DFG

SPP 2115

Polarimetric Radar simulations with realistic Ice and Snow properties and mulTI-frequeNcy consistency Evaluation

PRISTINE

Soumi Dutta and Davide Ori (University of Cologne)

Jana Mendrok and Ulrich Blahak (DWD)

PROM All-hands Meeting Kiel 2023

Preliminary Work: polarimetric FO

Polarimetric extension of EMVORADO

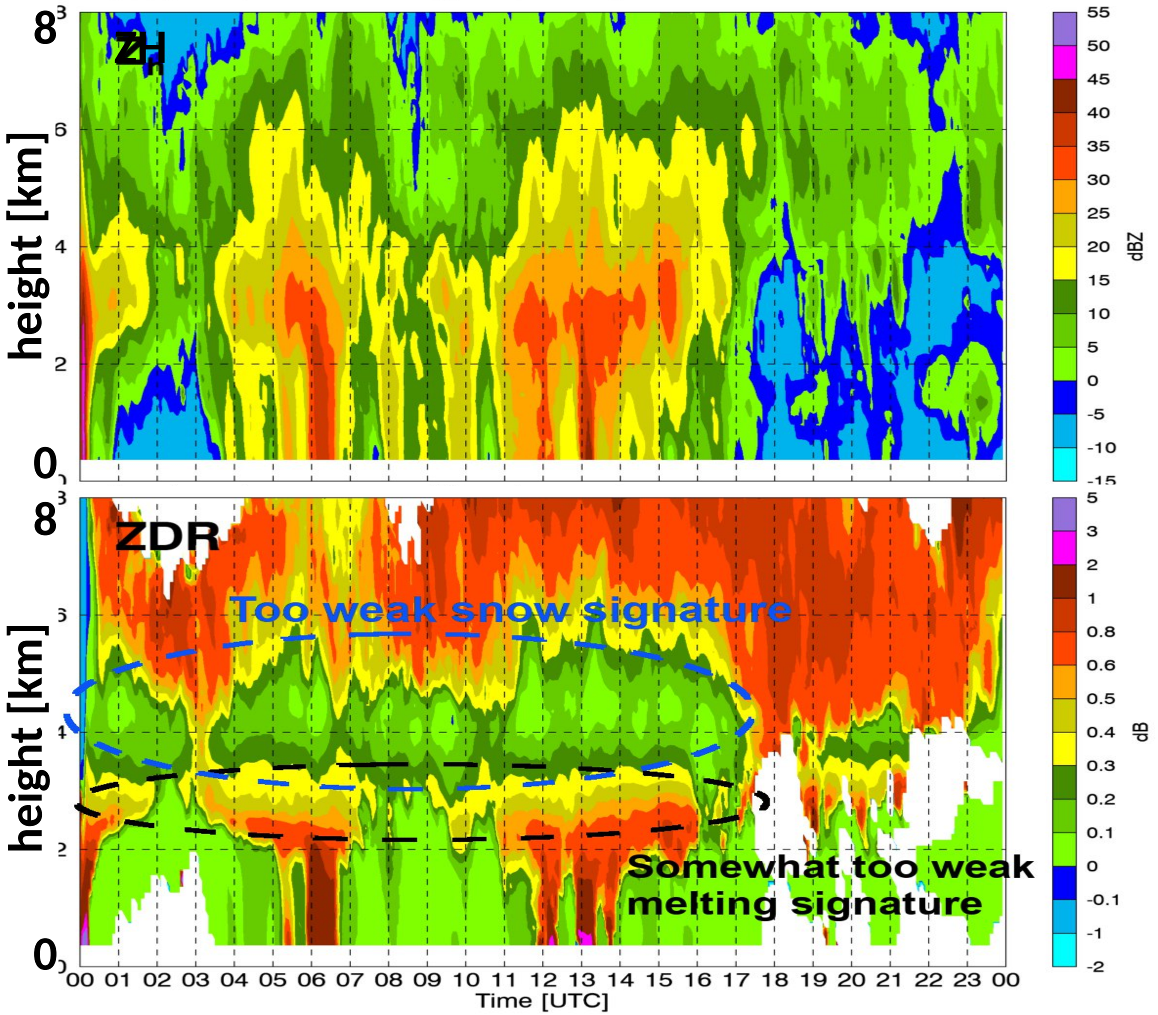
Based on T-matrix oblate soft spheroids:
ZH, ZDR, KDP, PhiDP, LDR, RhoHV, AH

Volume scans (range, azimuth, elevation)

Values on model grid as intermediate step

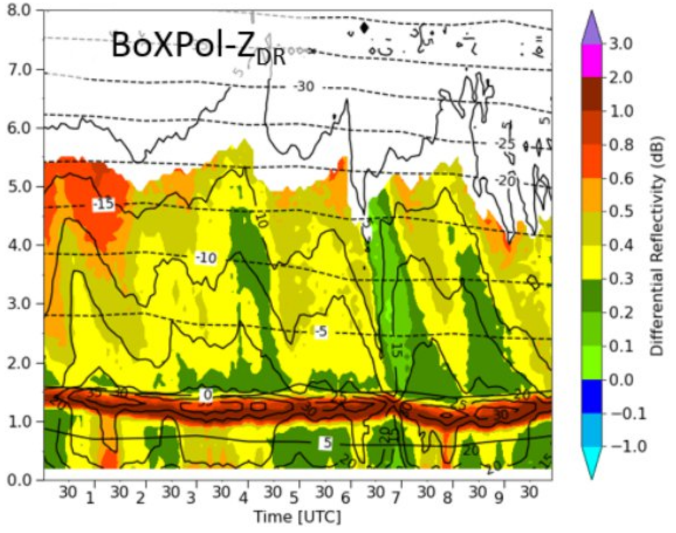
- PSDs and mass-size-relations consistent to model microphysics
- "Realistic" assumptions on Particle shapes / canting angles
- Volume scans include propagation effects: attenuation, beam blockage, beam smoothing
- Efficiency by use of look-up tables and parallelisation (MPI, OpenMP)
- Online coupled to COSMO and ICON, offline version available

24h timeseries of synthetic QVPs of ZH and ZDR from ICON-D2 (free) forecast

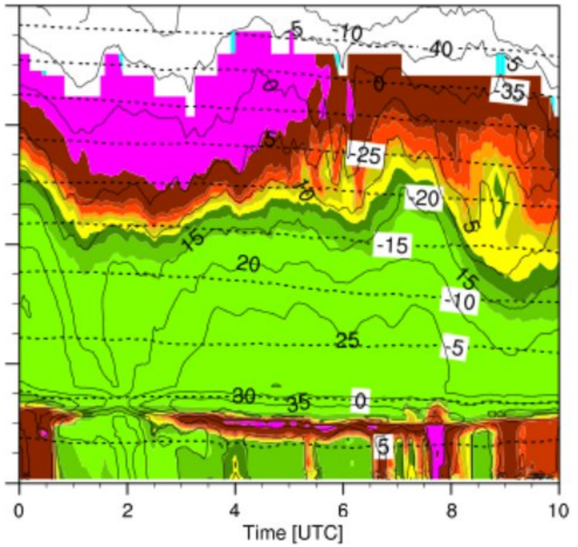


T-Matrix a great tool with some deficiencies

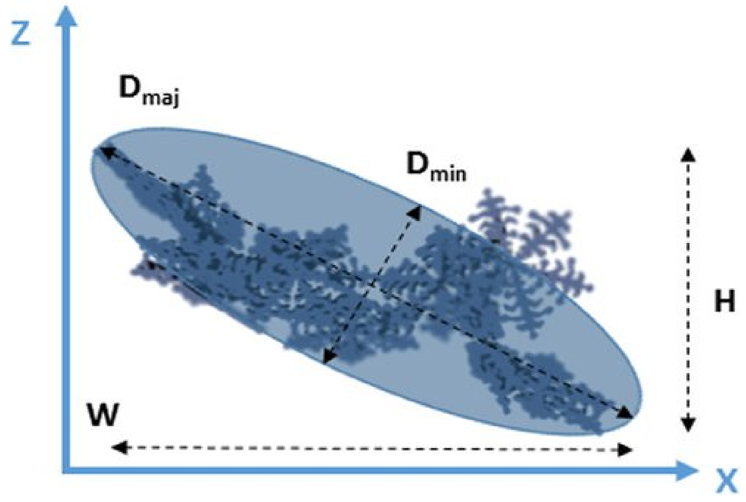
Observations



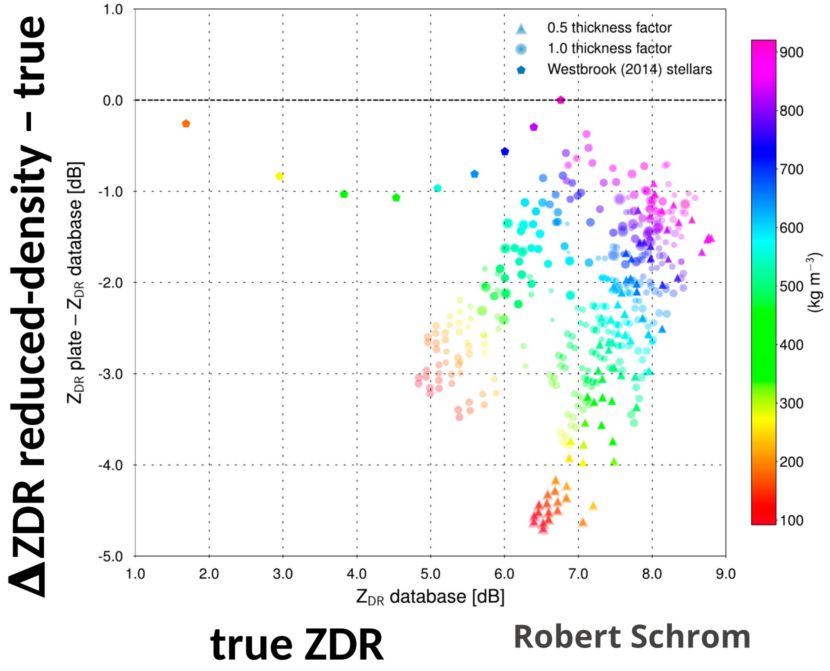
Model



T-Matrix based simulations show a **consistent deficit** in terms of **polarimetric response** in the dendritic growth layer where large, “fluffy” particles prevail.



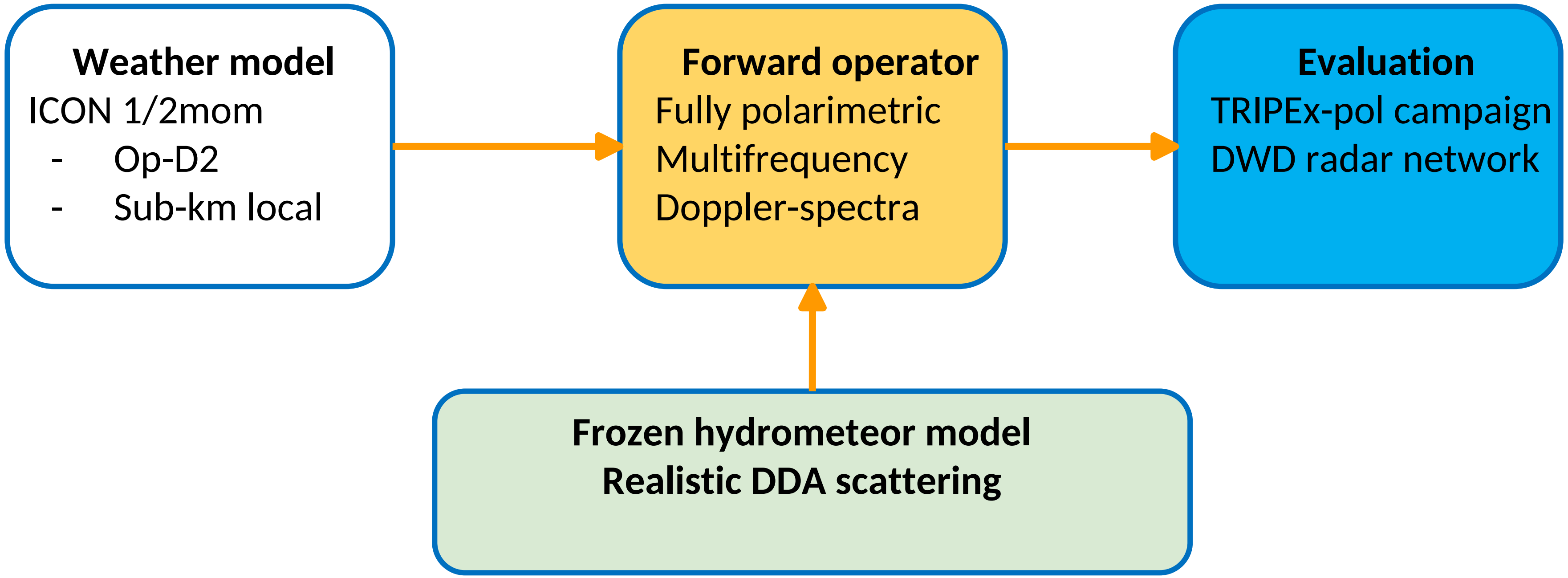
Multiple studies identified the spheroidal scattering model as a major source of uncertainty



Robert Schrom

Strategy

- Extend EMVORADO with new scattering tables and evaluate with real data



Strategy

Weather model
ICON 1/2mom
- Op-D2
- Sub-km local

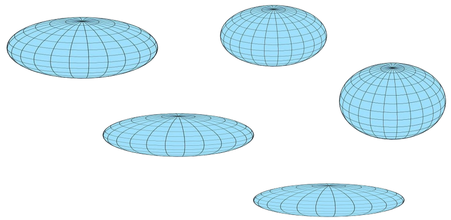
Forward operator
Fully polarimetric
Multifrequency
Doppler-spectra

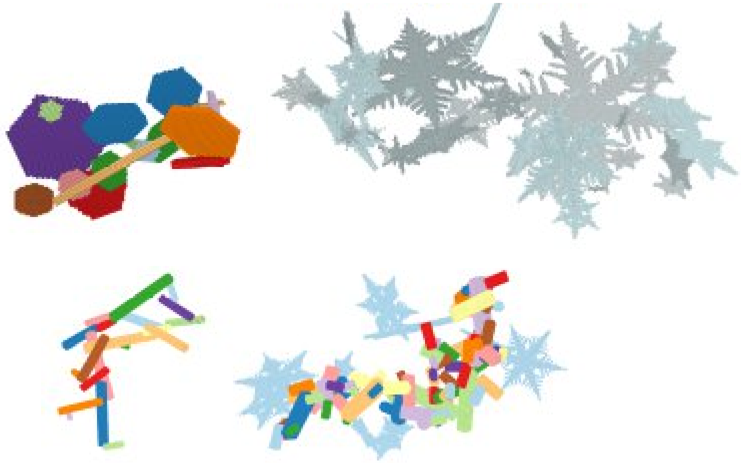
Evaluation
TRIPEx-pol campaign
DWD radar network

Frozen hydrometeor model
Realistic DDA scattering

- Extend EMVORADO with new scattering tables and evaluate with real data

- Simply substitute spheroids with realistic shapes





Strategy

Weather model
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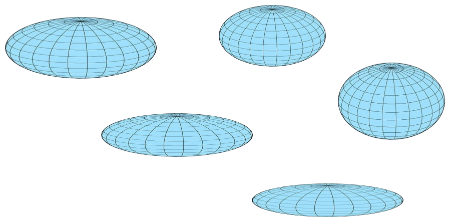
Frozen hydrometeor model
Realistic DDA scattering

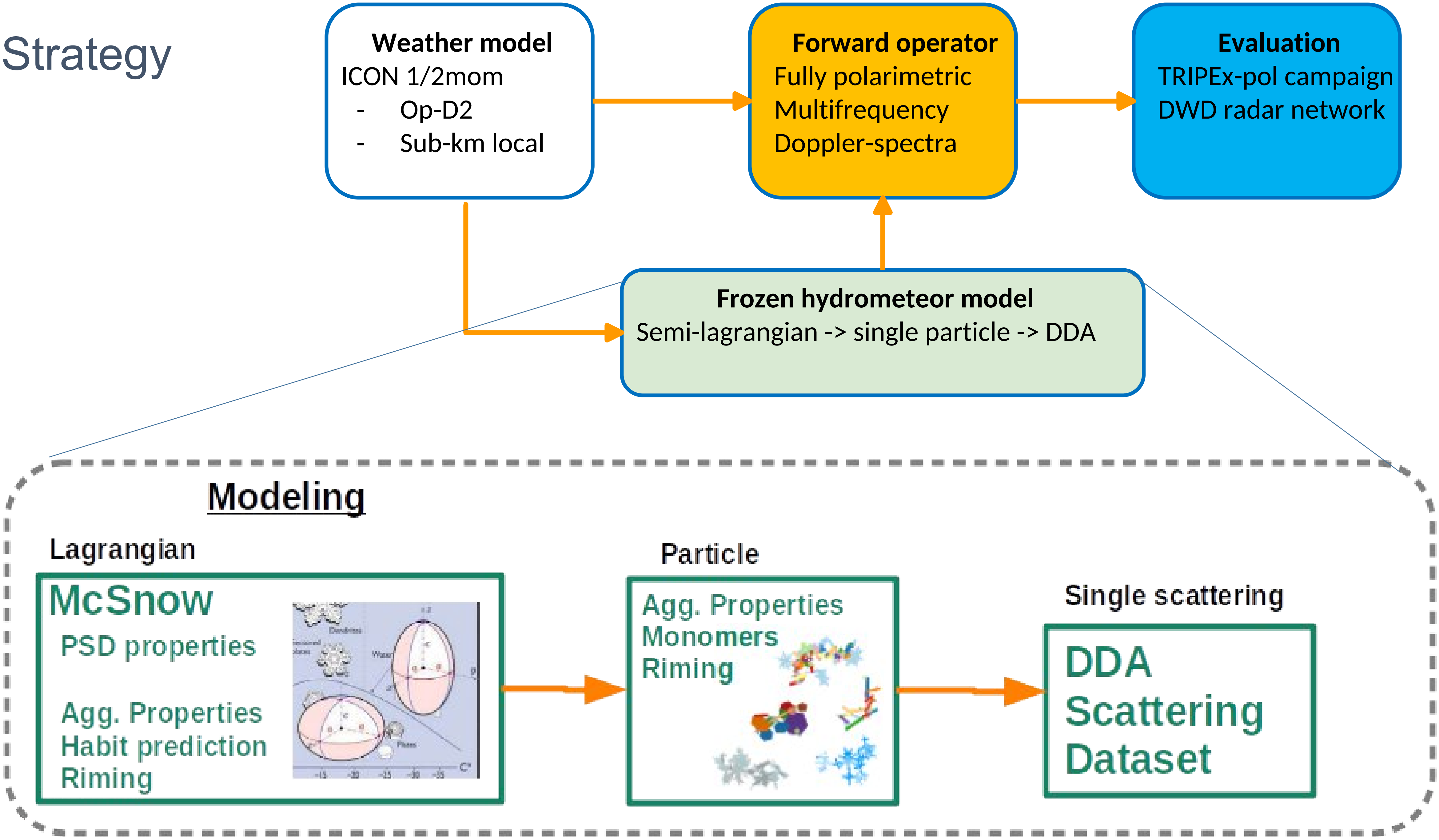
- Extend EMVORADO with new scattering tables and evaluate with real data

- Simply substitute spheroids with realistic shapes

- Ok, but … which one?



Strategy


Weather model
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DWD radar network
Frozen hydrometeor model
Semi-lagrangian -> single particle -> DDA
Modeling
Lagrangian
McSnow
PSD properties
Agg. Properties
Habit prediction
Riming
Particle
Agg. Properties
Monomers
Riming
Single scattering
DDA
Scattering
Dataset

Requirements

1) Maintain consistency with the model

2) Realistic particle modeling

3) Flexibility on orientation, sizes, frequencies

4) EMVORADO still fast

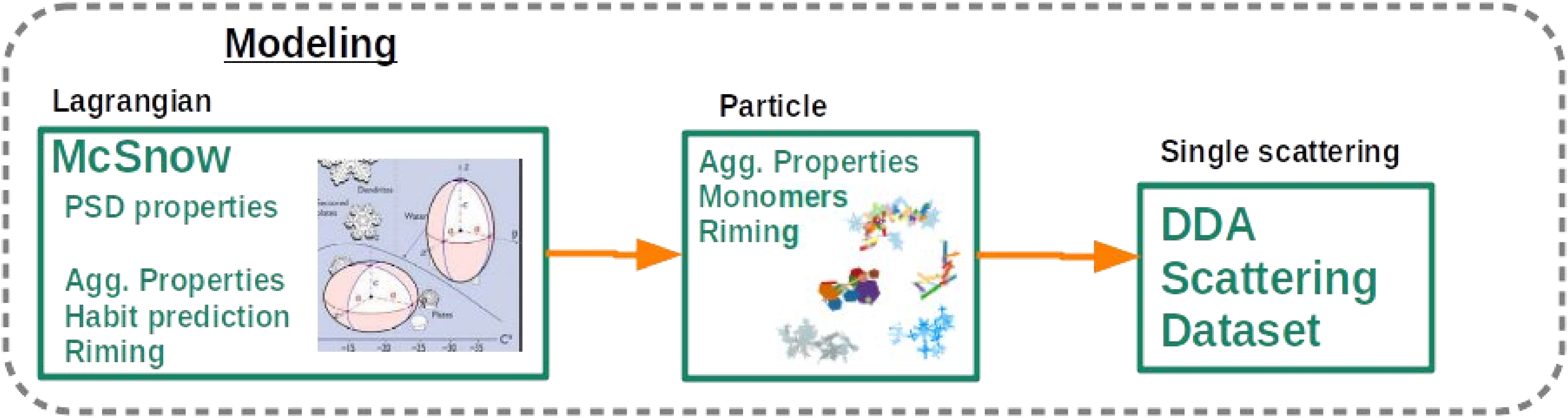
Questions

Is the model microphysics self-consistent?

What is the uncertainty due to natural variability of properties?

TECHNICAL: Address the dimensionality problem efficiently

TECHNICAL: How to preserve the complexity in Look-Up Tables



SELF INTRODUCTION

Soumi Dutta

Current Affiliation

PostDoctoral Researcher
Institute for Geophysics and Meteorology
University of Cologne, Germany

PhD

Centre for Atmospheric Sciences, IIT Delhi, India
&
Department of Atmospheric Sciences, UIUC, USA

Transition from Cloud Macro-physics to Cloud Micro-physics

Cloud Remote Sensing from Satellites

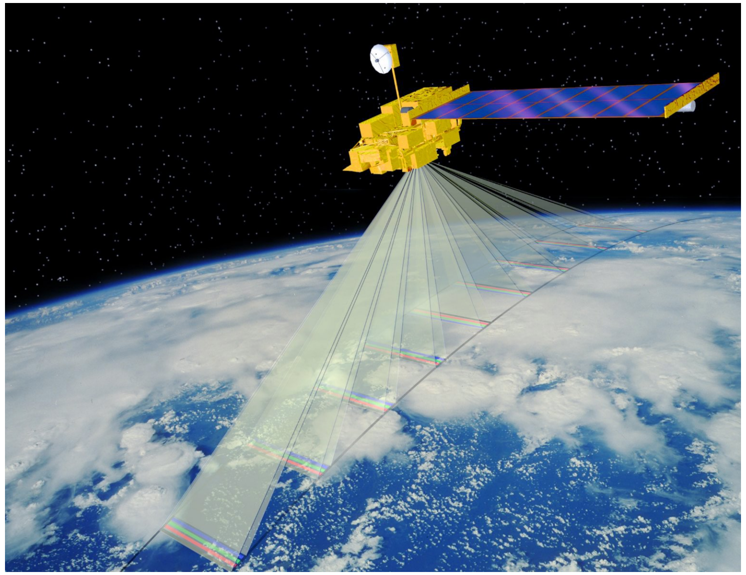
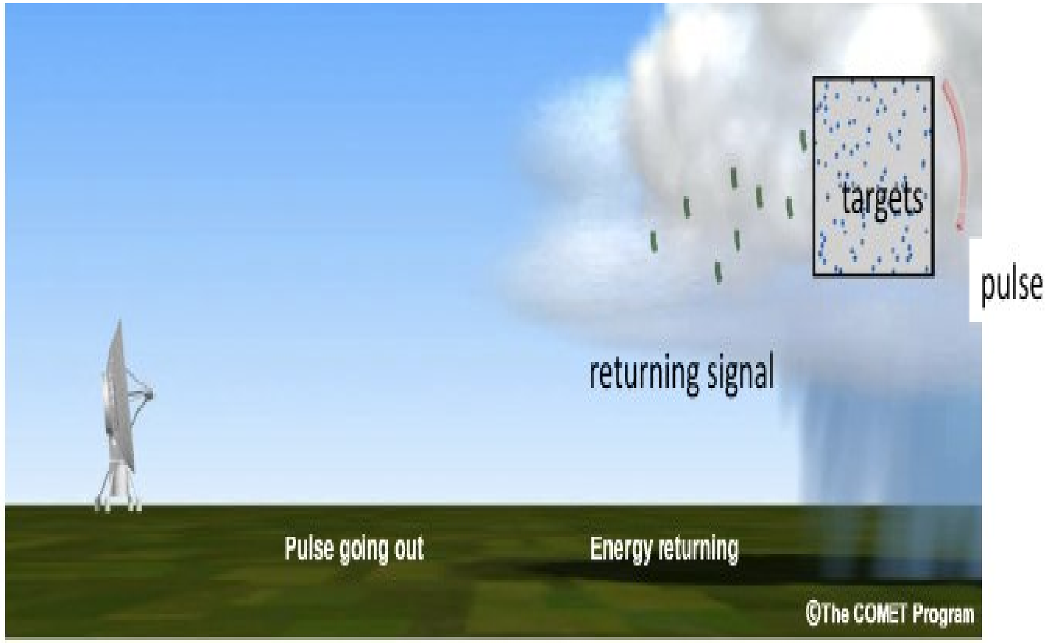


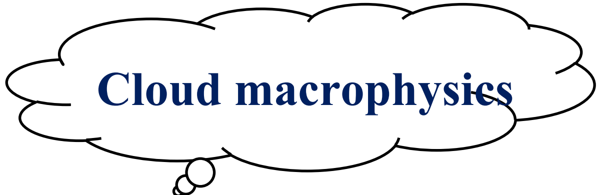
Image curtsey : MISR

Cloud Remote Sensing from Radars



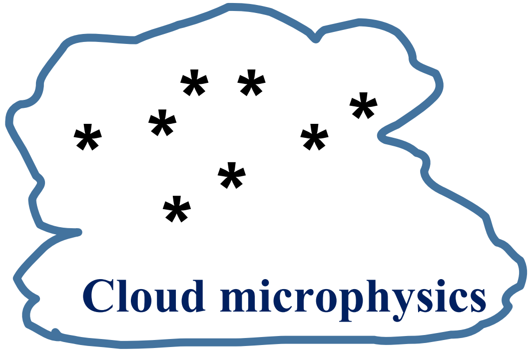
PhD Thesis

Towards Improved Estimates of Global Cloud Cover by Addressing Uncertainties Involved in Satellite Cloud Remote Sensing

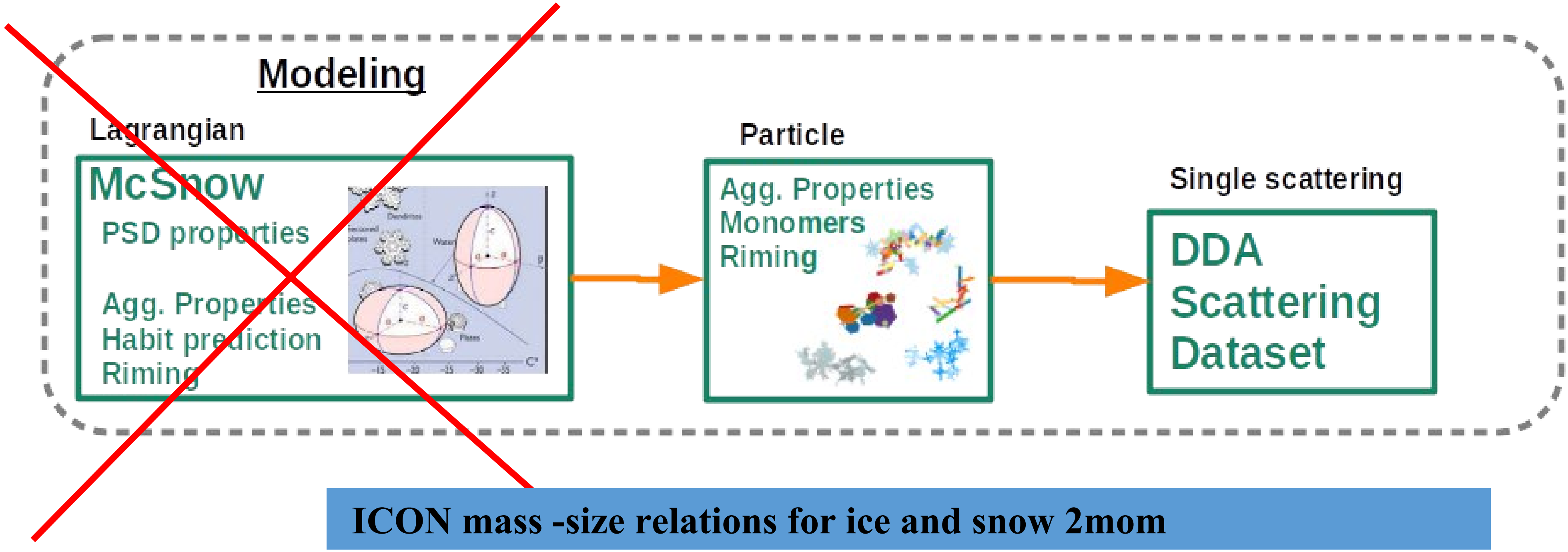


PostDoc Project

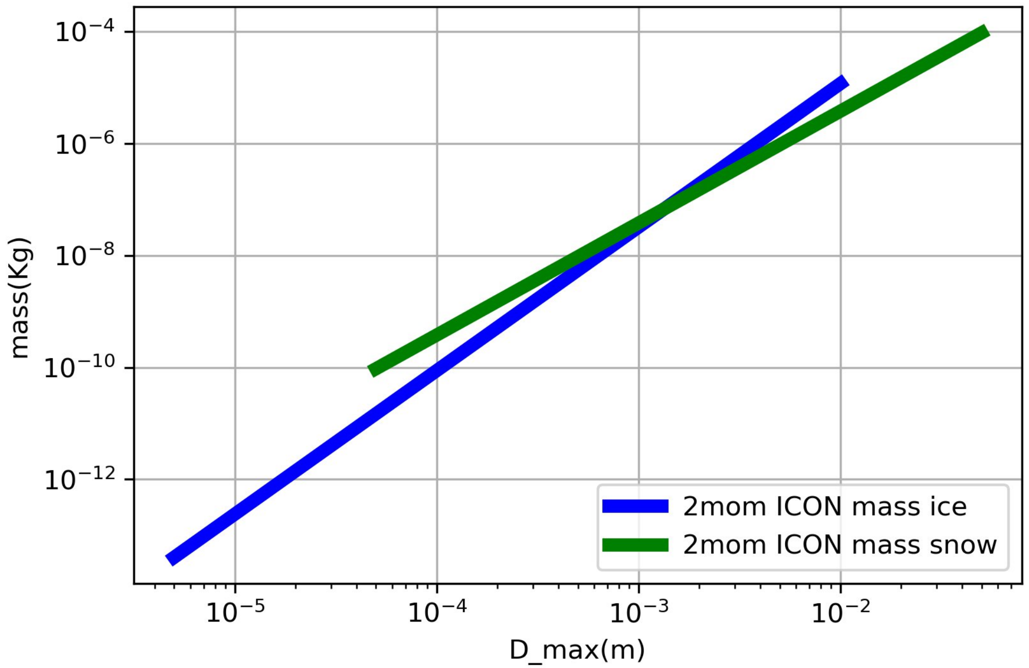
PRISTINE



Ice and snow simulations



ICON mass -size relations for ice and snow 2mom

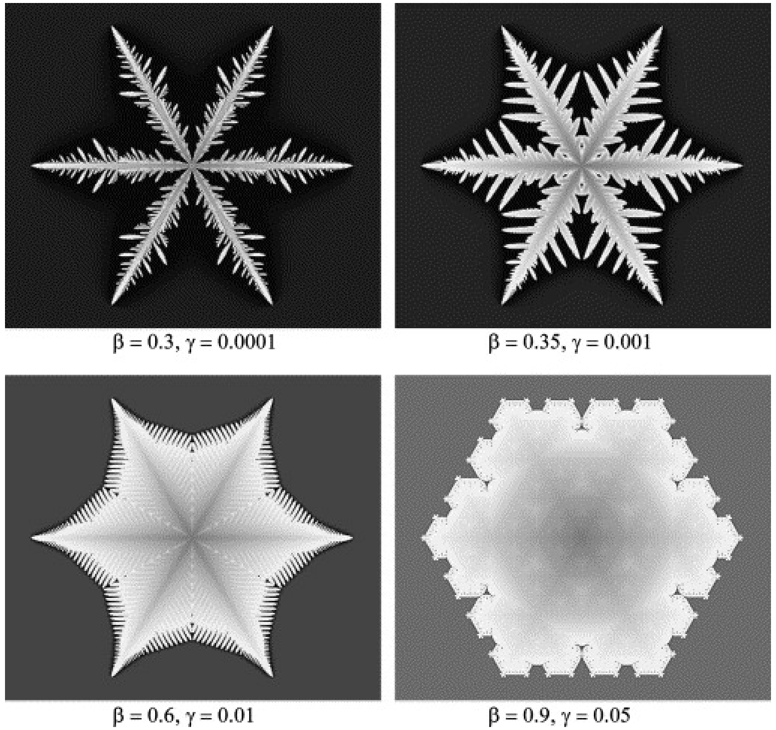


ICON assumptions

ice crystals
Dmin = 5.0e-6 ! 5um
Dmax = 10.0e-3 ! 10mm

snowflakes
Dmin = 50.0e-6 ! 50um
Dmax = 50.0e-3 ! 50mm

Reiter algorithm to make dendrites



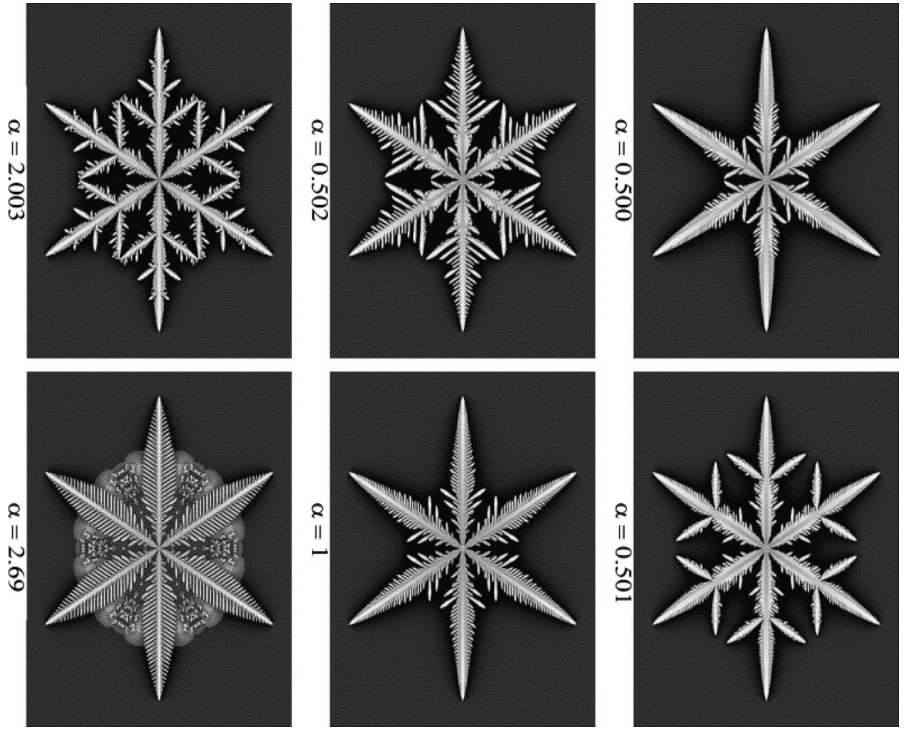


Image curtsey: Reiter, 2005

Simulated dendrite crystals

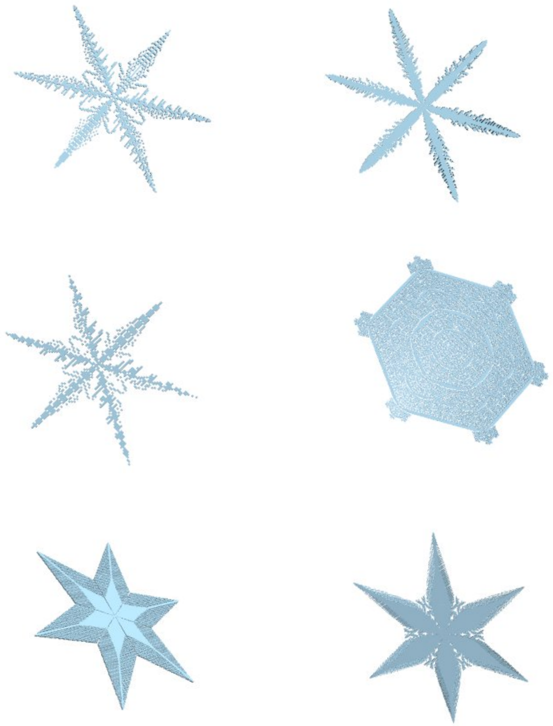
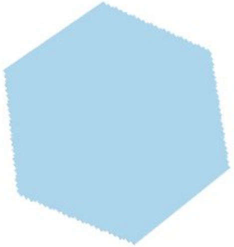
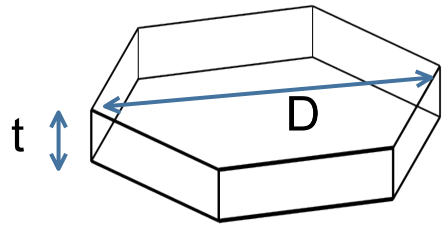


Plate crystals for very small (non branched)

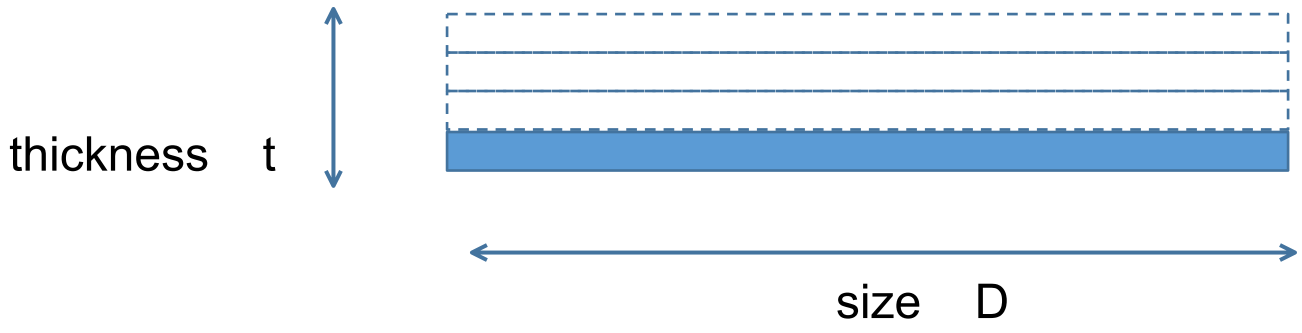


Aspect Ratio of Single Crystals

aspect ratio ar= t/D

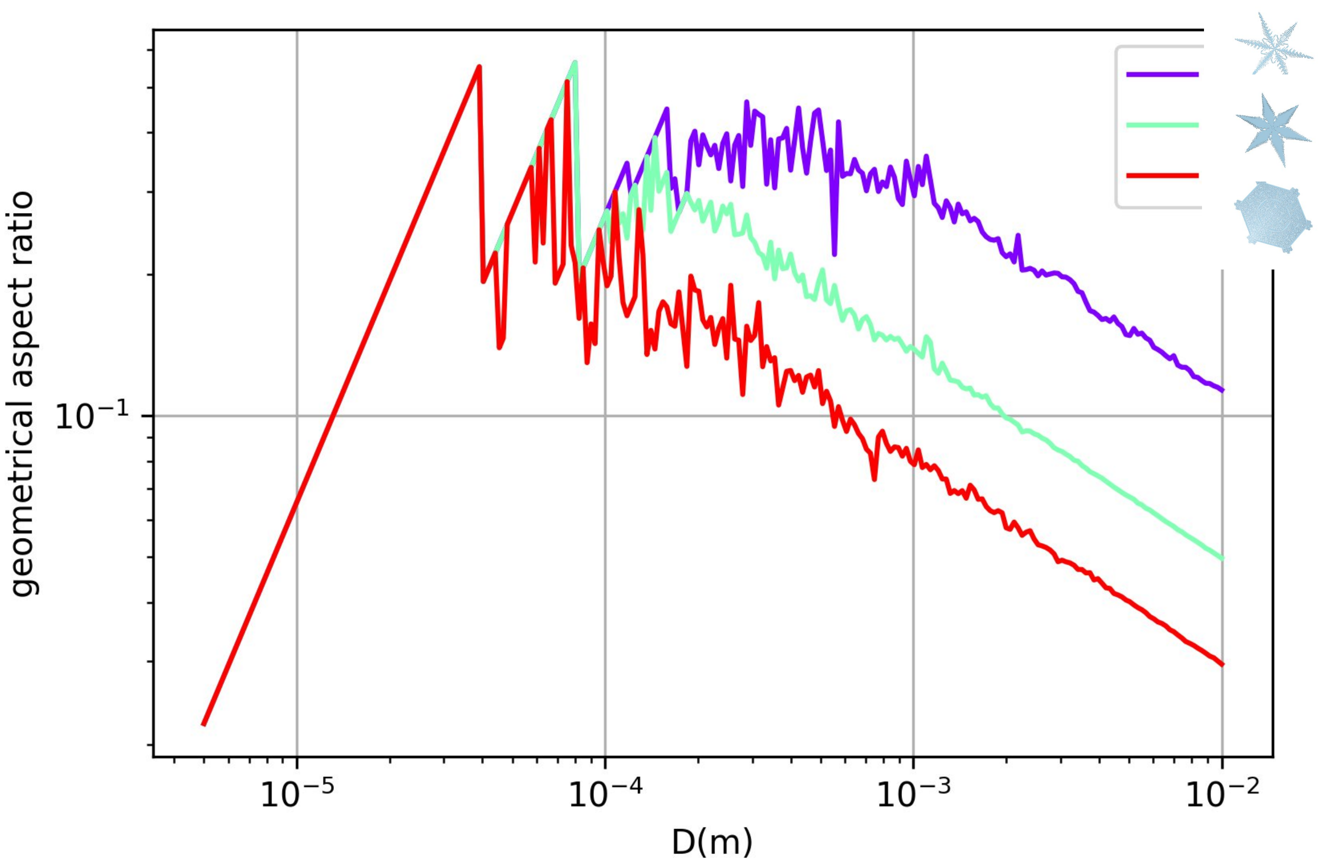


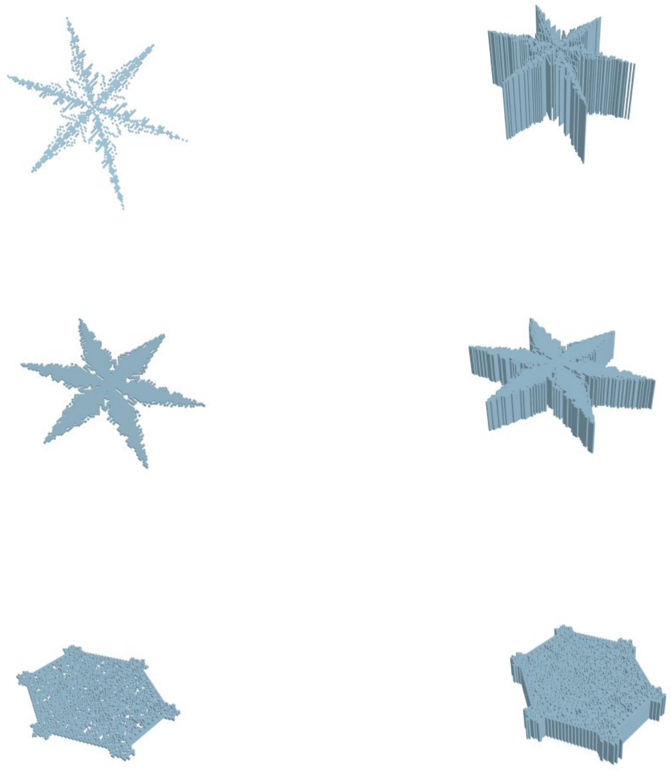
By adjusting aspect ratio we can match the desired mass consistent with ICON m-D relationship.



but we are limited by the resolution

Aspect ratio calculation for 2mom dendrite crystals to match with ICON 2mom mass-size relation

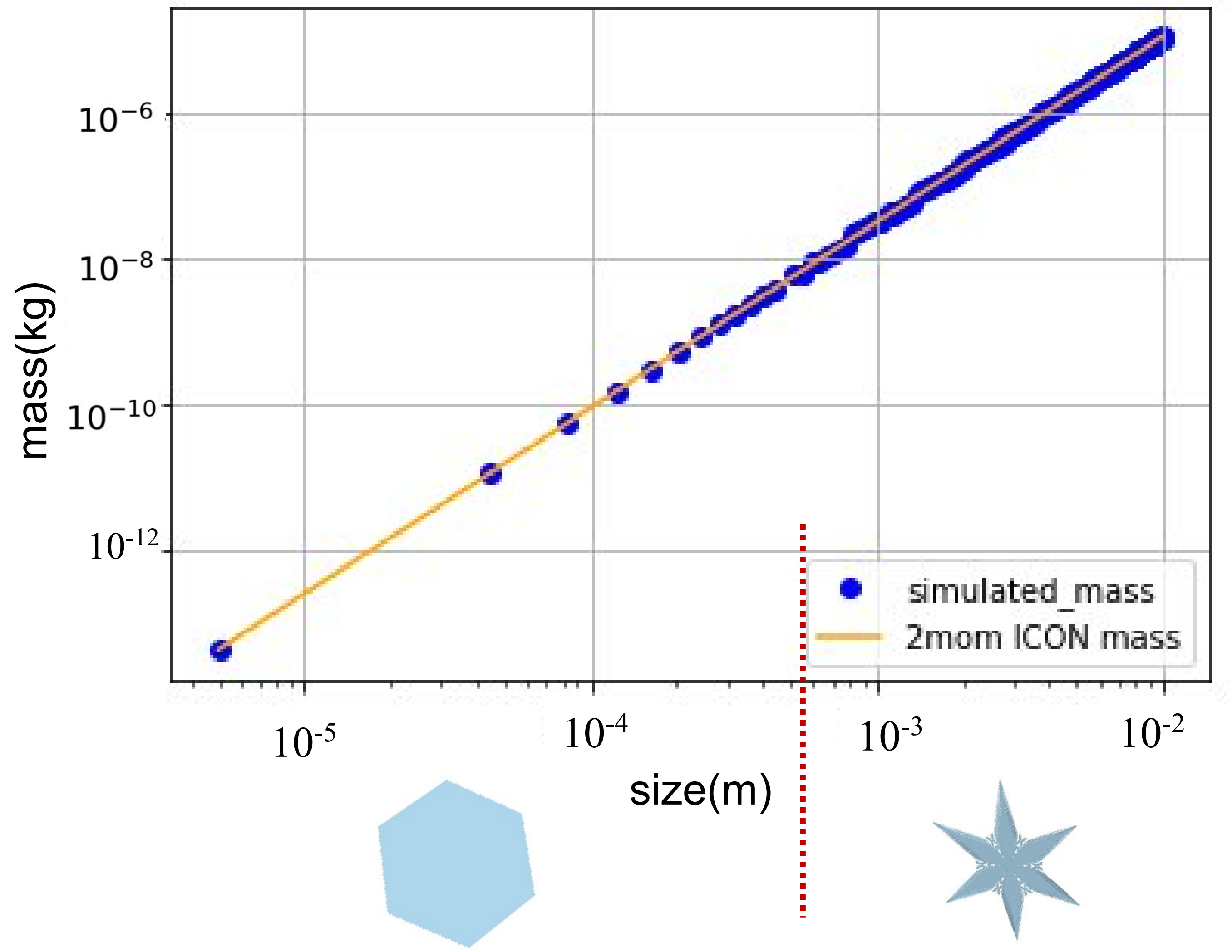




Crystal images with new_aspect ratios to match with ICON 2mom masses

Changed aspect ratio of ice crystals to match ICON m-D relationship

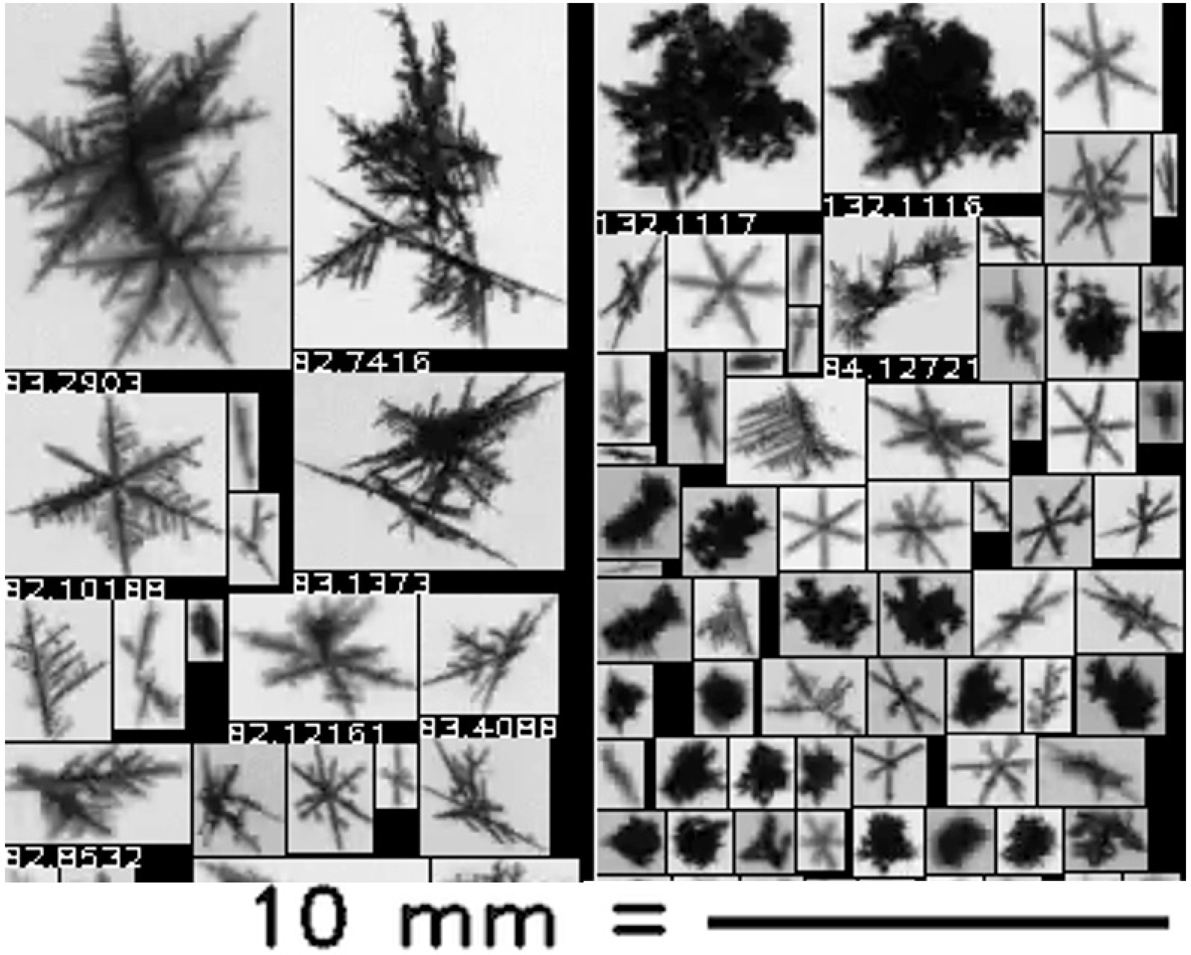
Plate size up to 0.5 mm size (Um et al., 2015) (IMPRINT under revision)
Dendrite size > 0.5mm



ICON size limit for ice
Dmin = 5.0e-6 ! 5um
Dmax = 10.0e-3 ! 10mm

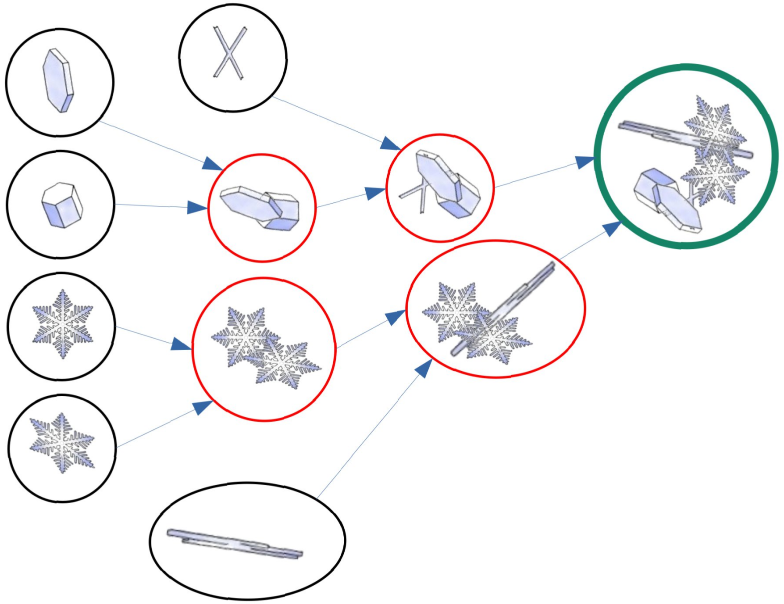
Aggregation is a key microphysical process for the formation of precipitable ice particles.

Observation

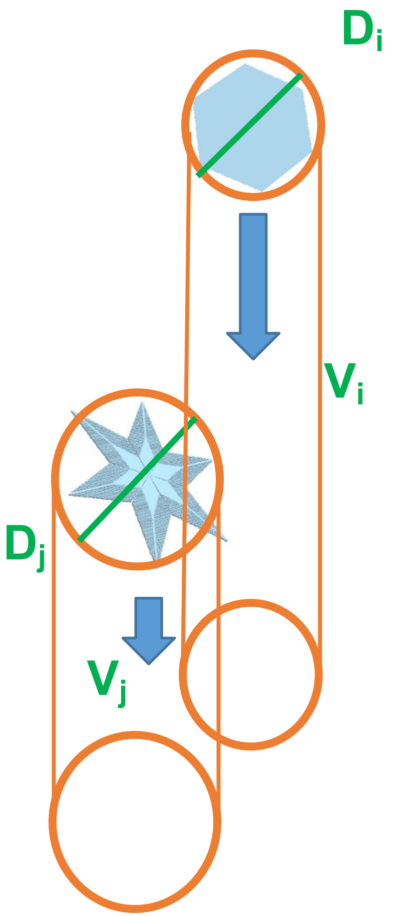


VISSS camera

Snow Aggregation Model

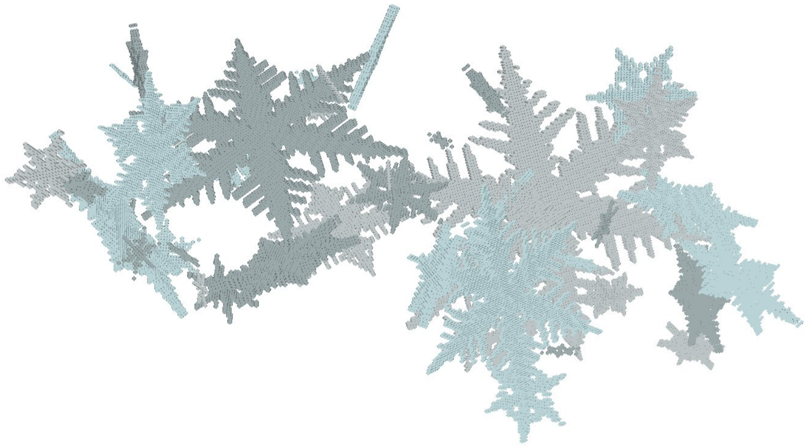


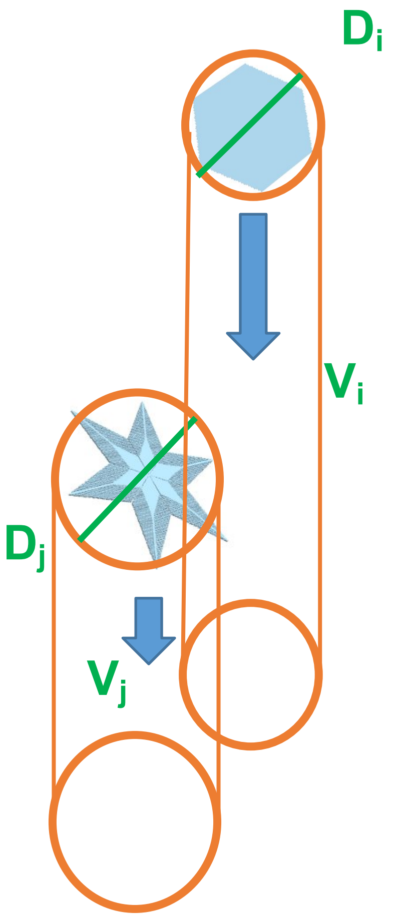
Schematic Diagram of aggregation process.



Differential Sedimentation Kernel

$$K_{i,j} = (D_i^2 + D_j^2)|v_i - v_j|$$

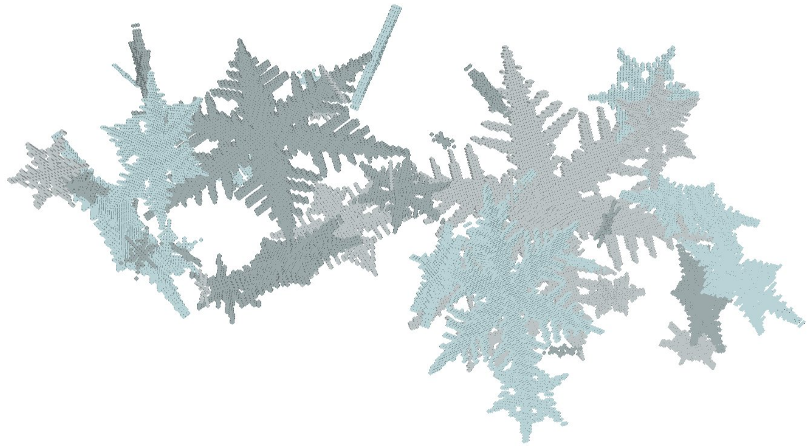


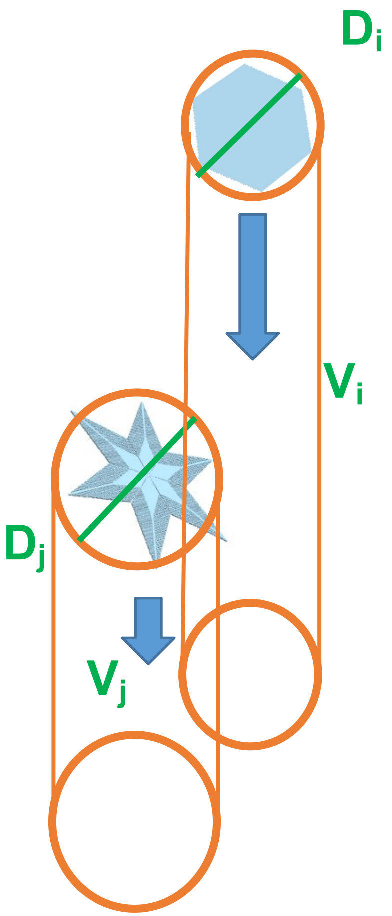


Differential Sedimentation Kernel

$$K_{i,j} = (D_i^2 + D_j^2)|v_i - v_j|$$

Type of monomers: ICON ice crystals



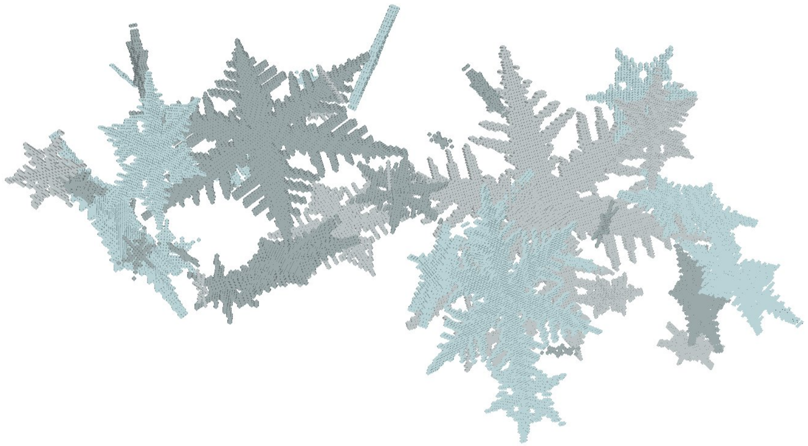


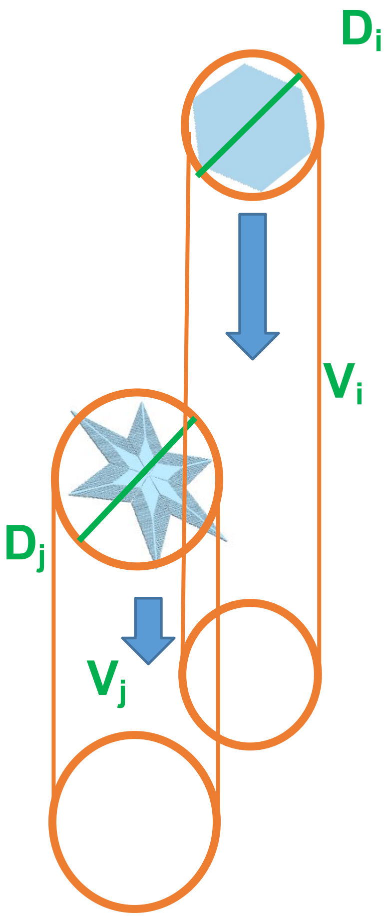
Differential Sedimentation Kernel

$$K_{i,j} = (D_i^2 + D_j^2)|v_i - v_j|$$

Type of monomers: ICON ice crystals

Number of monomers: 2 - 500





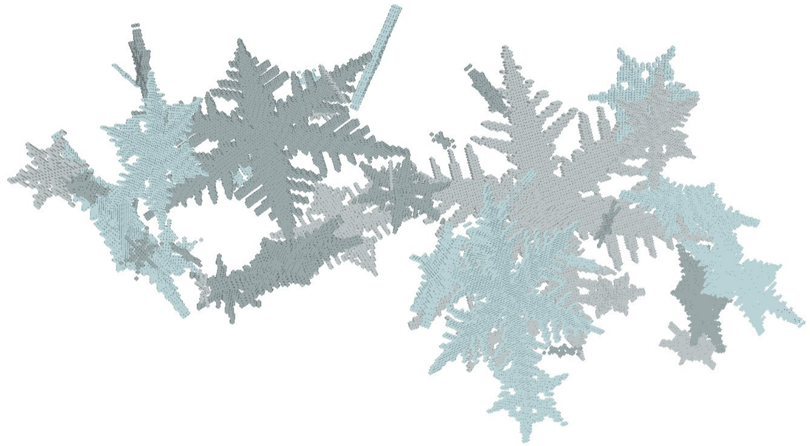
Differential Sedimentation Kernel

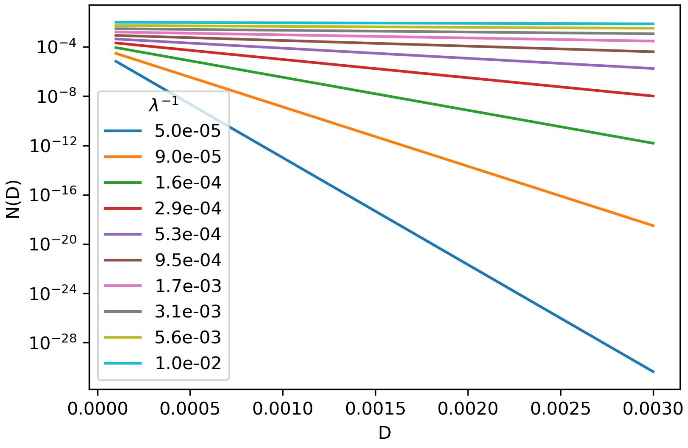
$$K_{i,j} = (D_i^2 + D_j^2)|v_i - v_j|$$

Type of monomers: ICON ice crystals

Number of monomers: 2 - 500

Monomer size distribution: inverse exponential
mean size 0.05 to 1 mm

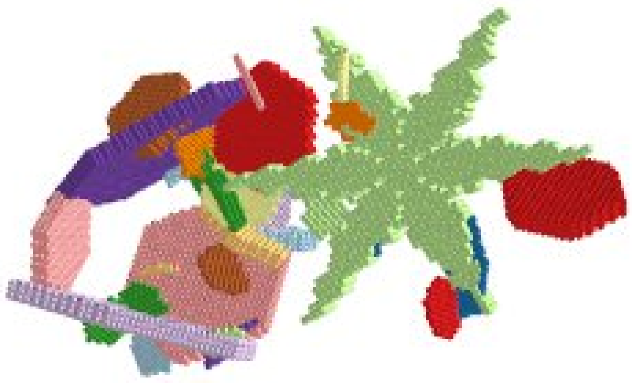




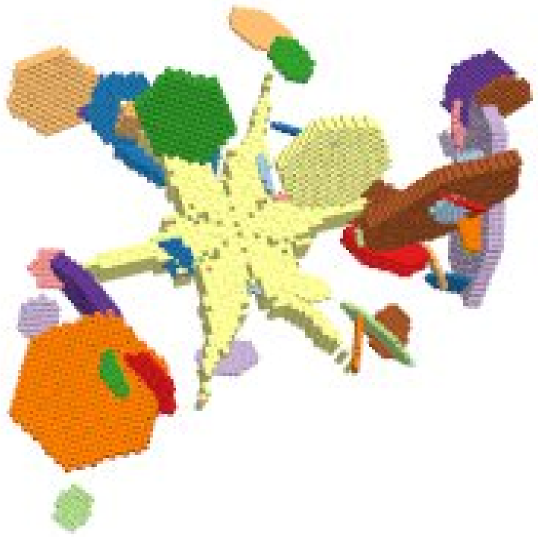
$$N(D) \propto \exp(-D/D_0)$$

Generation of realistic snowflakes using snow aggregation model

30 monomers of thin plate and dendrites

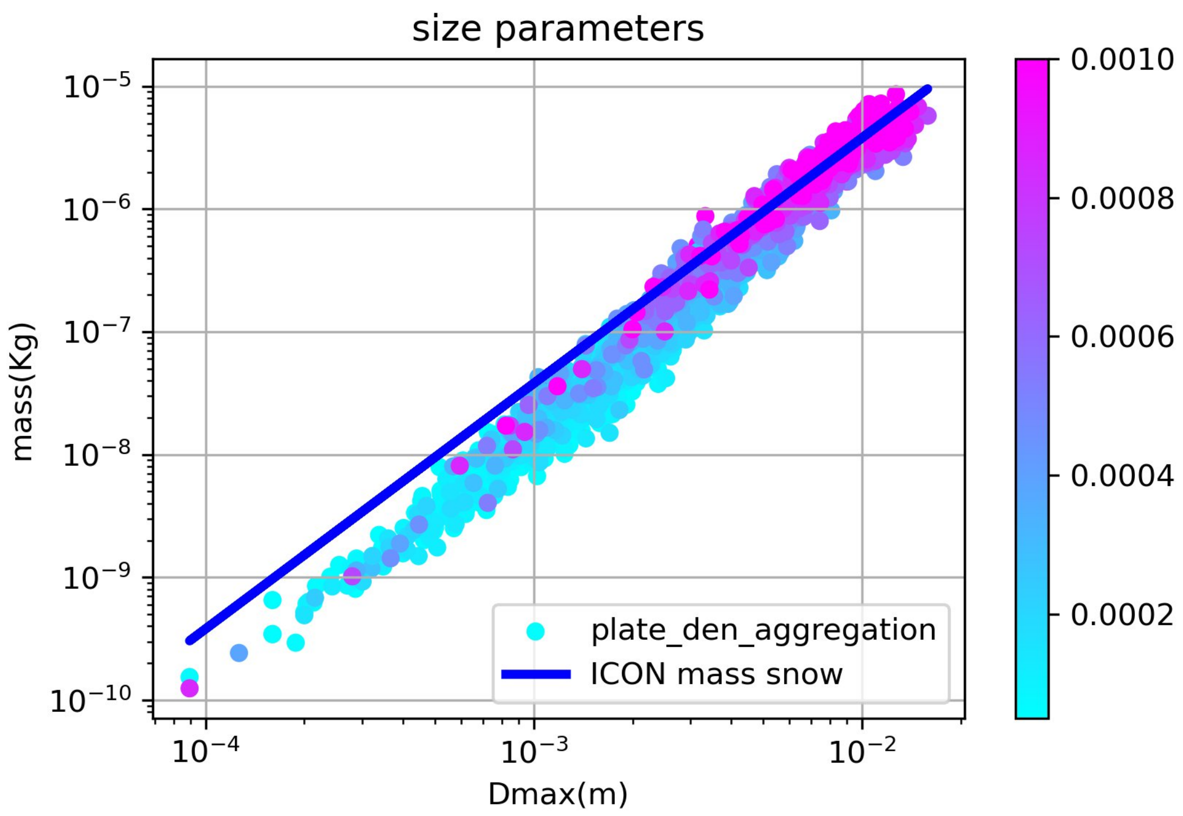


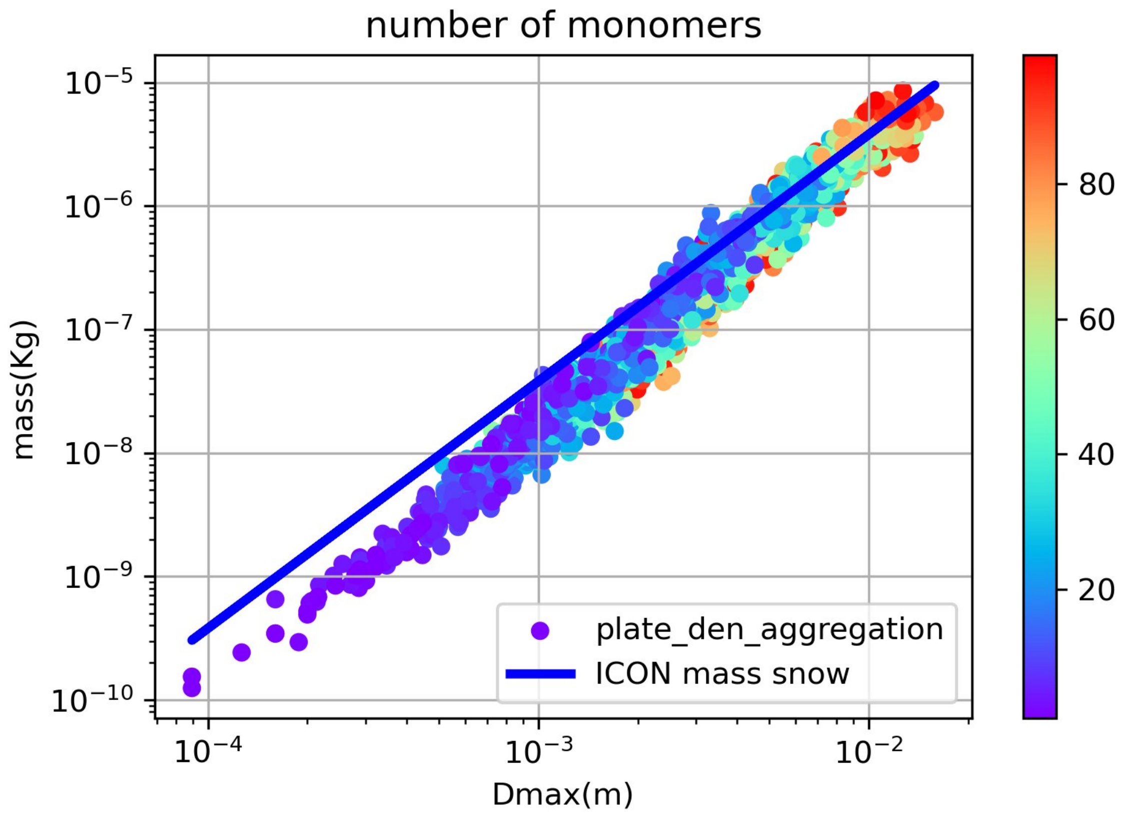
40 monomers of thin plate and dendrites



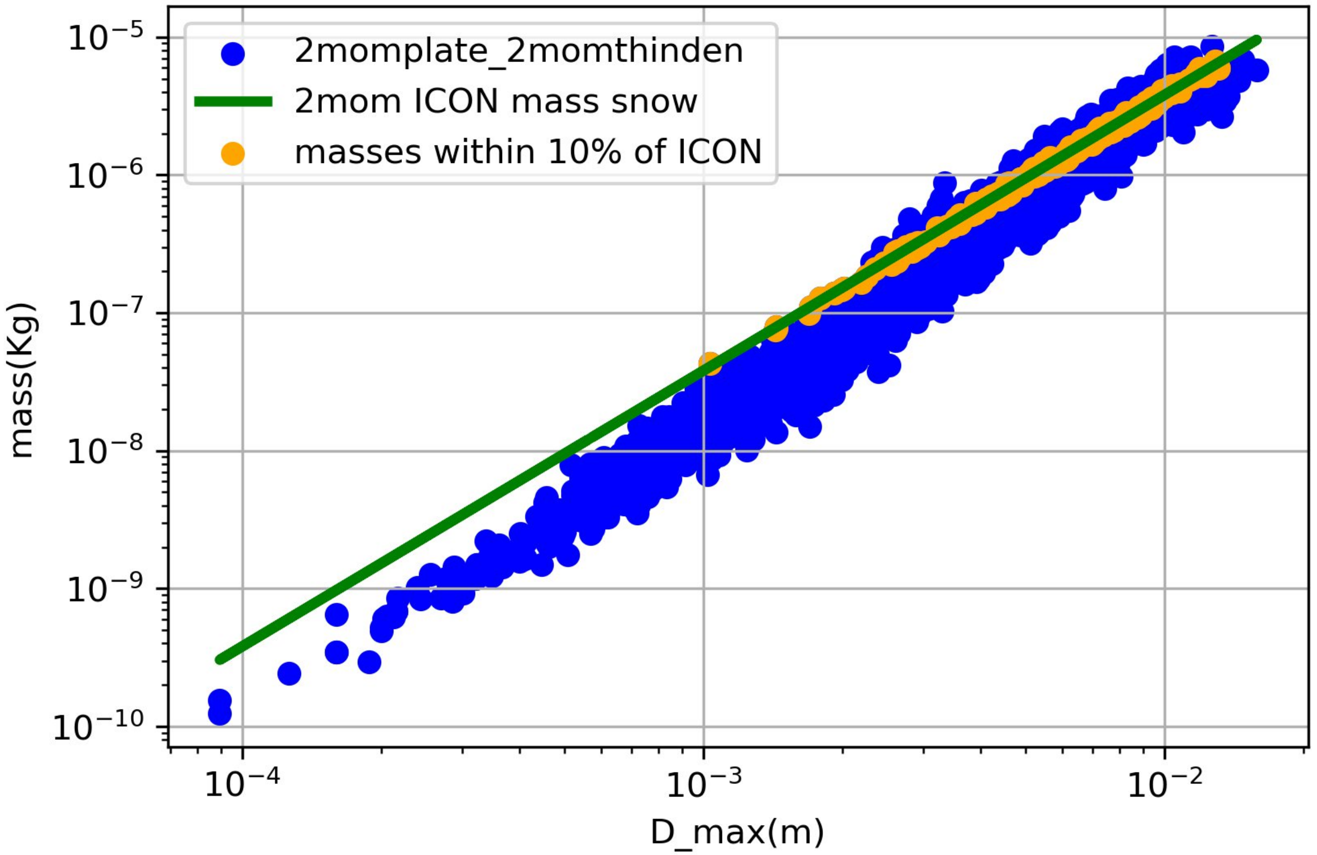
aggregates using plates (upto 0.5mm) and dendrites (for 2mom ICON microphysics)

ICON Dmin=50e-6m (50 um), Dmax=5cm



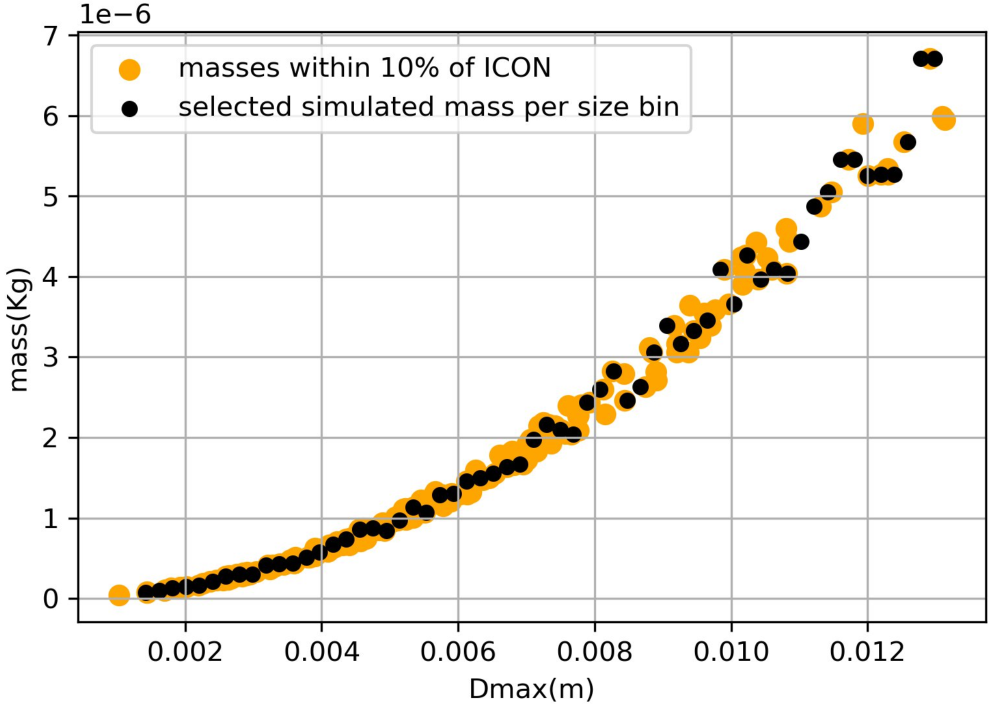


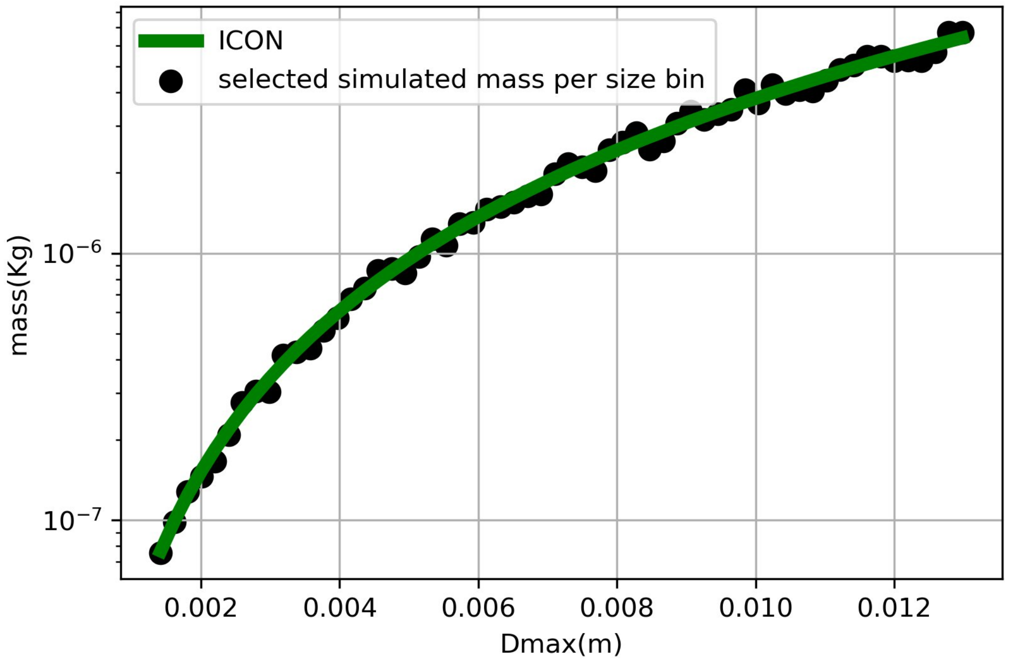
Selection of masses from simulated aggregates



aggregated masses within 10% of ICON 2mom masses for 1 to 100 monomers for size parameter 0.05 to 1 mm

mass values corresponding to each ICON size bin





ICON assumptions for snowflakes

Dmin = 50.0e-6 ! 50um and Dmax = 50.0e-3 ! 50mm

Divided into 256 linearly spaced size bins

around 70 linearly spaced ICON size bins are filled with snow aggregates for size 1mm to 2cm

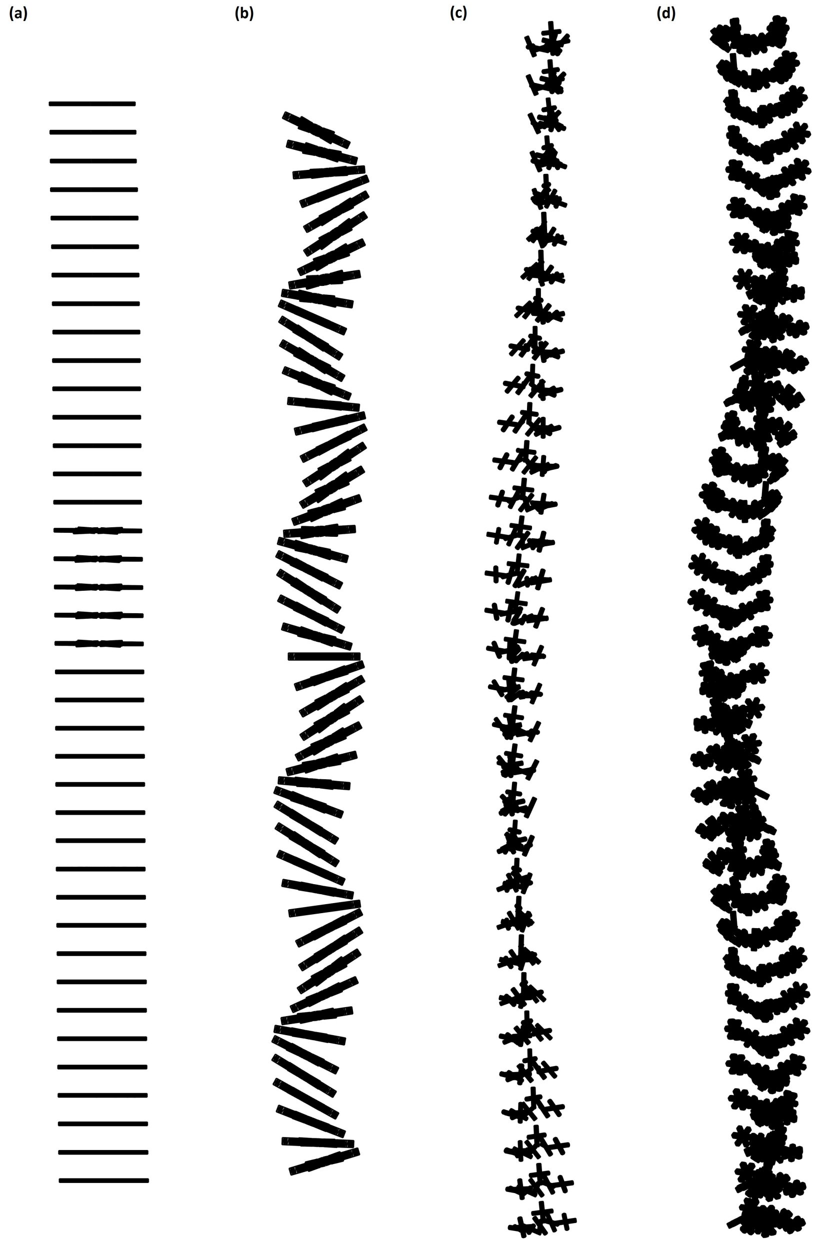
Scattering

Orientation averaging?

7D complex problem in Lab Reference Frame

$$\begin{bmatrix} E^{\text{sca}}_{\vartheta L}(r\hat{\mathbf{n}}^{\text{sca}}) \\ E^{\text{sca}}_{\varphi L}(r\hat{\mathbf{n}}^{\text{sca}}) \end{bmatrix} = \frac{\exp(\mathrm{i}k_1 r)}{r}\mathbf{S}^L(\hat{\mathbf{n}}^{\text{sca}}, \hat{\mathbf{n}}^{\text{inc}}; \alpha, \beta, \gamma)\begin{bmatrix} E^{\text{inc}}_{0\vartheta L} \\ E^{\text{inc}}_{0\varphi L} \end{bmatrix}$$

actually 5D *computationally* (scattering directions are for free)
and for radar (only backward and forward scattering)



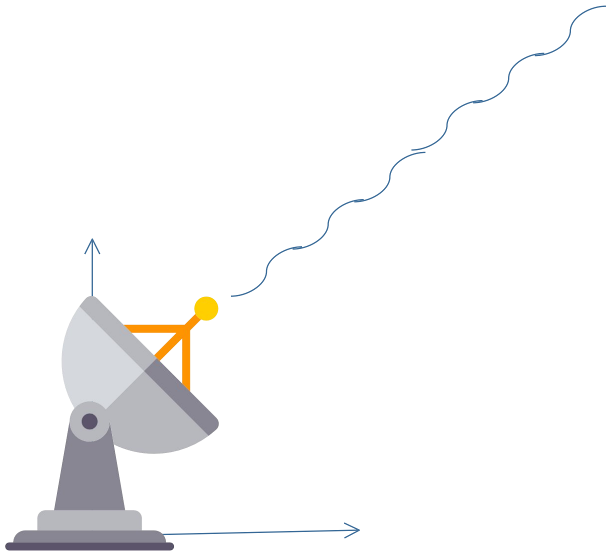
Mark McCorquodale

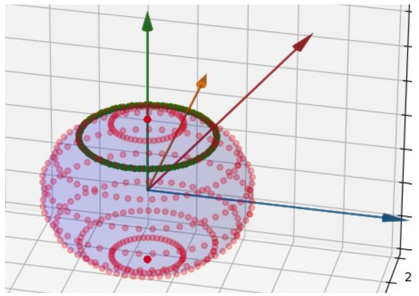
Orientation averaging?

7D complex problem in LRF

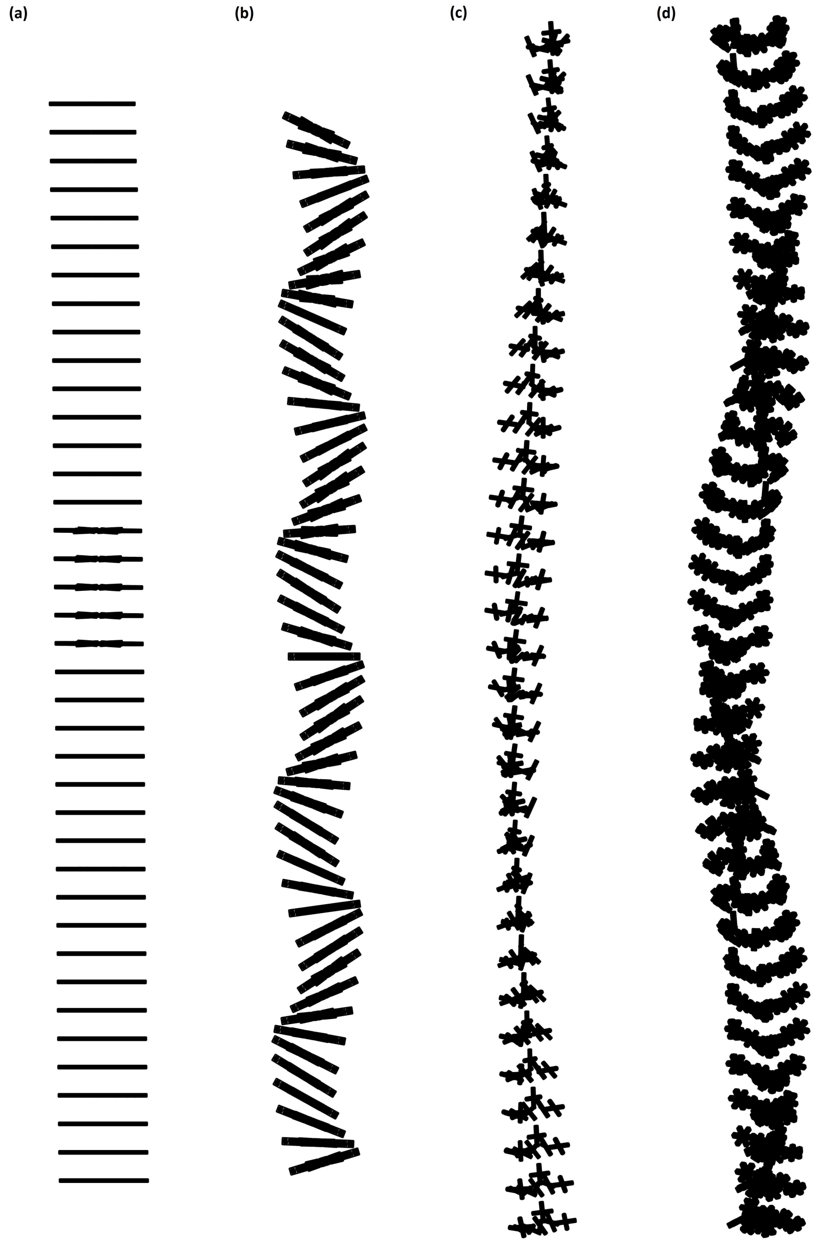
$$\begin{bmatrix} E^{\mathrm{sca}}_{\vartheta L}(r\hat{\mathbf{n}}^{\mathrm{sca}}) \\ E^{\mathrm{sca}}_{\varphi L}(r\hat{\mathbf{n}}^{\mathrm{sca}}) \end{bmatrix} = \frac{\exp(ik_1 r)}{r}\mathbf{S}^L(\hat{\mathbf{n}}^{\mathrm{sca}},\hat{\mathbf{n}}^{\mathrm{inc}};\alpha,\beta,\gamma)\begin{bmatrix} E^{\mathrm{inc}}_{0\vartheta L} \\ E^{\mathrm{inc}}_{0\varphi L} \end{bmatrix}$$

5D problem for radar (only backward and forward scattering)





2D if horizontally aligned (elevation, azimuth)



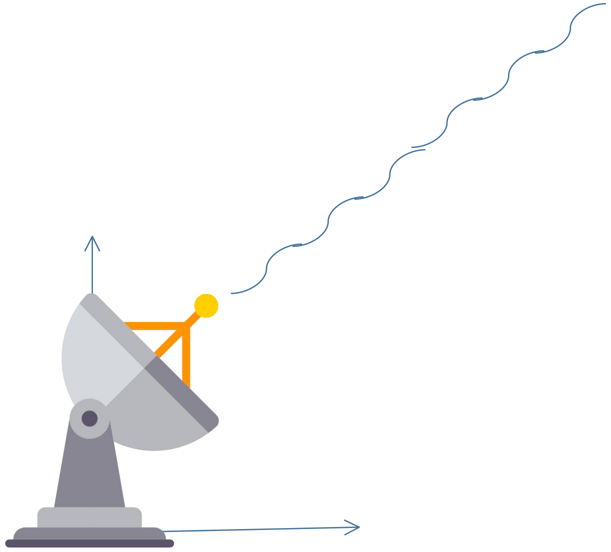
Mark McCorquodale

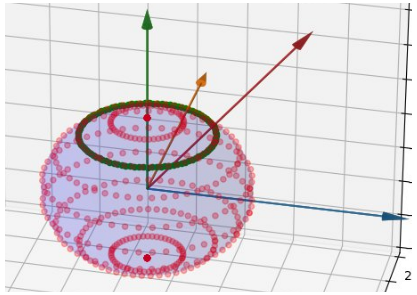
Orientation averaging?

7D complex problem in LRF

$$\begin{bmatrix} E^{\mathrm{sca}}_{\vartheta L}(r\hat{\mathbf{n}}^{\mathrm{sca}}) \\ E^{\mathrm{sca}}_{\varphi L}(r\hat{\mathbf{n}}^{\mathrm{sca}}) \end{bmatrix} = \frac{\exp(ik_1 r)}{r}\mathbf{S}^L(\hat{\mathbf{n}}^{\mathrm{sca}}, \hat{\mathbf{n}}^{\mathrm{inc}}; \alpha, \beta, \gamma) \begin{bmatrix} E^{\mathrm{inc}}_{0\vartheta L} \\ E^{\mathrm{inc}}_{0\varphi L} \end{bmatrix}$$

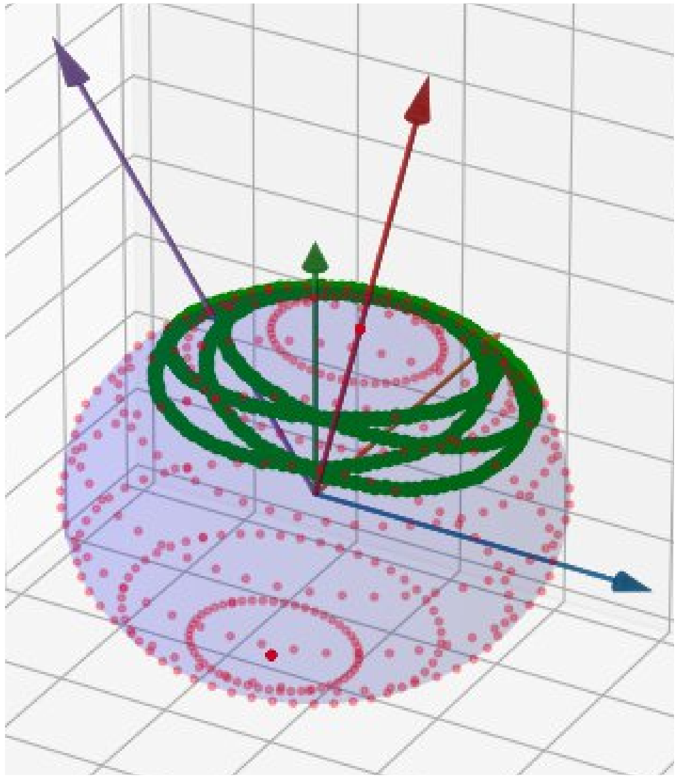
5D problem for radar (only backward and forward scattering)





2D if horizontally aligned (elevation, azimuth)

Constant tilt 10 deg



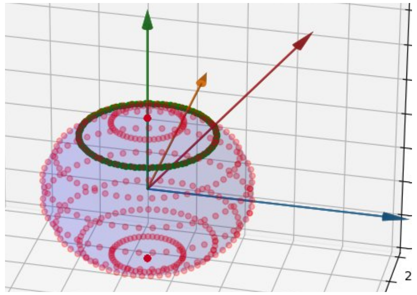
$$\alpha = avg \;\; \beta = 10 \;\; \gamma = avg$$

Orientation averaging?

7D complex problem in LRF

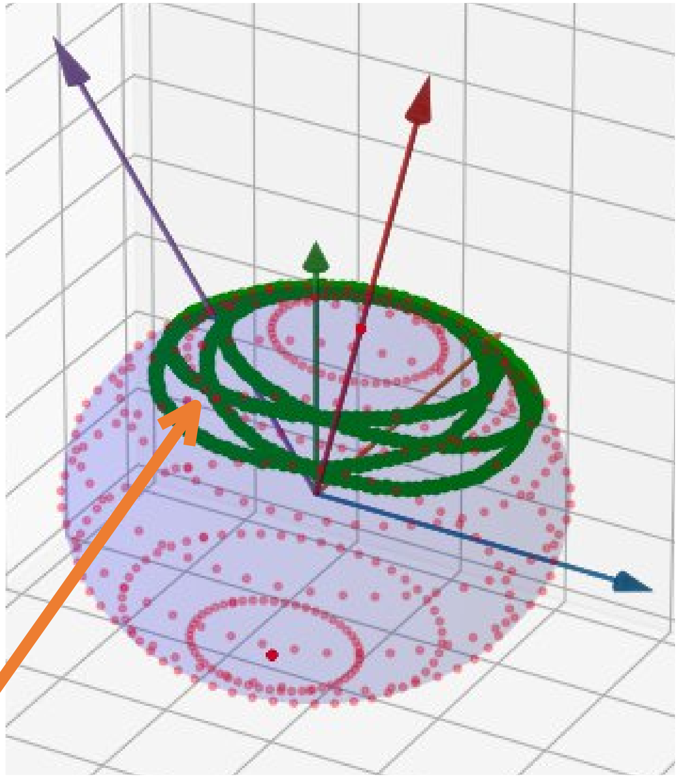
$$\begin{bmatrix} E^{\text{sca}}_{\vartheta L}(r\hat{\mathbf{n}}^{\text{sca}}) \\ E^{\text{sca}}_{\varphi L}(r\hat{\mathbf{n}}^{\text{sca}}) \end{bmatrix} = \frac{\exp(ik_1 r)}{r}\mathbf{S}^L(\hat{\mathbf{n}}^{\text{sca}}, \hat{\mathbf{n}}^{\text{inc}}; \alpha, \beta, \gamma)\begin{bmatrix} E^{\text{inc}}_{0\vartheta L} \\ E^{\text{inc}}_{0\varphi L} \end{bmatrix}$$

5D problem for radar (only backward and forward scattering)



2D if horizontally aligned (elevation, azimuth)

Constant tilt 10 deg



$\alpha = avg \ \beta = 10 \ \gamma = avg$

Wait! Am I revisiting the same point multiple times?

Orientation averaging?

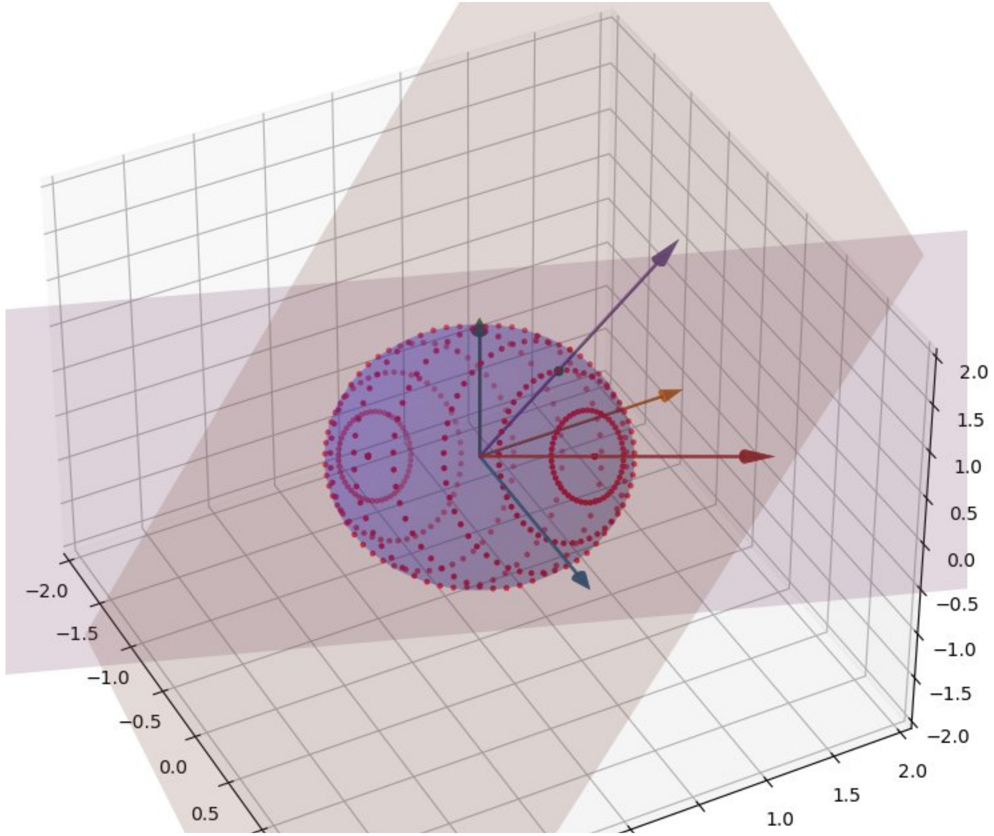
7D complex problem in LRF

$$\begin{bmatrix} E^{\text{sca}}_{\vartheta L}(r\hat{\mathbf{n}}^{\text{sca}}) \\ E^{\text{sca}}_{\varphi L}(r\hat{\mathbf{n}}^{\text{sca}}) \end{bmatrix} = \frac{\exp(\mathrm{i}k_1 r)}{r}\mathbf{S}^L(\hat{\mathbf{n}}^{\text{sca}}, \hat{\mathbf{n}}^{\text{inc}}; \alpha, \beta, \gamma)\begin{bmatrix} E^{\text{inc}}_{0\vartheta L} \\ E^{\text{inc}}_{0\varphi L} \end{bmatrix}$$

5D problem for radar (only backward and forward scattering)

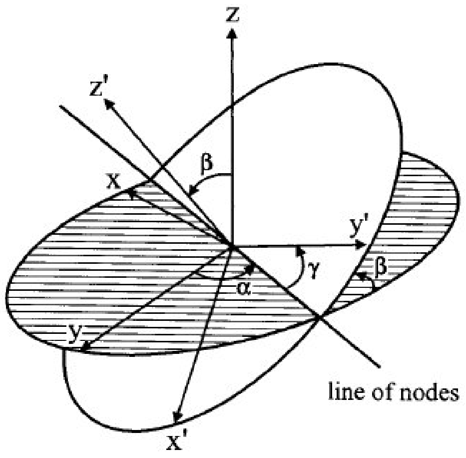
2D complex problem in
Particle Reference Frame

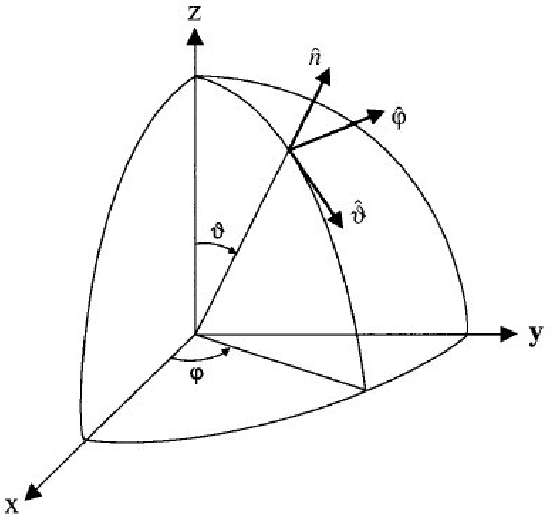
$$\begin{bmatrix} E^{\text{sca}}_{\vartheta P}(r\hat{\mathbf{n}}^{\text{sca}}) \\ E^{\text{sca}}_{\varphi P}(r\hat{\mathbf{n}}^{\text{sca}}) \end{bmatrix} = \frac{\exp(\mathrm{i}k_1 r)}{r}\mathbf{S}^P(\hat{\mathbf{n}}^{\text{sca}}, \hat{\mathbf{n}}^{\text{inc}})\begin{bmatrix} E^{\text{inc}}_{0\vartheta P} \\ E^{\text{inc}}_{0\varphi P} \end{bmatrix}$$



... as long as you know how to account for the rotate polarization plane...

Transform PRF to LRF





$$\mathbf{S}^L(\vartheta_L^{\text{sca}}, \varphi_L^{\text{sca}}; \vartheta_L^{\text{inc}}, \varphi_L^{\text{inc}}; \alpha, \beta, \gamma) = \hat{\rho}^{-1}(\hat{n}^{\text{sca}}; \alpha, \beta, \gamma) \times \mathbf{S}^P(\vartheta_P^{\text{sca}}, \varphi_P^{\text{sca}}; \vartheta_P^{\text{inc}}, \varphi_P^{\text{inc}})\hat{\rho}(\hat{n}^{\text{inc}}; \alpha, \beta, \gamma)$$

$$\hat{\rho}(\hat{n}; \alpha, \beta, \gamma) = \hat{\alpha}^{-1}(\vartheta_P, \varphi_P)\hat{\beta}(\alpha, \beta, \gamma)\hat{\alpha}(\vartheta_L, \varphi_L)$$

$$\hat{\beta}(\alpha, \beta, \gamma) = \begin{bmatrix} \cos\alpha\cos\beta\cos\gamma - \sin\alpha\sin\gamma & \sin\alpha\cos\beta\cos\gamma + \cos\alpha\sin\gamma & -\sin\beta\cos\gamma \\ -\cos\alpha\cos\beta\sin\gamma - \sin\alpha\cos\gamma & -\sin\alpha\cos\beta\sin\gamma + \cos\alpha\cos\gamma & \sin\beta\sin\gamma \\ \cos\alpha\sin\beta & \sin\alpha\sin\beta & \cos\beta \end{bmatrix}$$

$$\cos\vartheta_P = \cos\vartheta_L\cos\beta + \sin\vartheta_L\sin\beta\cos(\varphi_L - \alpha), \quad (9)$$

$$\cos\varphi_P = \frac{1}{\sin\vartheta_P}[\cos\beta\cos\gamma\sin\vartheta_L\cos(\varphi_L - \alpha) + \sin\gamma\sin\vartheta_L\sin(\varphi_L - \alpha) - \sin\beta\cos\gamma\cos\vartheta_L], \quad (10)$$

$$\sin\varphi_P = \frac{1}{\sin\vartheta_P}[-\cos\beta\sin\gamma\sin\vartheta_L\cos(\varphi_L - \alpha) + \cos\gamma\sin\vartheta_L\sin(\varphi_L - \alpha) + \sin\beta\sin\gamma\cos\vartheta_L]. \quad (11)$$

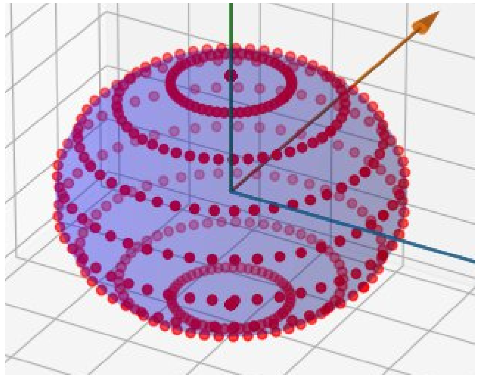
$$\hat{\alpha}(\vartheta, \varphi) = \begin{bmatrix} \cos\vartheta\cos\varphi & -\sin\varphi \\ \cos\vartheta\sin\varphi & \cos\varphi \\ -\sin\vartheta & 0 \end{bmatrix},$$

$$\hat{\alpha}^{-1}(\vartheta, \varphi) = \begin{bmatrix} \cos\vartheta\cos\varphi & \cos\vartheta\sin\varphi & -\sin\vartheta \\ -\sin\varphi & \cos\varphi & 0 \end{bmatrix}$$

Michael Mishchenko

How to sample the sphere

Regular “lat-lon” grids are easy to implement but inefficient

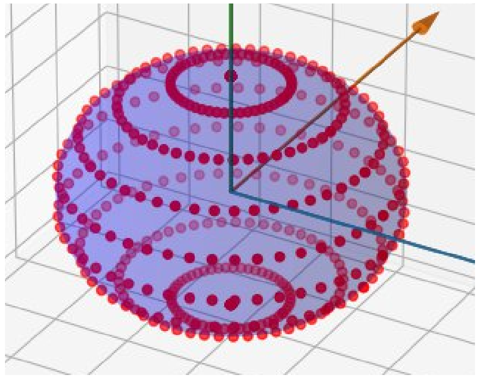


inefficient
great for horiz. aligned

How to sample the sphere

Regular “lat-lon” grids are easy to implement but inefficient

icosphere grids are equally spaced



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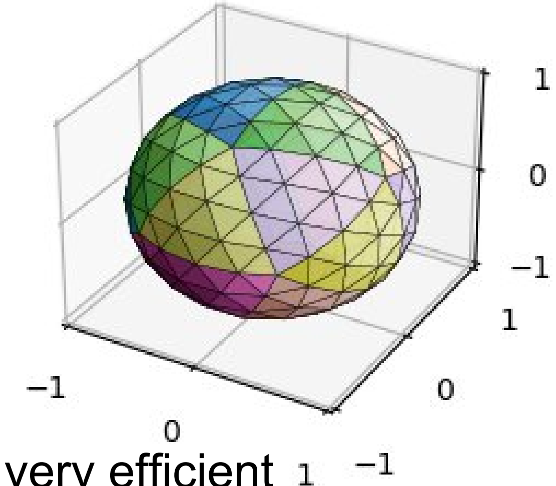


very efficient
not great 4 horiz. aligned

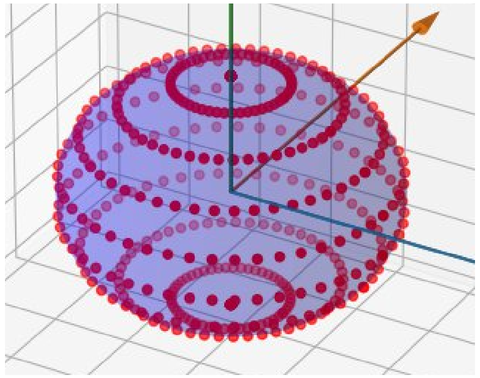
How to sample the sphere

Regular “lat-lon” grids are easy to implement but inefficient

icosphere grids are equally spaced

Taking power of 2 subdivisions of the seed icosahedron we can improve resolution while “recycling” previous calculations

8 subdivisions:
- **642 nodes**
- 1.34 deg angular separation



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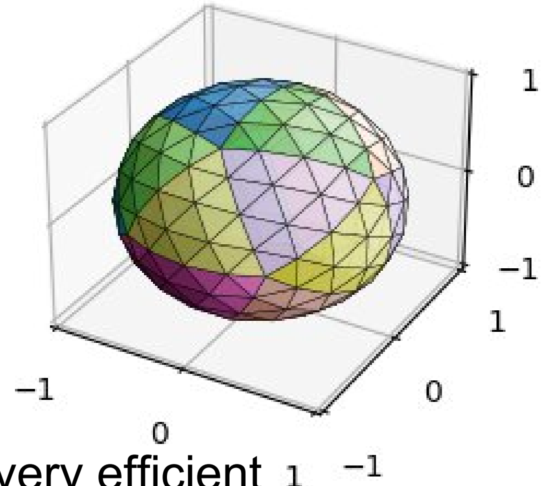

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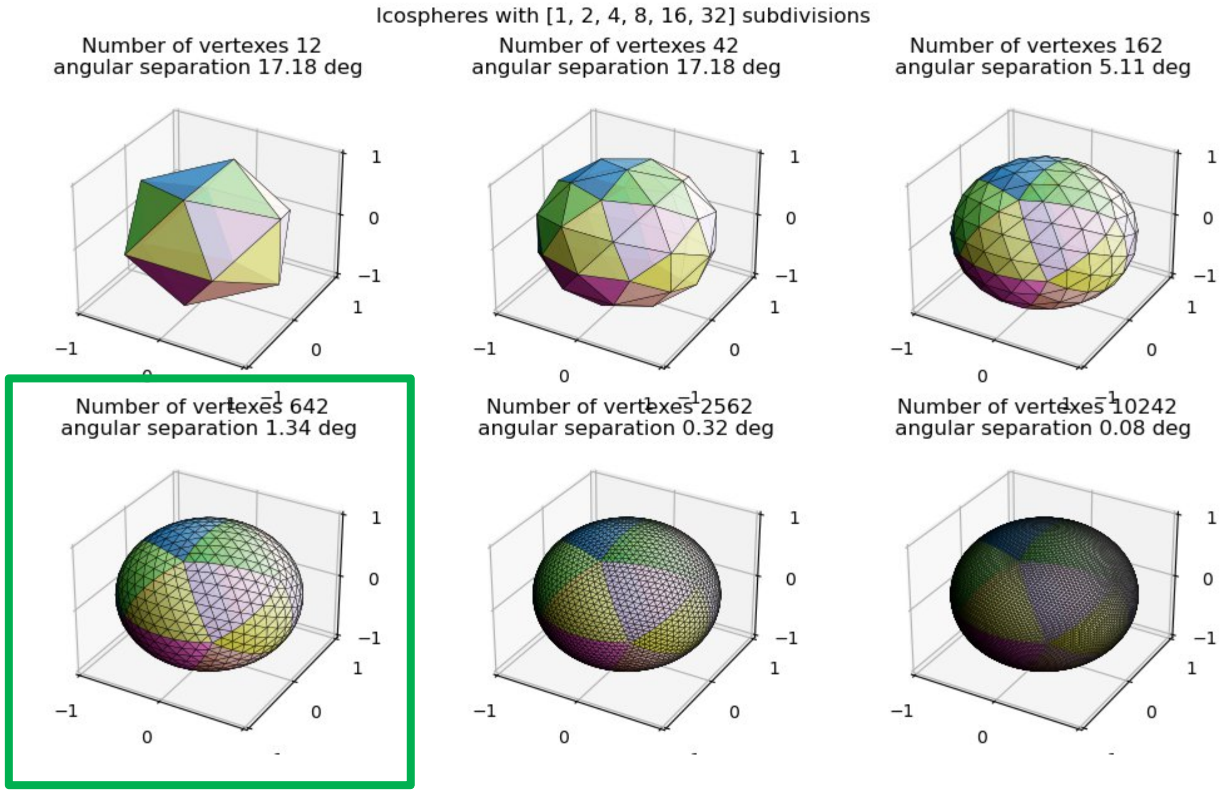

How to sample the sphere

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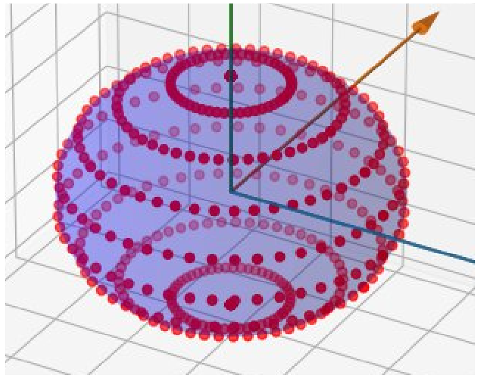
would have been **36k nodes** on lat-lon!!



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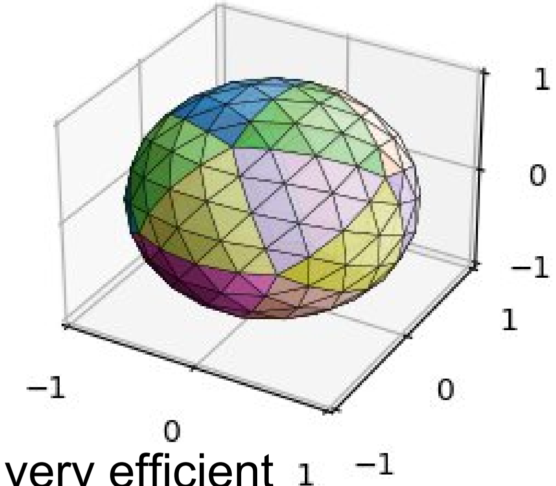

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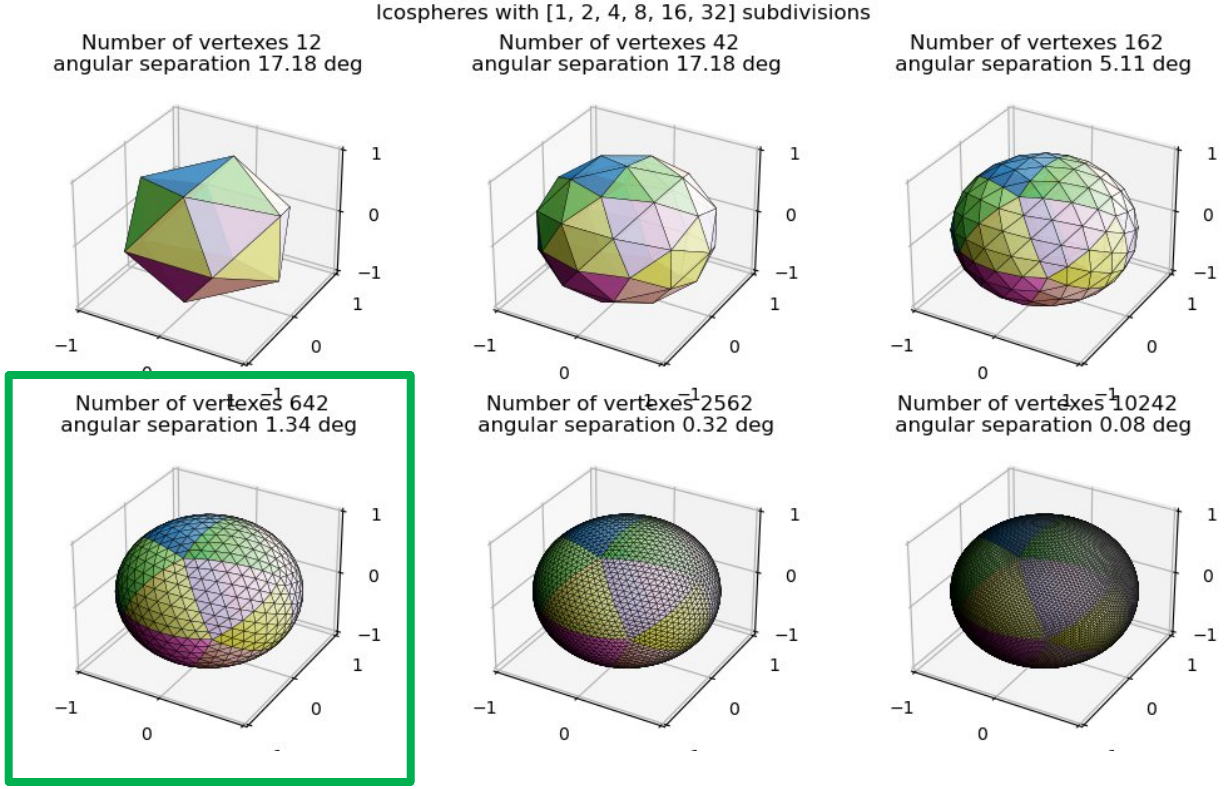
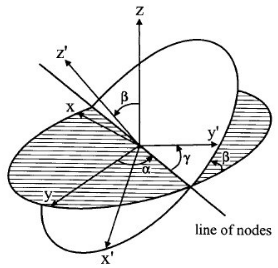


Preliminary results for single crystals

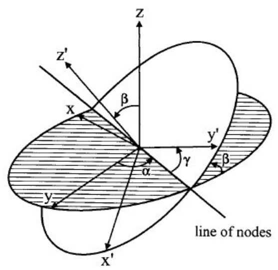


$$\hat{Z}(el) = \int f_\alpha(\alpha) f_\beta(\beta) f_\gamma(\gamma) \underline{Z(\alpha, \beta, \gamma, el)}$$

4D again!! but..

$$f_\alpha(\alpha) = f_\gamma(\gamma) = \frac{1}{2\pi}$$

Preliminary results for single crystals



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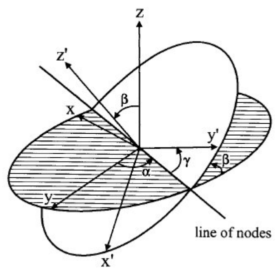
$$< Z >_{aro} (el, \beta) = \int f_\alpha(\alpha) f_\gamma(\gamma) Z(\alpha, \beta, \gamma, el)$$

2D !!

Preliminary results for single crystals



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2D !!

$$\hat{Z}(el) = \int f_\beta(\beta) < Z >_{aro} (el, \beta)$$