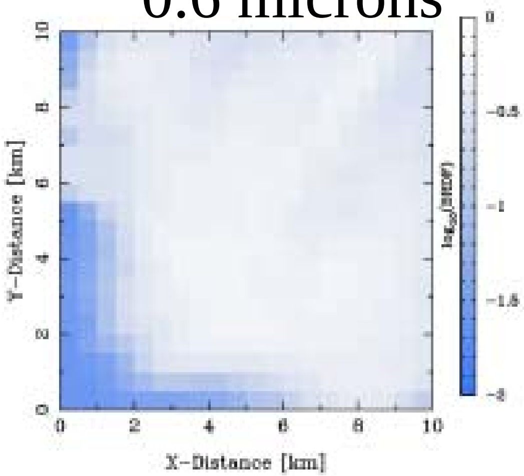
	True	Retrieved
SW TOA (W/m^2)	*286*	*290*
LW TOA (W/m^2)	*274.9*	*273.9*

Differences: SW TOA **4 W/m^2**
LW TOA **1 W/m^2**

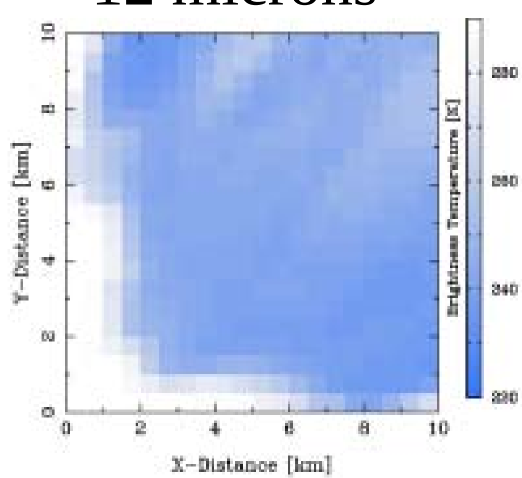


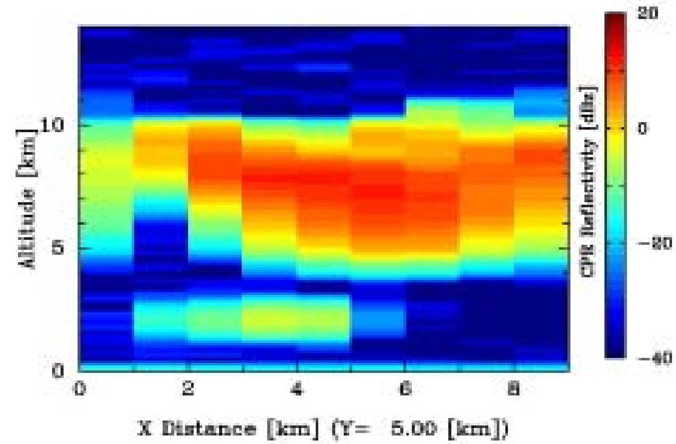


0.6 microns



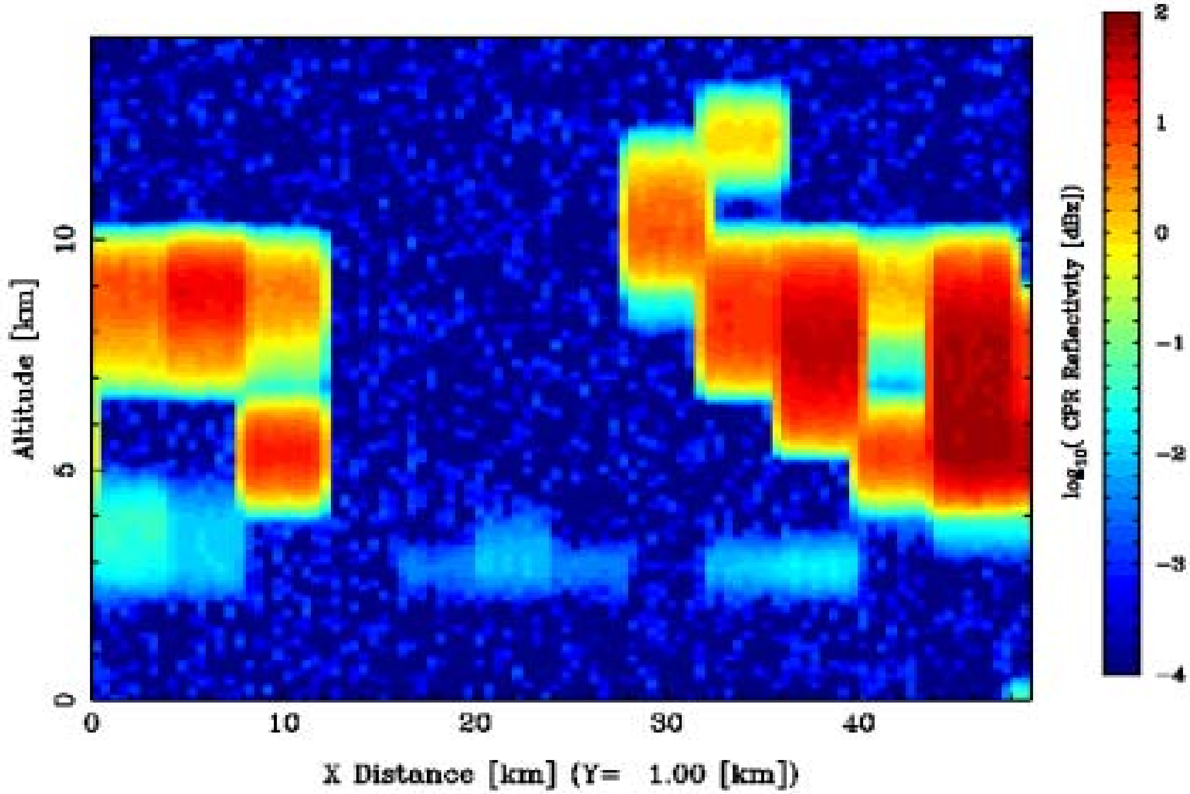
12 microns





Other Points:

Package can ingest data from different sources:



Example from MSM (super-parameterization) field

Conclusions I

- The EarthCARE simulator is a powerful, flexible package.
- Detailed but is what is required to do the job right.
- But..its slow. Should be moved to a parallel machine.
- Surfaces could be improved.
- Ice scattering info also should be improved.
- End-to-end procedure experimental but highly promising.
- SW MSI should be incorporated into end-to-end procedure.
- Users manual and final report in preperation.

Conclusions II

- The 3-D information content of the ECARE combined measurements is high.
- End-to-End studies show that innovative **self-verifying** procedures can be implemented.
- As a by-product, accurate Rad-to-flux conversion factors are generated on an instaneous case-by-case basis.
- 10 W/m^2 instaneous TOA flux accuracy for the retrieved atmospheric column on the 10 km scale is an achievable goal.

Donovan and Van Lammeren.

Based on fact that $\frac{\alpha}{Z_e} = F(R'_{eff})$ $\left(\frac{\alpha}{Z_e} \neq F(R_{eff})\right)$

$$R'_{eff} = \left(\frac{9}{16\Pi} \frac{\langle (Mass(D)/\rho)^2 \rangle}{\langle Area(D) \rangle} \right)^{1/4}$$

$$R_{eff} = \left(\frac{3}{4} \frac{\langle (Mass(D)/\rho) \rangle}{\langle Area(D) \rangle} \right)$$

Conversion from R'_{eff} to R_{eff} depends on crystal type and nature of size-dist

Extinction is retrieved using `Klett-like' boundary value method

Multiple scattering is accounted for using a modified form of the model due to Eloranta.

Validated using CLARE'98 data.

Basic Considerations

The lidar extinction must first be extracted from the lidar signal (or, equivalently, the observed lidar backscatter must be corrected for attenuation).

$$P_{\mathrm{ss}}(z) = C_{\mathrm{lid}} z^{-2} \beta_{\mathrm{lid}}(z) \exp\left[-2\int_{z_o}^{z} \alpha(z')dz'\right]$$

Observed signal ($P_{\mathrm{ss}}(z)$)

Calibration Constant (C_{lid})

Backscatter ($\beta_{\mathrm{lid}}(z)$)

Extinction ($\alpha(z')$)

Ze used to link backscatter and extinction and facilitate extinction determination.

The retrieved extinction (corrected backscatter) can then be used to estimate an effective particle size.

Effective size for ice crystals

Exact treatment of scattering difficult (impossible?)

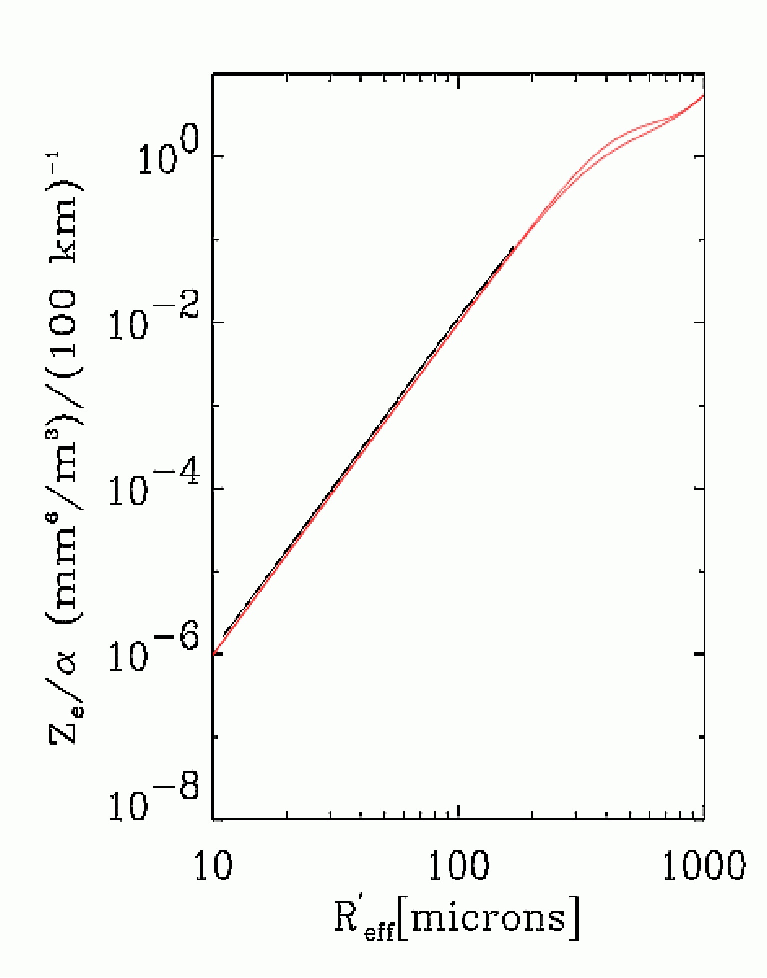
However:

Ice particles are large compared to λ_{lid} (Optical scattering regime)

Ice particles are small compared to λ_{rad} (Rayleigh scattering regime)

$$R'_{eff} = \left(\frac{9}{16\Pi} \frac{\langle (Mass(D)/\rho)^2 \rangle}{\langle Area(D) \rangle} \right)^{1/4}$$

Confirmed using DDA and RT calculations



Backward (Klett) inversion

IF $z < z_m$

$$\alpha(z) = \frac{\left(S(z)/S(z_m)\right)^{1/k}}{\frac{1}{\alpha(z_m)} + \frac{2}{k}\int_z^{z_m} \left(S(z')/S(z_m)\right)^{1/k} dz'}$$

Must estimate extinction at z_m(cloud bottom looking from space)

Difficult to do directly if one only has lidar info

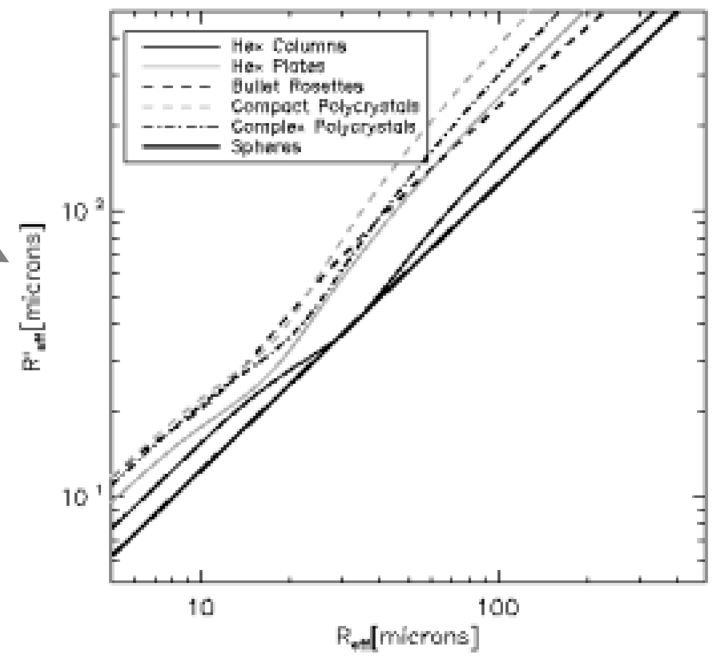
Use smoothness constraint on ratio of derived extinction to reflectivity (derived lidar/radar particle size)

Must also account for multiple scattering

KNMI

R'_{eff}-vs-R_{eff} for ice crystals

$$R'_{eff} = \left(\frac{9}{16\,\Pi} \frac{\langle (Mass(D)/\rho)^2 \rangle}{\langle Area(D) \rangle} \right)^{1/4}$$



Must know relationship between crystal Mass and maximum dimension (D) in order to predict R_{eff} and IWC !

$$R_{eff} = \left(\frac{3}{4} \frac{\langle (Mass(D)/\rho) \rangle}{\langle Area(D) \rangle} \right)$$

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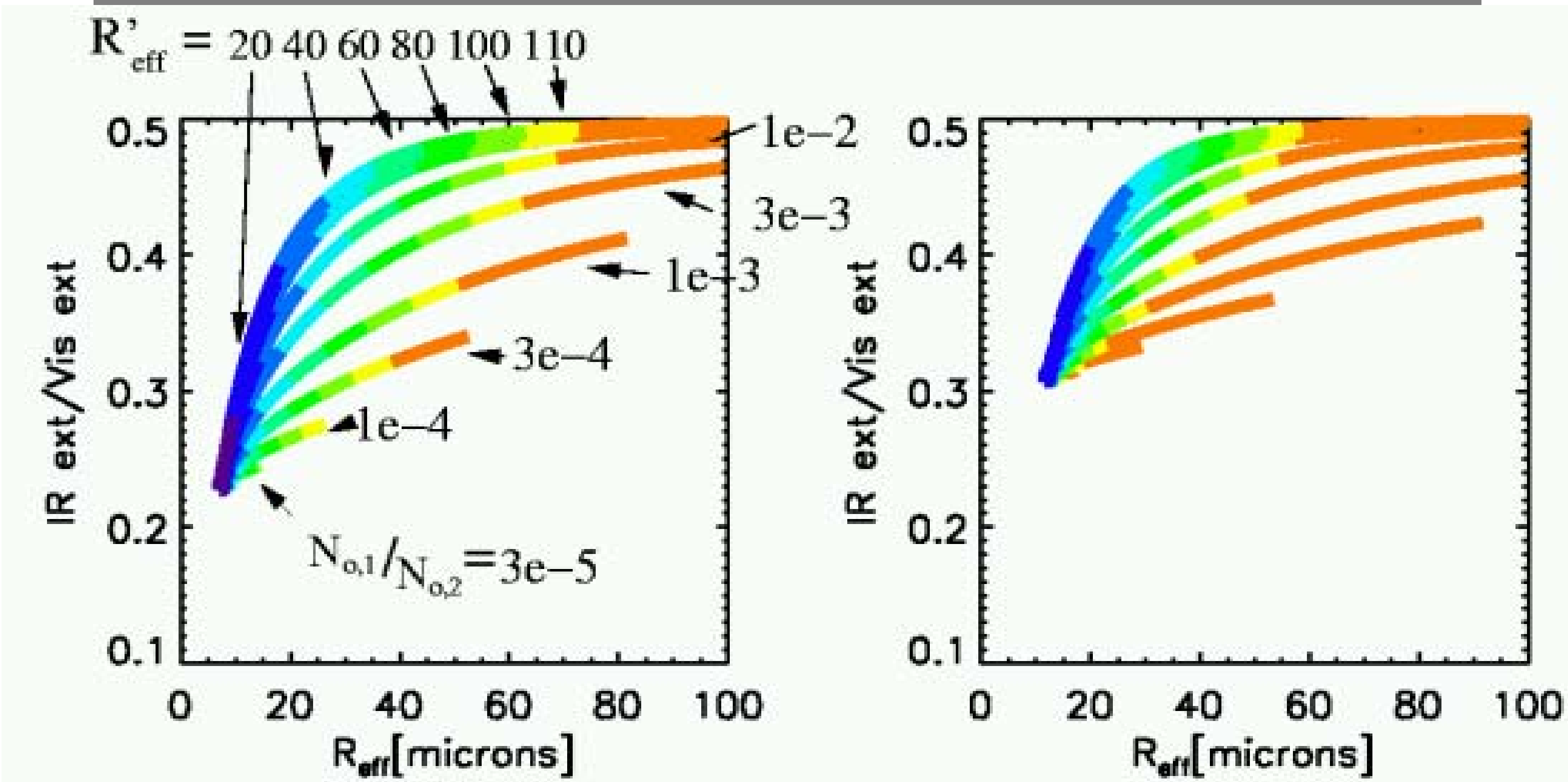
Example: Use of 8.3-9.4 um MSI channel

Can help pin down Habit+size dist. dispersion !!



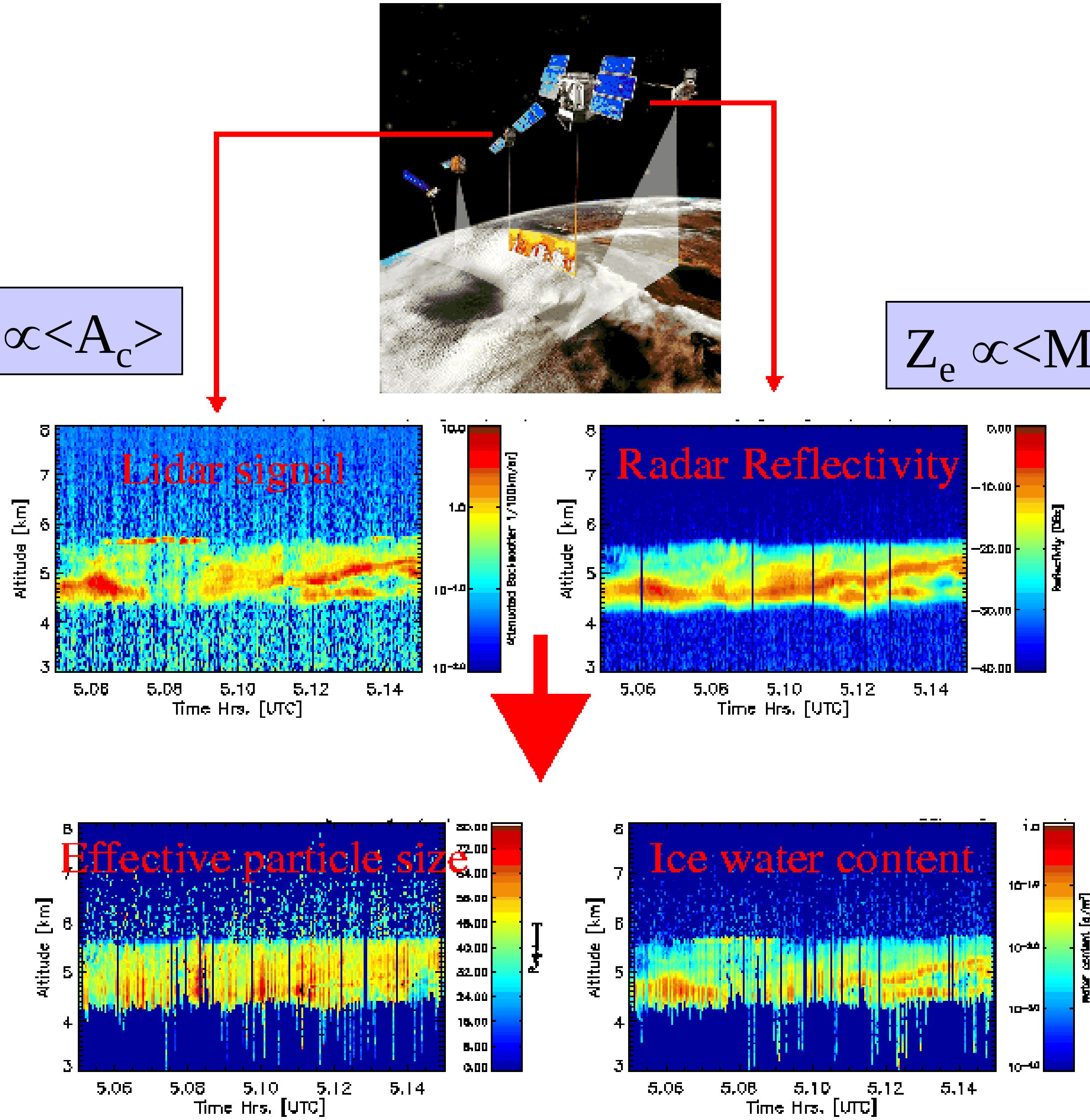
Bi-modal plates

Bi-modal bullet rosettes

KNMI

$\text{Ext} \propto \langle A_c \rangle$

$Z_e \propto \langle \text{Mass}^2 \rangle$



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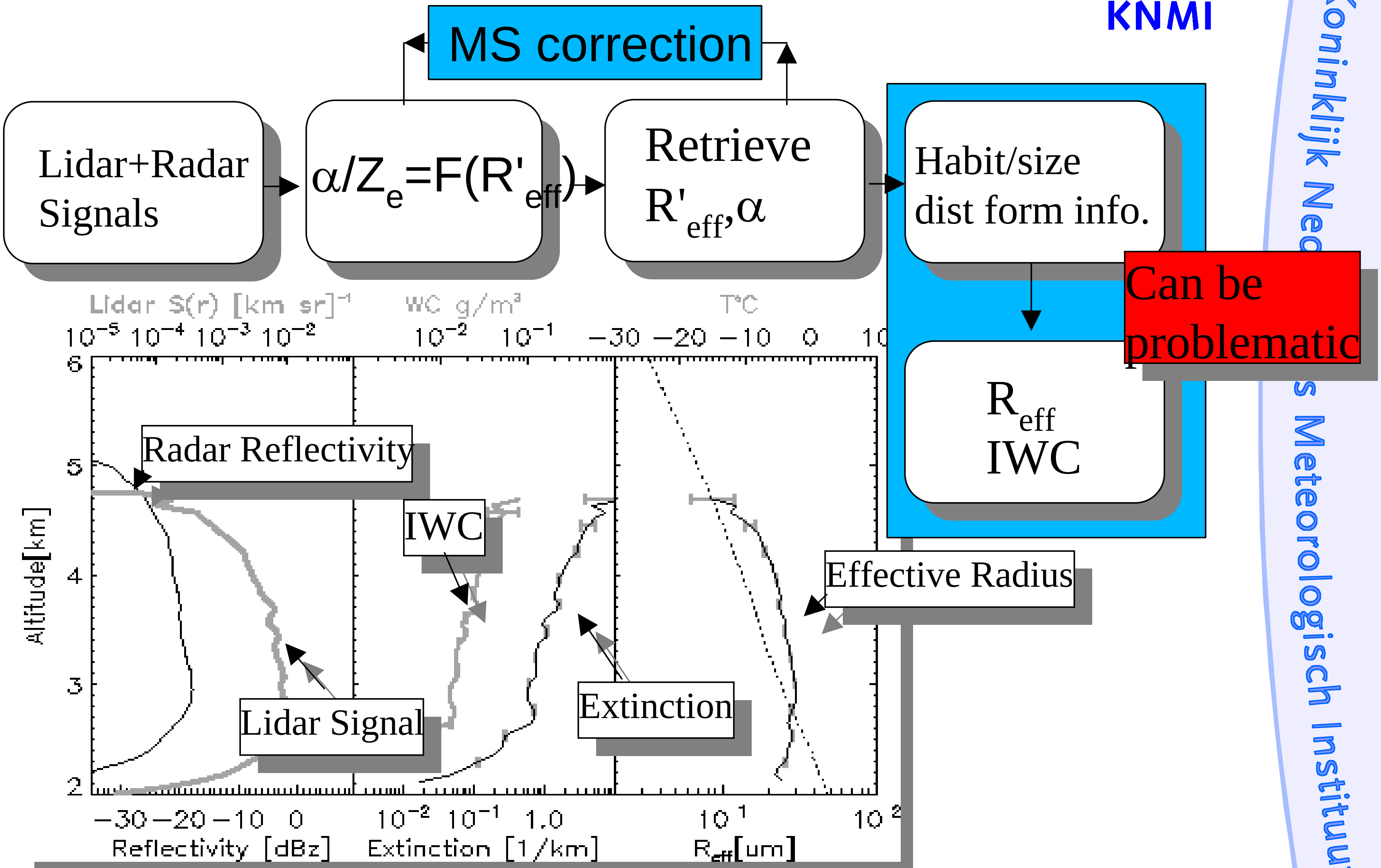
Lidar/Radar Inversion Procedure



Beyond direct lidar+radar

- Procedure works fine when lidar+radar both see all the ice cloud.
- Even if all clouds are seen we still must make assumptions regarding ice habit.
- Can we fill in the gaps and help reduce ambiguity?
- Comparing Emissivity of ice-clouds at two IR wavelengths where the absorption properties of ice are different can be used to estimate the size.
- Same sort of ambiguities regarding habit and modal nature of the size-dist are present but the information is complementary to the lidar/radar R'_{eff} size info !!

Mission Performance

EarthCARE Simulator - Example atmospheric scene