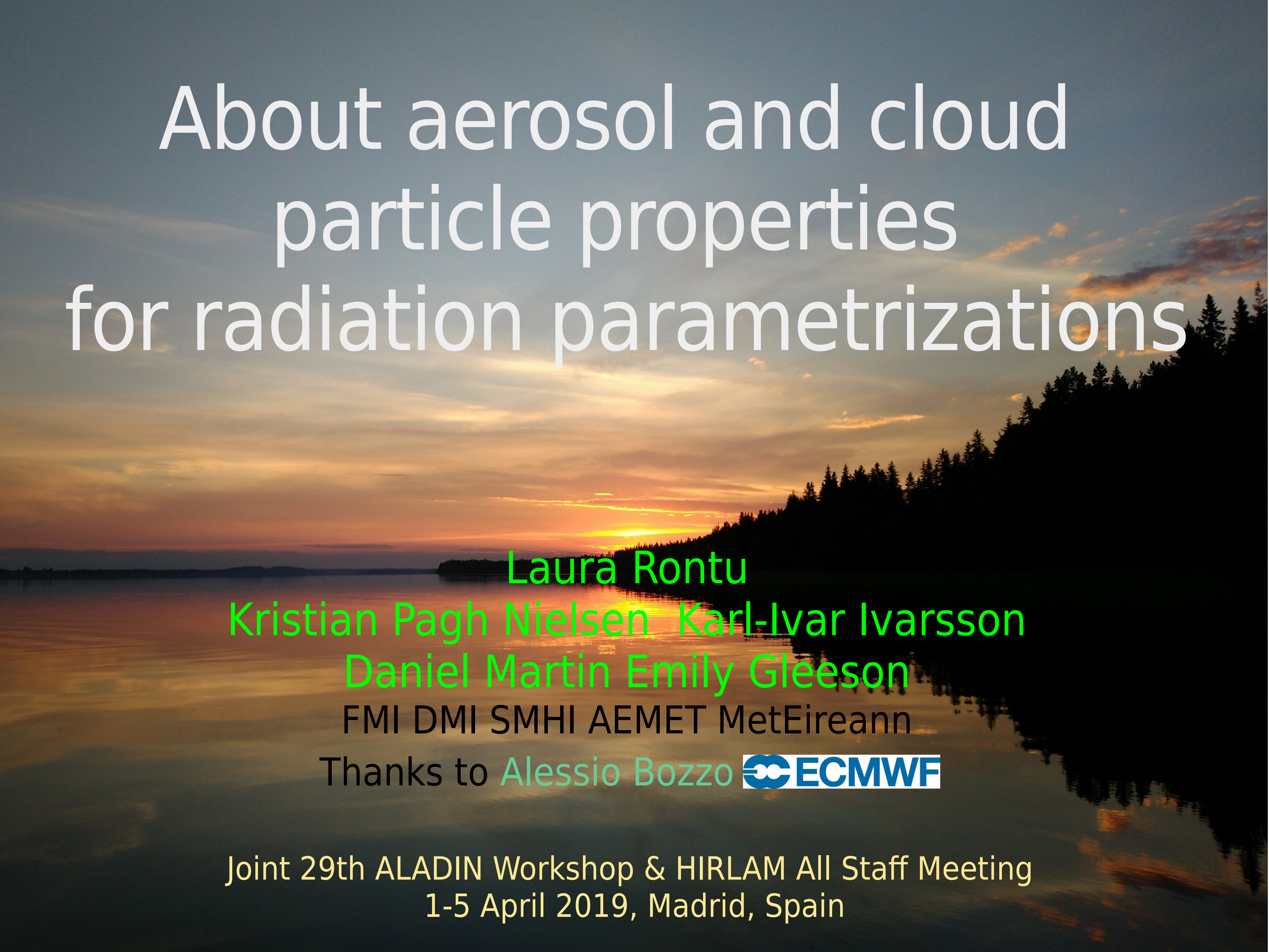
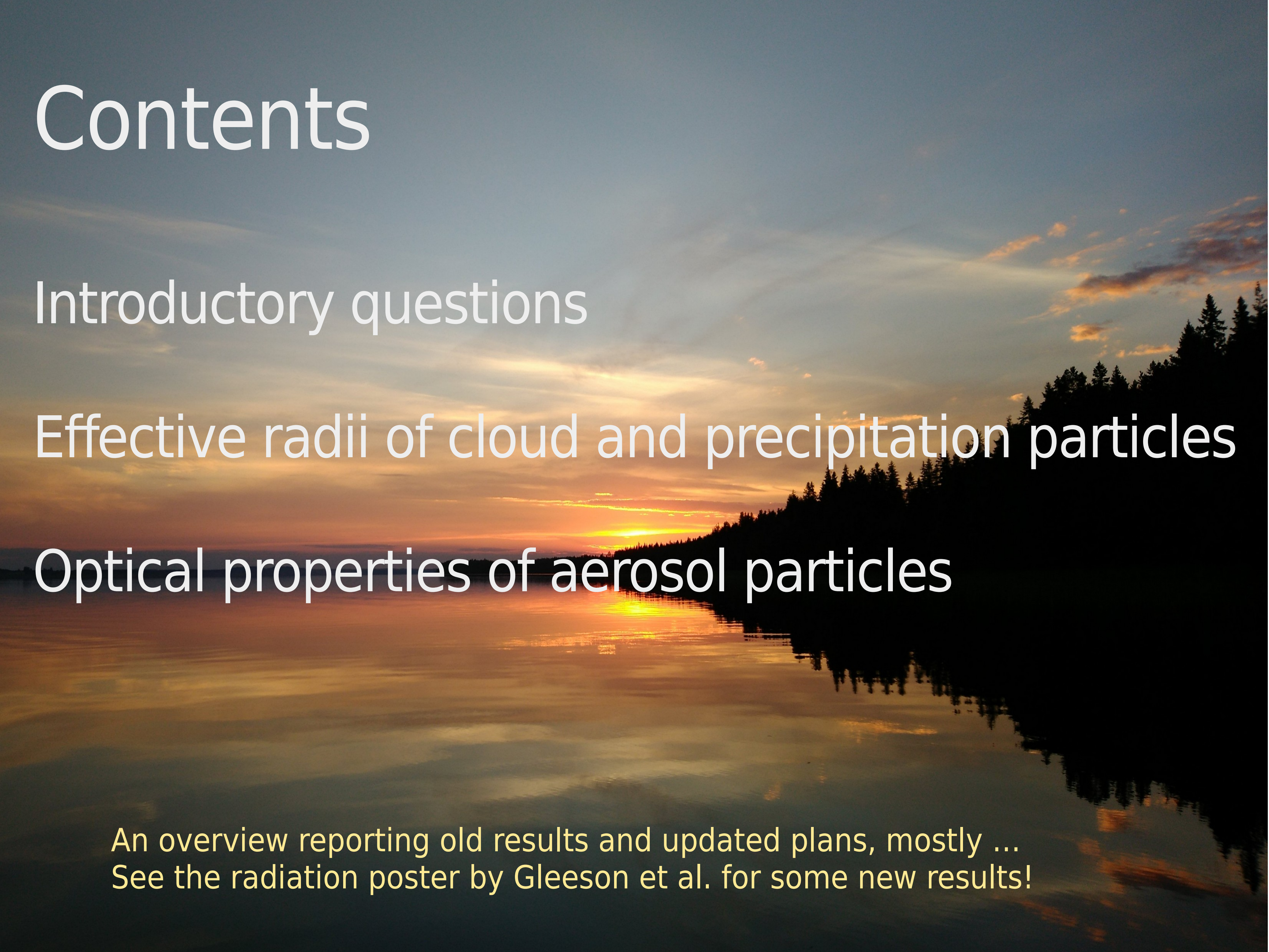


About aerosol and cloud particle properties for radiation parametrizations

Laura Rontu
Kristian Pagh Nielsen Karl-Ivar Ivarsson
Daniel Martin Emily Gleeson
FMI DMI SMHI AEMET MetEireann

Thanks to Alessio Bozzo ECMWF

Joint 29th ALADIN Workshop & HIRLAM All Staff Meeting
1-5 April 2019, Madrid, Spain



Contents

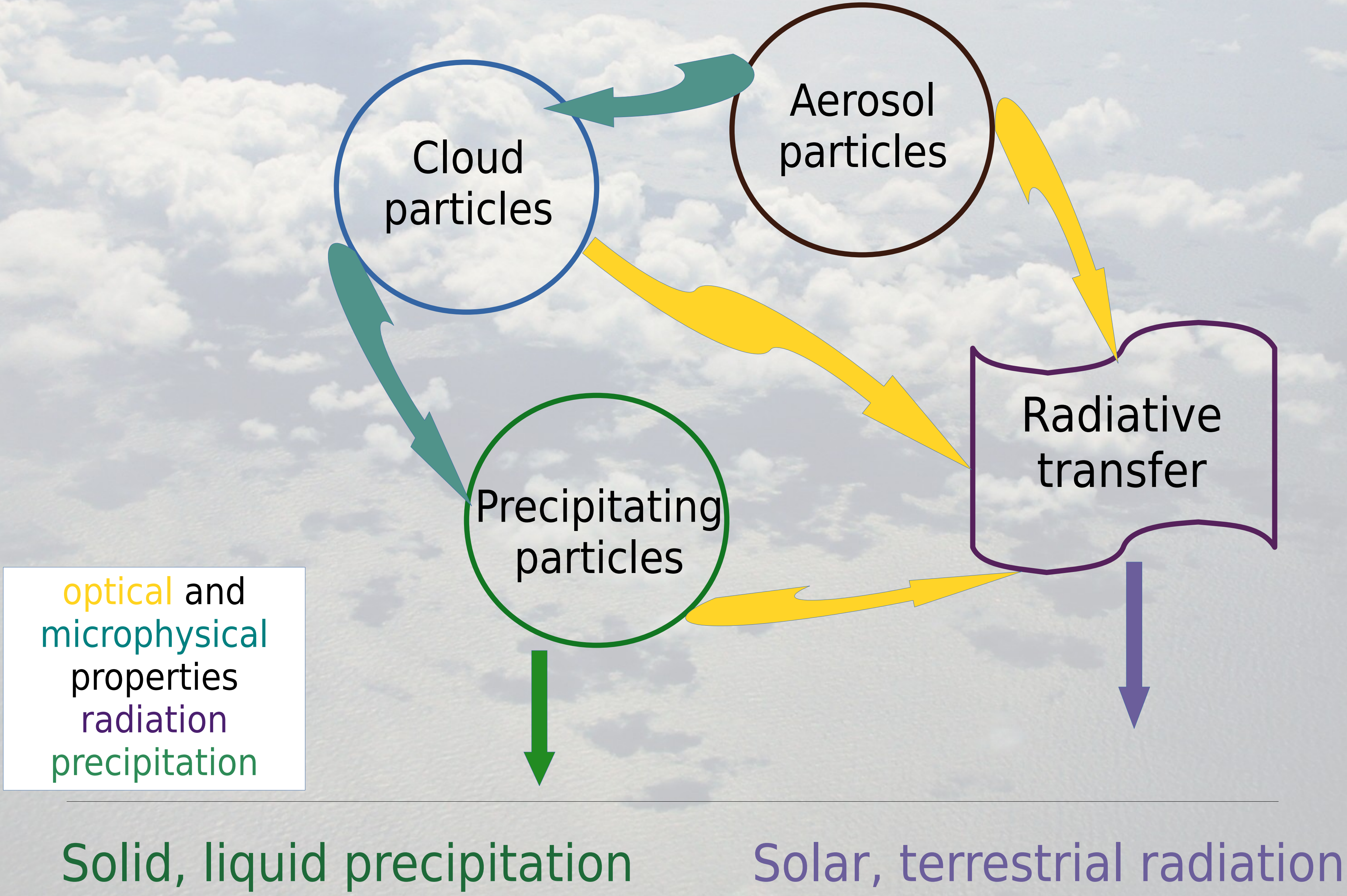
Introductory questions

Effective radii of cloud and precipitation particles

Optical properties of aerosol particles

An overview reporting old results and updated plans, mostly ...
See the radiation poster by Gleeson et al. for some new results!

Parametrization of microphysics and optical properties



Cloud particles

Aerosol particles

Precipitating particles

Radiative transfer

optical and
microphysical
properties
radiation
precipitation

Solid, liquid precipitation

Solar, terrestrial radiation

What is the needed level of complexity?

Can we learn from the evolution of the parametrizations during the last 20 years?

Does everything correspond to observations?

Observation campaigns, air-borne measurements, satellite data?

What are the estimated uncertainties of our schemes?

Is the chain consistent?

Should the parametrizations benefit from each other, be consistent, avoid double work?

What can be externalized, shared, made more transparent and modular in the model code?

* * *

Parametrization of the radiative transfer

Solar (SW) radiation: scattering and absorption
Terrestrial (LW) radiation: emission, absoption, scattering

In the air:
Gas molecules
Cloud droplets and crystals
Aerosol particles

Physico-chemical properties:
Mass concentration
Size
Shape
Composition

Grid-scale variables:
T, q_v, q_i, q_l, q_s, q_g
Aerosol (concentration)
Radiative fluxes

Optical properties:
Optical depth
Single scattering albedo
Asymmetry factor

Surface-atmosphere radiative interactions

Surface albedo and emissivity
Orographic radiation effects

Characteristics of surface types
Surface elevation

Accepted (practical) postulates

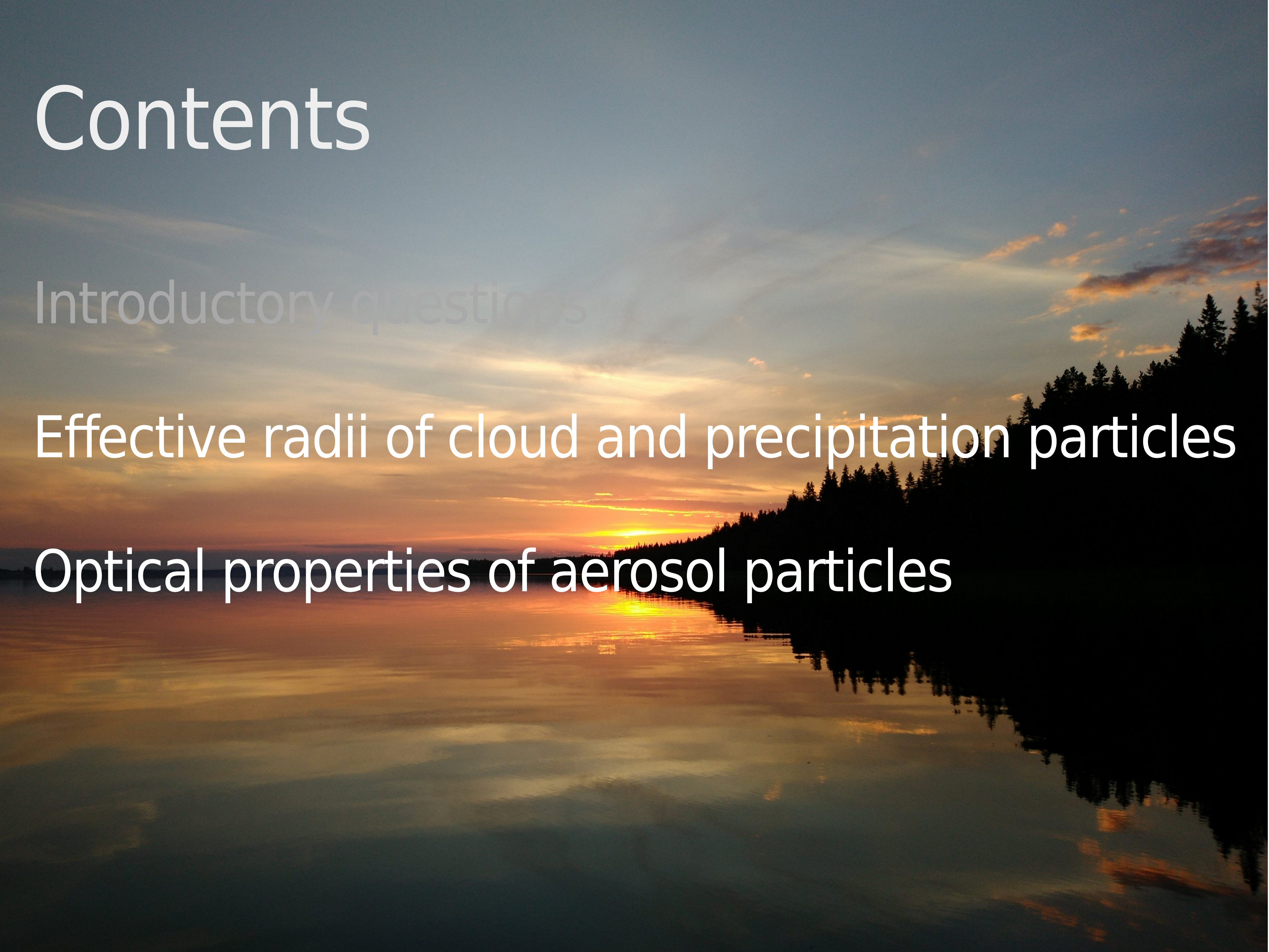
A NWP model should grow its own clouds and create the precipitation, using external aerosol data as a starting point

* * *

A NWP model should not grow its own aerosol particles but take their concentration and optical properties from somewhere else

* * *

The radiation parametrizations should use ready-made physical properties of cloud particles and optical properties of the aerosol particles



Contents

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Levels of complexity HIRLAM ⇒ HARMONIE

Cloud microphysics		**Radiative transfer**	**Year**
$RH > RH_{cr}$	⇒	3D cloud fraction	1990
→ parametrized precipitation			
→ diagnostic 2D cloud cover			
+ prognostic cloud condensate	⇒	cloud condensate	1995
	⇒	diagnostic fraction of ice	
		effective/equivalent radii	1999
+ prognostic q_{ice}, q_{liq}	⇒	q_{ice}, q_{liq}	> 2000
+ prognostic q_{rain}, q_{snow}, q_{grau}		–	2005
→ prognostic precipitation			
	⇒	$(q_{solid} = q_{ice} + q_{snow} + q_{grau})$	2015
assumed $5 \times q_{xx}$ size, shape	⇒	$5 \times r_{e,xx}$	suggested 2018

Effective (equivalent) radius of cloud particles

Radiation needs:
number concentration and the cross section area per unit volume of the particles

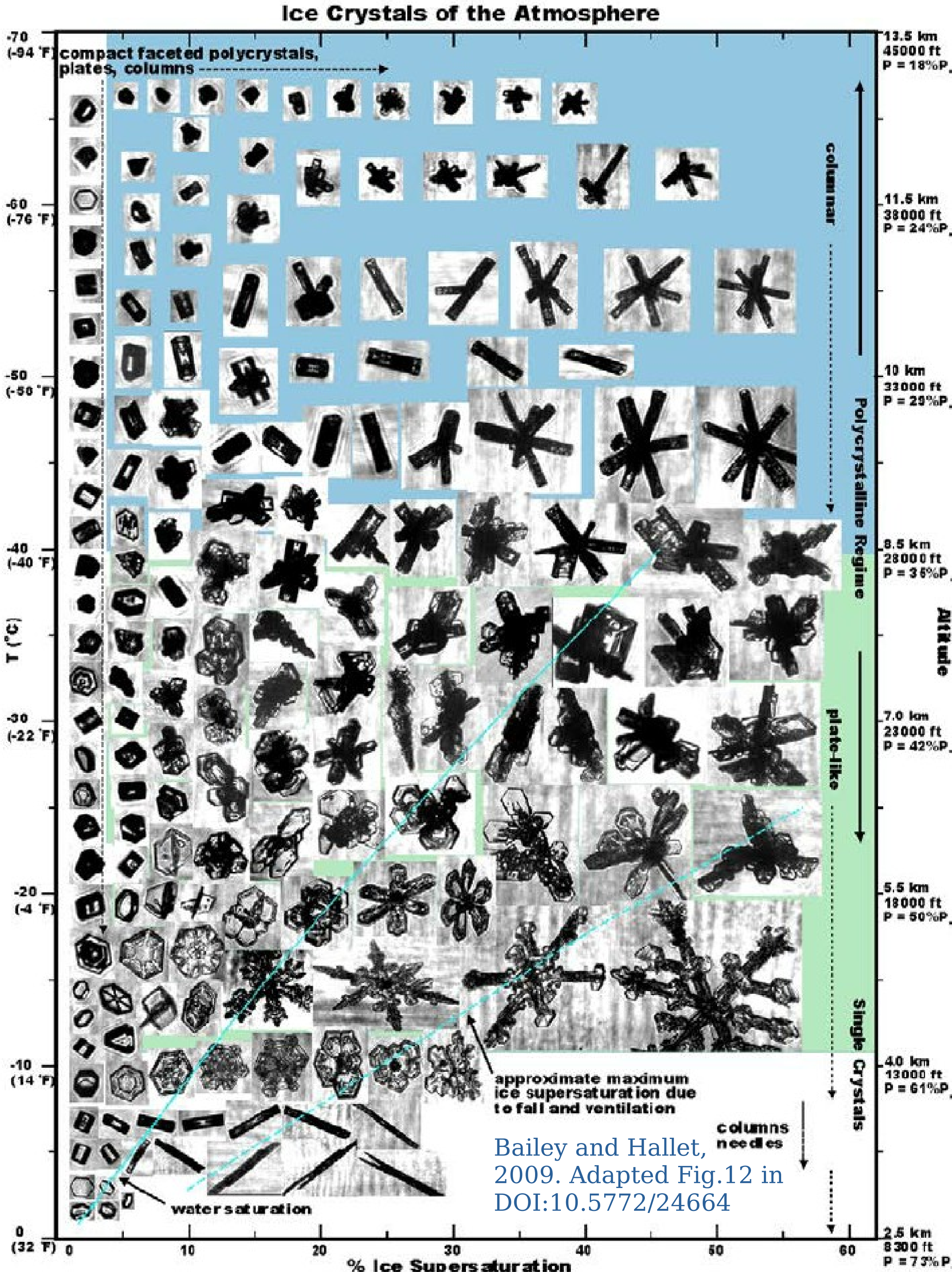
* * *

Effective (equivalent) radius aims at combination of phase, volume and shape of cloud particles for radiation on empirical basis

* * *

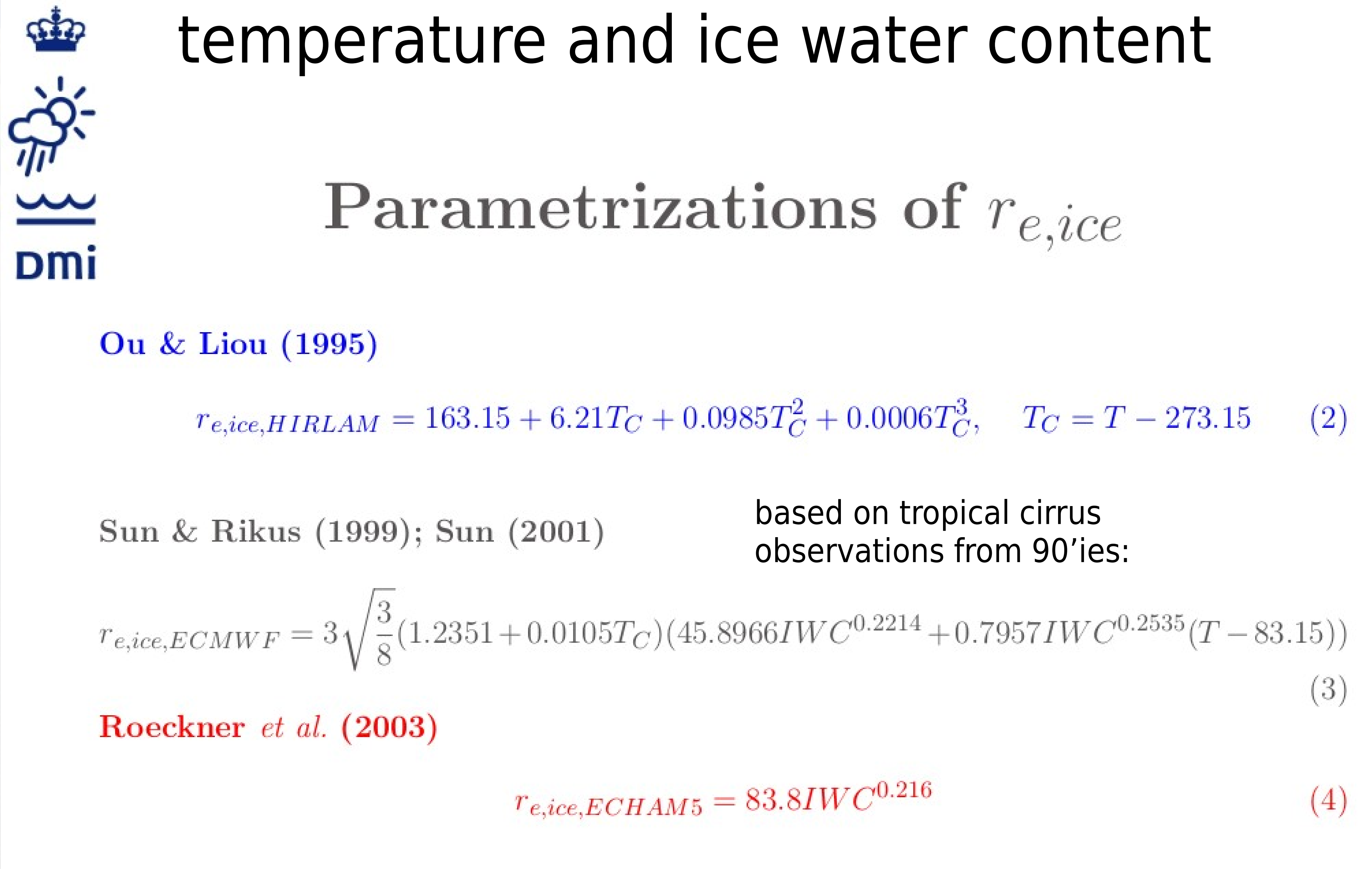
The zoo of observed ice particles in the atmosphere, in-cloud and precipitating

→



Bailey and Hallet, 2009. Adapted Fig.12 in DOI:10.5772/24664

Empirical equivalent radii as functions of temperature and ice water content



Parametrizations of $r_{e,ice}$

Ou & Liou (1995)

$$r_{e,ice,HIRLAM} = 163.15 + 6.21T_C + 0.0985T_C^2 + 0.0006T_C^3, \quad T_C = T - 273.15 \qquad (2)$$

Sun & Rikus (1999); Sun (2001)

based on tropical cirrus
observations from 90'ies:

$$r_{e,ice,ECMWF} = 3\sqrt{\frac{3}{8}}(1.2351 + 0.0105T_C)(45.8966IWC^{0.2214} + 0.7957IWC^{0.2535}(T - 83.15)) \qquad (3)$$

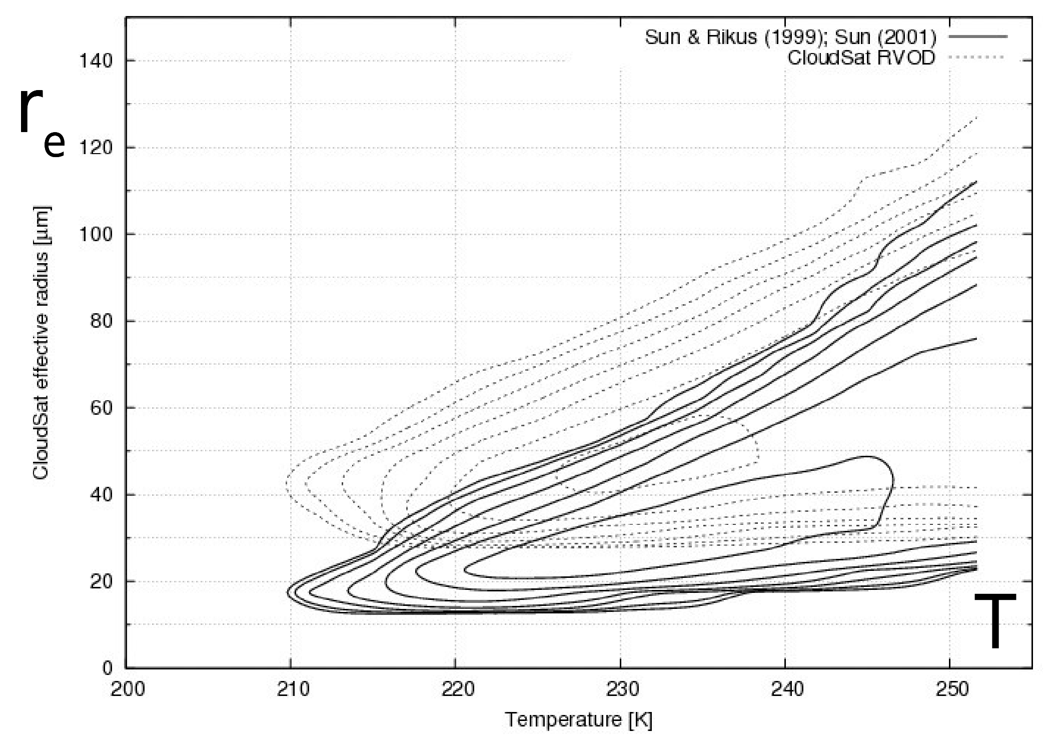
Roeckner *et al.* (2003)

$$r_{e,ice,ECHAM5} = 83.8IWC^{0.216} \qquad (4)$$

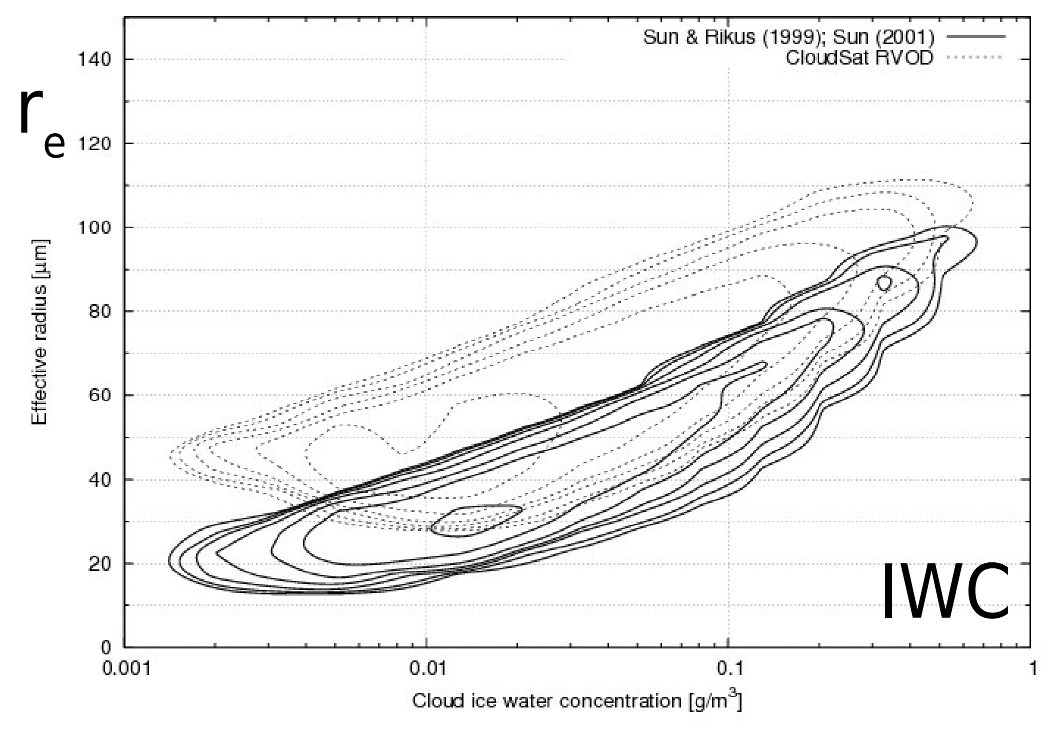
From Kristian Pagh Nielsen's presentation in 2011 ALADIN Ẁorkshop/HIRLAM ASM

Sun-Rikus-Sun r_e v.s. CloudSat r_e with respect to

Temperature →



Ice water content →



Ice cloud microphysical parameters from CloudSat millimeter-wave radar and temperature from the North Atlantic in the days following the 2011 Eyjafjallajökull eruption.

CloudSat: http://www.cloudsat.cira.colostate.edu/data-products/level-2b/2b-cwc-rvod Austin et al., 2009 https://doi.org/10.1029/2008JD010049

How is r_e applied in radiative transfer calculations?

IFSRADIA (also the new ecrad):
create cloud optical properties using a dedicated scheme

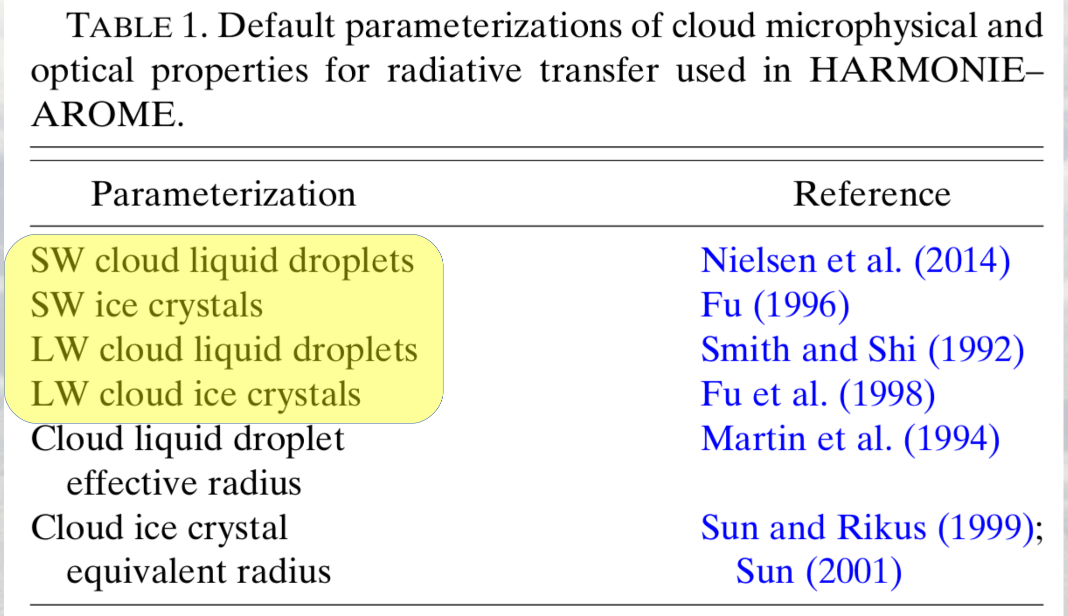


TABLE 1. Default parameterizations of cloud microphysical and optical properties for radiative transfer used in HARMONIE–AROME.

Parameterization	Reference
SW cloud liquid droplets	Nielsen et al. (2014)
SW ice crystals	Fu (1996)
LW cloud liquid droplets	Smith and Shi (1992)
LW cloud ice crystals	Fu et al. (1998)
Cloud liquid droplet effective radius	Martin et al. (1994)
Cloud ice crystal equivalent radius	Sun and Rikus (1999); Sun (2001)

HLRADIA:
modify coefficients to fit LW emissivity and SW transmissivity to the results of detailed reference radiative transfer calculations

Mind the consistency between the parametrizations of r_e and optical properties (e.g. the assumed crystal shapes – spherical, hexagonal ...)!

More questions ...

How sensitive to r_e and how uncertain are the resulting radiative fluxes?

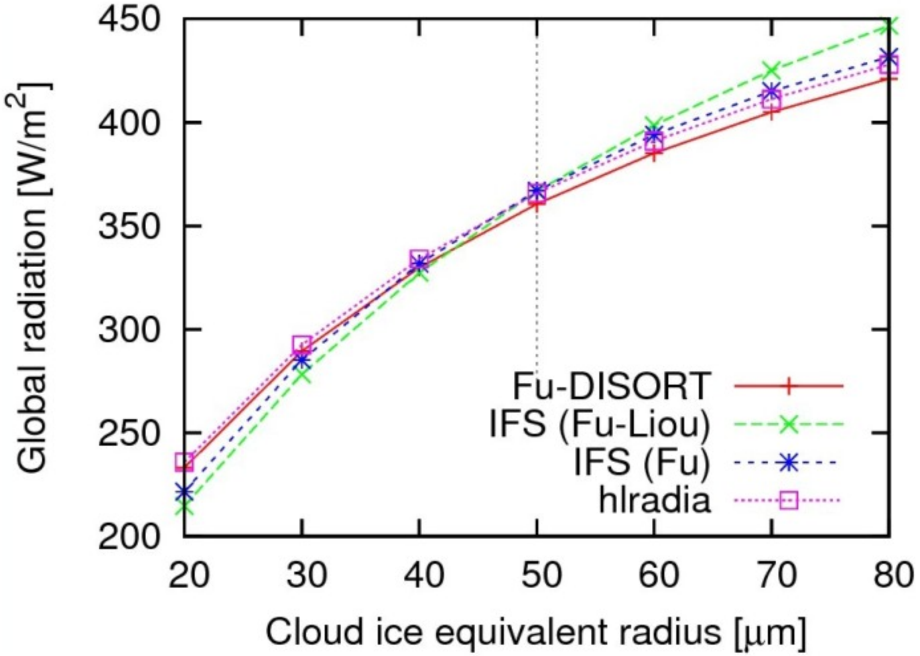


Figure 24. As for Fig. 1 but for varying $r_{\mathrm{e,ice}}$ and fixed surface albedo = 0.18 (experiment 10). The vertical dashed line at 50 µm marks the $r_{\mathrm{e,ice}}$ value used in experiments 8 and 9.

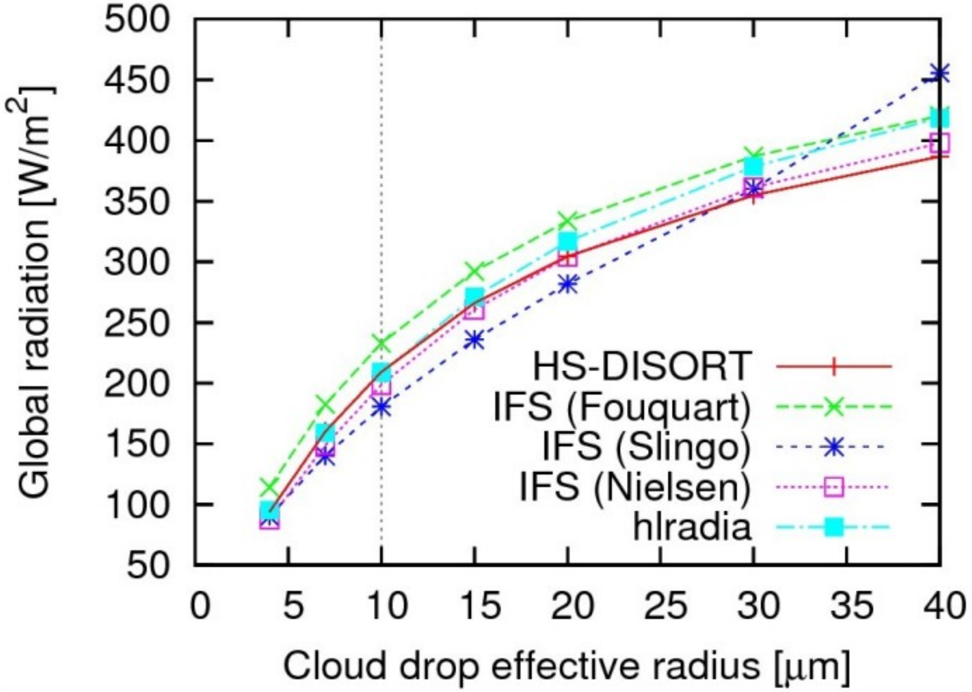


Figure 15. As for Fig. 10 but for varying $r_{\mathrm{e,liq}}$ (experiment 5). The vertical dashed line at 10 µm marks $r_{\mathrm{e,liq}}$ used in experiment 4, 6 and 7.

Nielsen et al. https://doi.org/10.5194/gmd-7-1433-2014

More questions ...

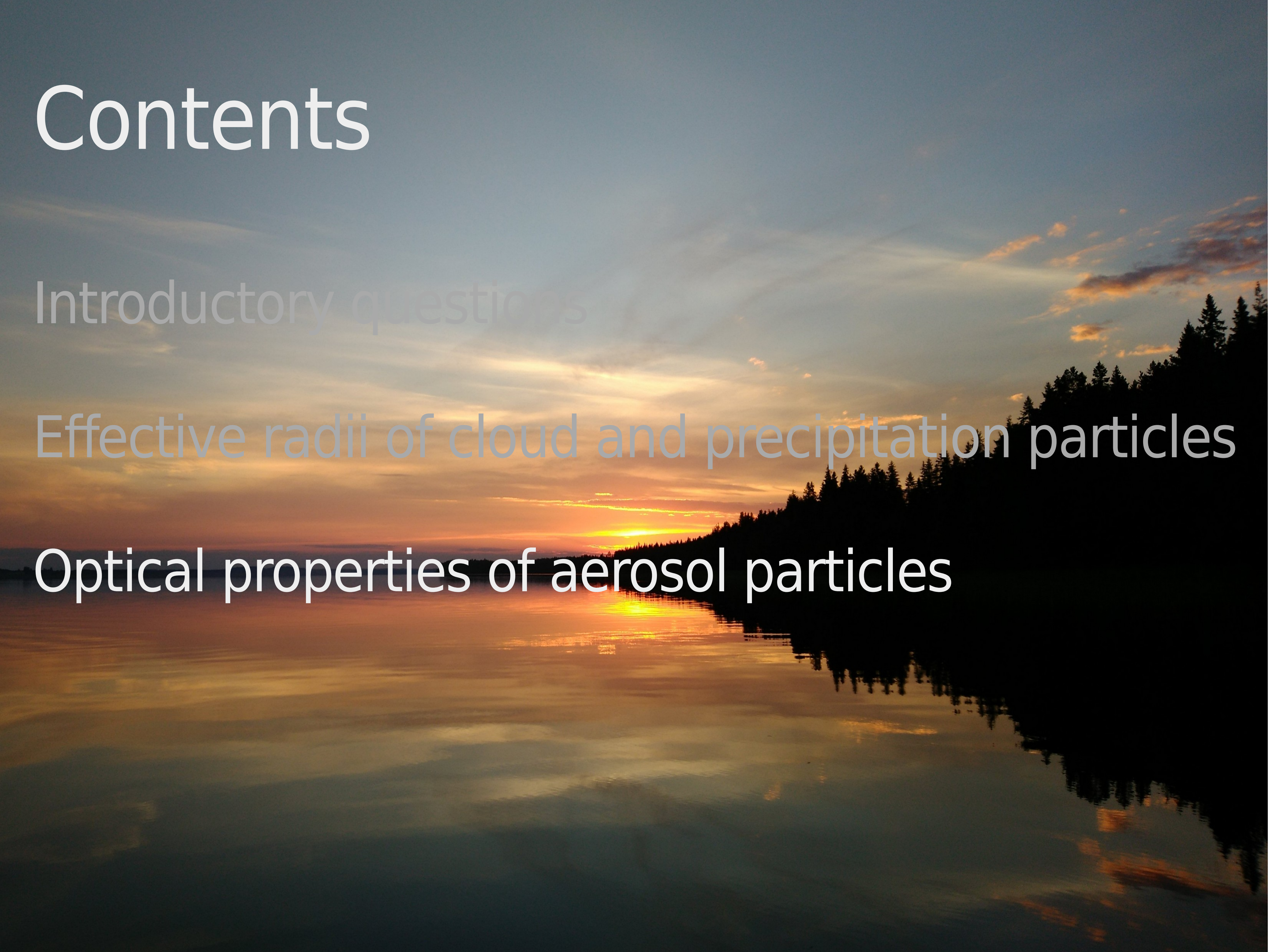
The particle equivalent size increases with almost an order of magnitude when a super-cooled cloud droplet freezes. This increases the cloud SW transmittance with roughly 50% → phase is critical!

Would the cloud-precipitation microphysics provide better effective radii to calculate radiative transfer through cloud, that consists of liquid droplets and ice crystals,
precipitating rain drops, snow flakes, graupels?

How to apply/weight the 5 new effective radii to parametrize radiative transfer in the in-cloud mixture of these particles?

The other way round: would the cloud-precipitation microphysics benefit from r_e applied in radiative transfer calculations?

See also the radiation poster Gleeson et al.!



Contents

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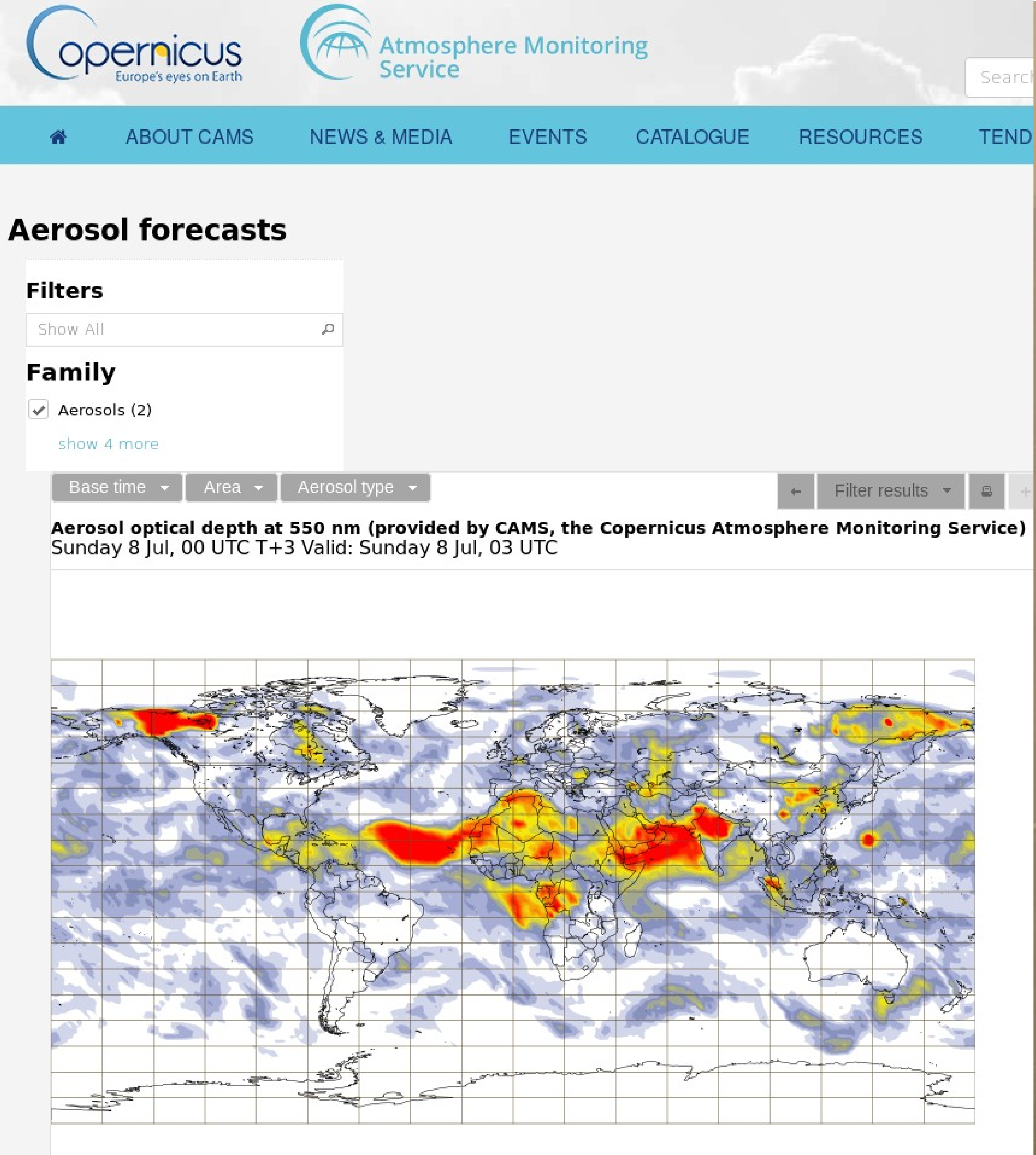


Aerosol forecasts

Filters

Show All

Family

☑ Aerosols (2)

show 4 more

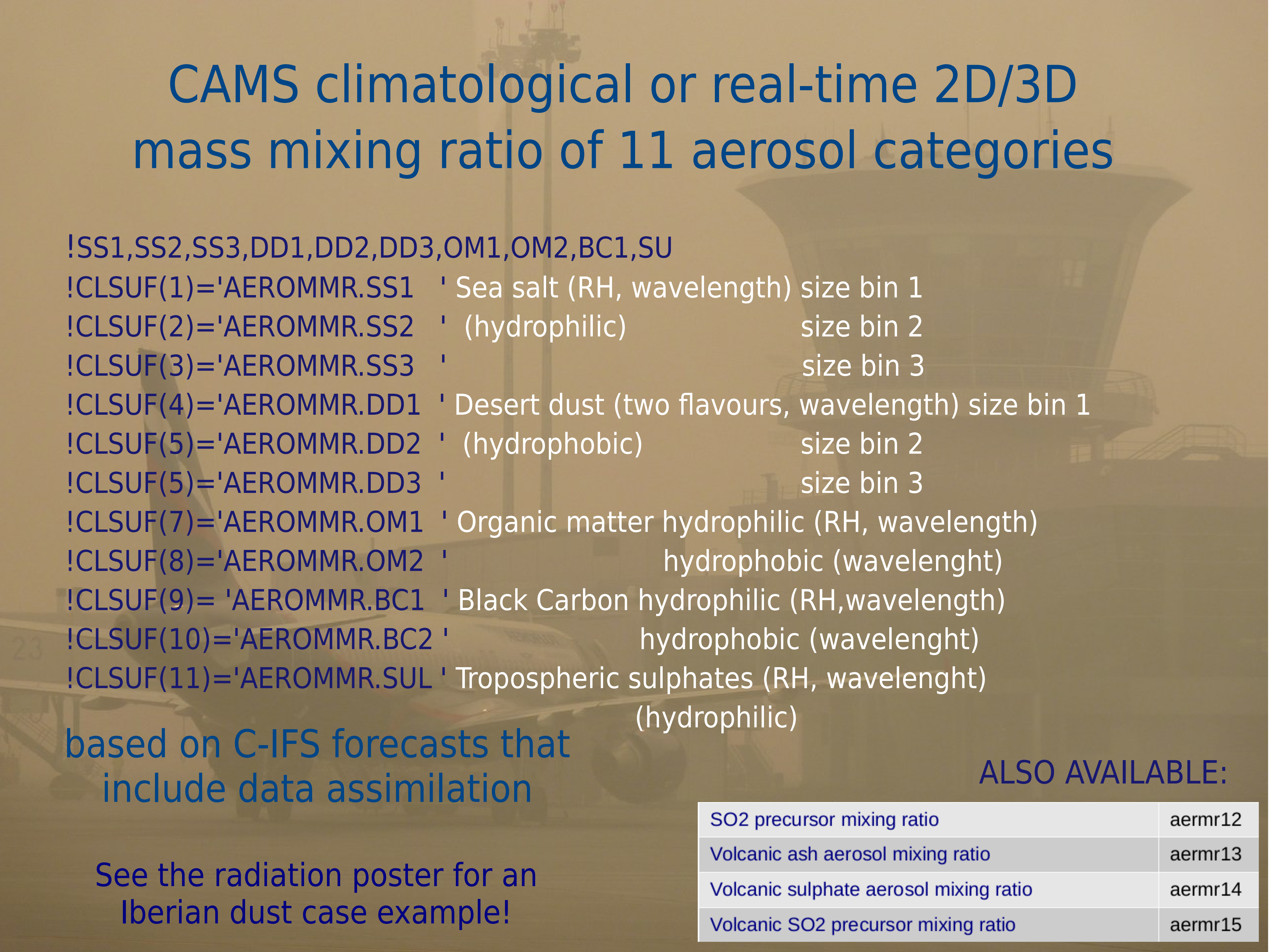
Aerosol optical depth at 550 nm (provided by CAMS, the Copernicus Atmosphere Monitoring Service)
Sunday 8 Jul, 00 UTC T+3 Valid: Sunday 8 Jul, 03 UTC

Aerosol data are available from CAMS

Climatology and near-real-time

Mass concentration (x,y,z)

Inherent optical properties:
mass extinction, single scattering albedo, asymmetry factor as functions of wavelength and aerosol species



CAMS climatological or real-time 2D/3D mass mixing ratio of 11 aerosol categories

```
!SS1,SS2,SS3,DD1,DD2,DD3,OM1,OM2,BC1,SU
!CLSUF(1)='AEROMMR.SS1   ' Sea salt (RH, wavelength) size bin 1
!CLSUF(2)='AEROMMR.SS2   '  (hydrophilic)              size bin 2
!CLSUF(3)='AEROMMR.SS3   '                             size bin 3
!CLSUF(4)='AEROMMR.DD1  ' Desert dust (two flavours, wavelength) size bin 1
!CLSUF(5)='AEROMMR.DD2  '  (hydrophobic)               size bin 2
!CLSUF(5)='AEROMMR.DD3  '                              size bin 3
!CLSUF(7)='AEROMMR.OM1  ' Organic matter hydrophilic (RH, wavelength)
!CLSUF(8)='AEROMMR.OM2  '                hydrophobic (wavelenght)
!CLSUF(9)= 'AEROMMR.BC1  ' Black Carbon hydrophilic (RH,wavelength)
!CLSUF(10)='AEROMMR.BC2 '              hydrophobic (wavelenght)
!CLSUF(11)='AEROMMR.SUL ' Tropospheric sulphates (RH, wavelenght)
                                      (hydrophilic)
```

based on C-IFS forecasts that include data assimilation

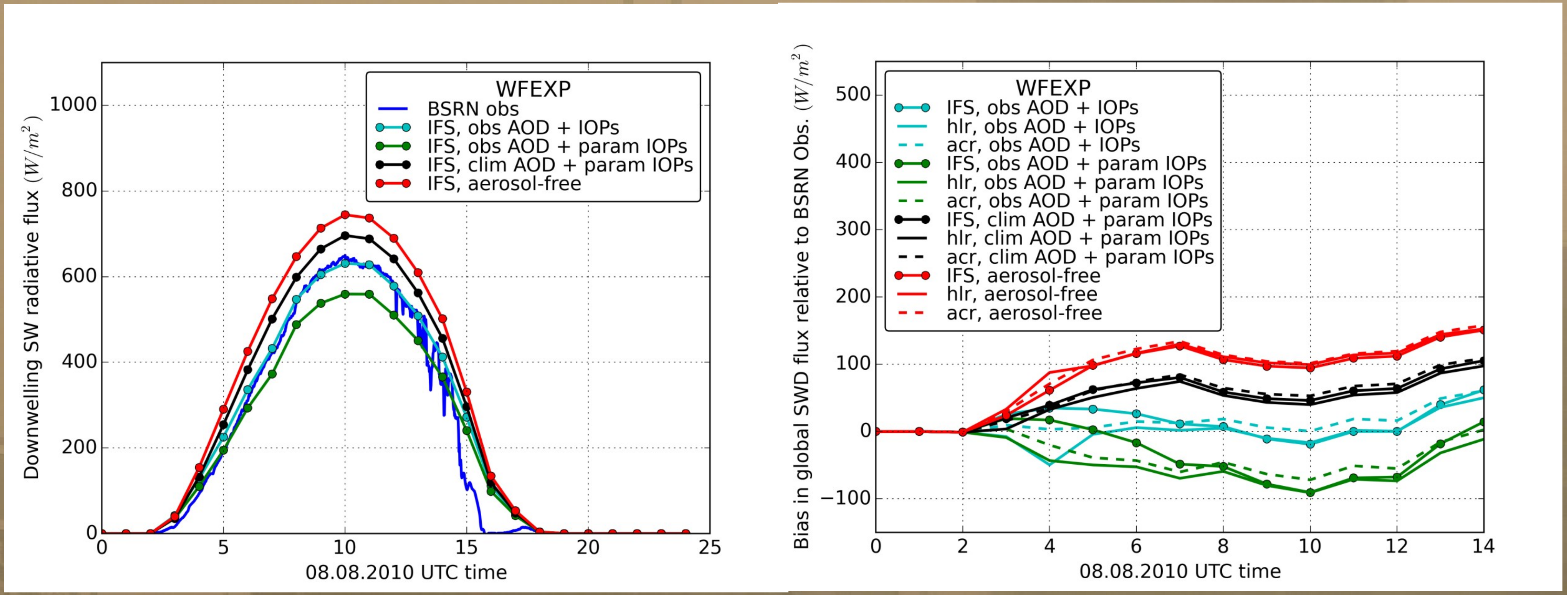
See the radiation poster for an Iberian dust case example!

ALSO AVAILABLE:

SO2 precursor mixing ratio	aermr12
Volcanic ash aerosol mixing ratio	aermr13
Volcanic sulphate aerosol mixing ratio	aermr14
Volcanic SO2 precursor mixing ratio	aermr15

Aerosol direct radiative effect: a study of short-wave clear-sky sensitivities

SWD observed and simulated with 3 radiation schemes using MUSC Toravere, Estonia during 2010 Russian forest fires

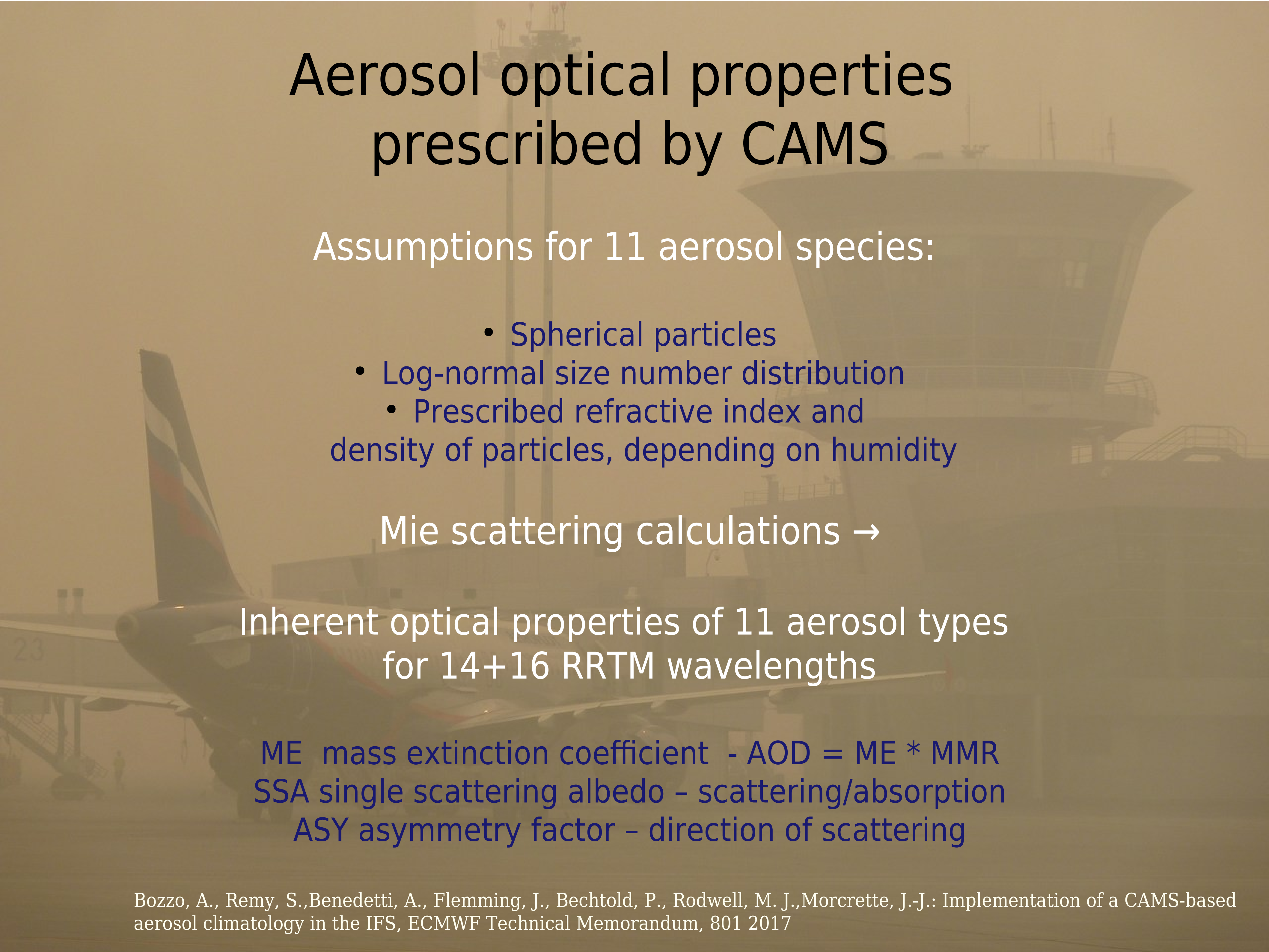


Optical properties of aerosol, not only the mass concentration, are important.

Broadband radiation schemes are O.K. compared to those resolving spectral details.

Gleeson, E., Toll, V., Nielsen, K. P., Rontu, L., and Mašek, J.: Effects of aerosols on solar radiation in the ALADIN-HIRLAM NWP system, Atmos. Chem. Phys. Discuss., 15, 32519-32560, doi: http://dx.doi.org/10.5194/acpd-15-32519-2015, 2015.

Aerosol optical properties prescribed by CAMS



Assumptions for 11 aerosol species:

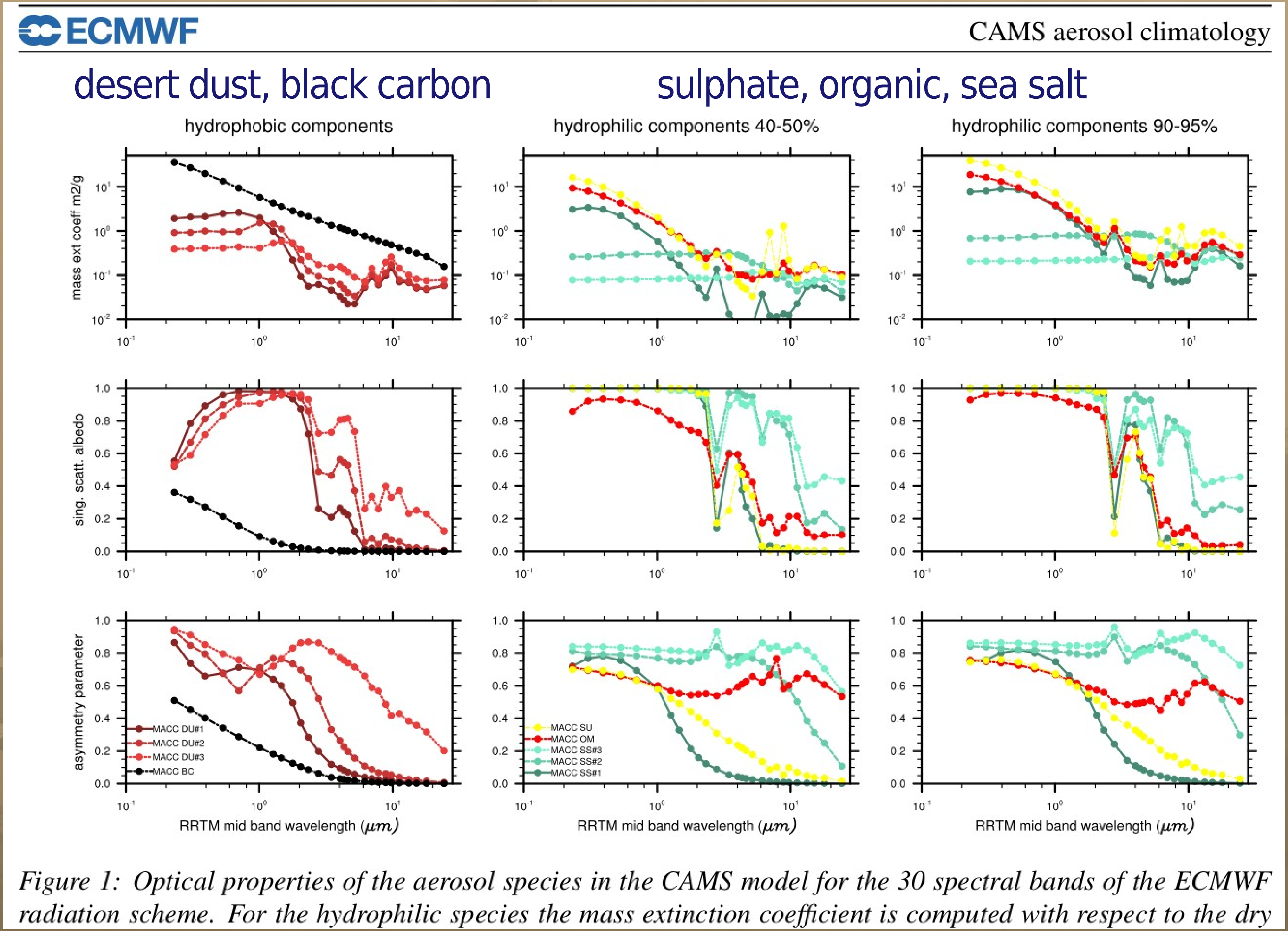
- Spherical particles
- Log-normal size number distribution
- Prescribed refractive index and density of particles, depending on humidity

Mie scattering calculations →

Inherent optical properties of 11 aerosol types for 14+16 RRTM wavelengths

ME mass extinction coefficient - AOD = ME * MMR
SSA single scattering albedo – scattering/absorption
ASY asymmetry factor – direction of scattering

Bozzo, A., Remy, S.,Benedetti, A., Flemming, J., Bechtold, P., Rodwell, M. J.,Morcrette, J.-J.: Implementation of a CAMS-based aerosol climatology in the IFS, ECMWF Technical Memorandum, 801 2017



CAMS aerosol climatology

desert dust, black carbon

sulphate, organic, sea salt

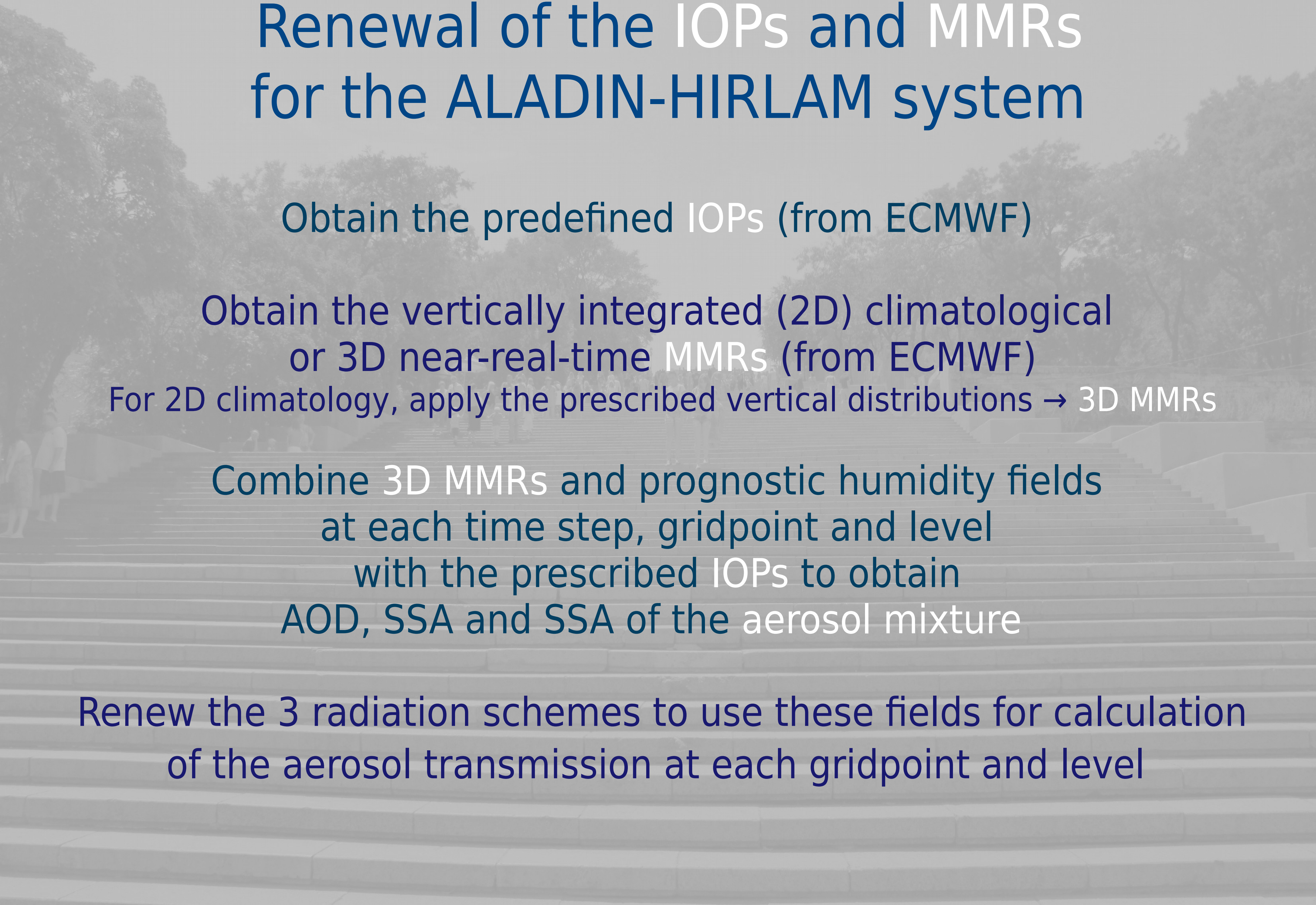
ME

SSA

ASY

Figure 1: Optical properties of the aerosol species in the CAMS model for the 30 spectral bands of the ECMWF radiation scheme. For the hydrophilic species the mass extinction coefficient is computed with respect to the dry

Bozzo, A., Remy, S.,Benedetti, A., Flemming, J., Bechtold, P., Rodwell, M. J.,Morcrette, J.-J.: Implementation of a CAMS-based aerosol climatology in the IFS, ECMWF Technical Memorandum, 801 2017



Renewal of the IOPs and MMRs for the ALADIN-HIRLAM system

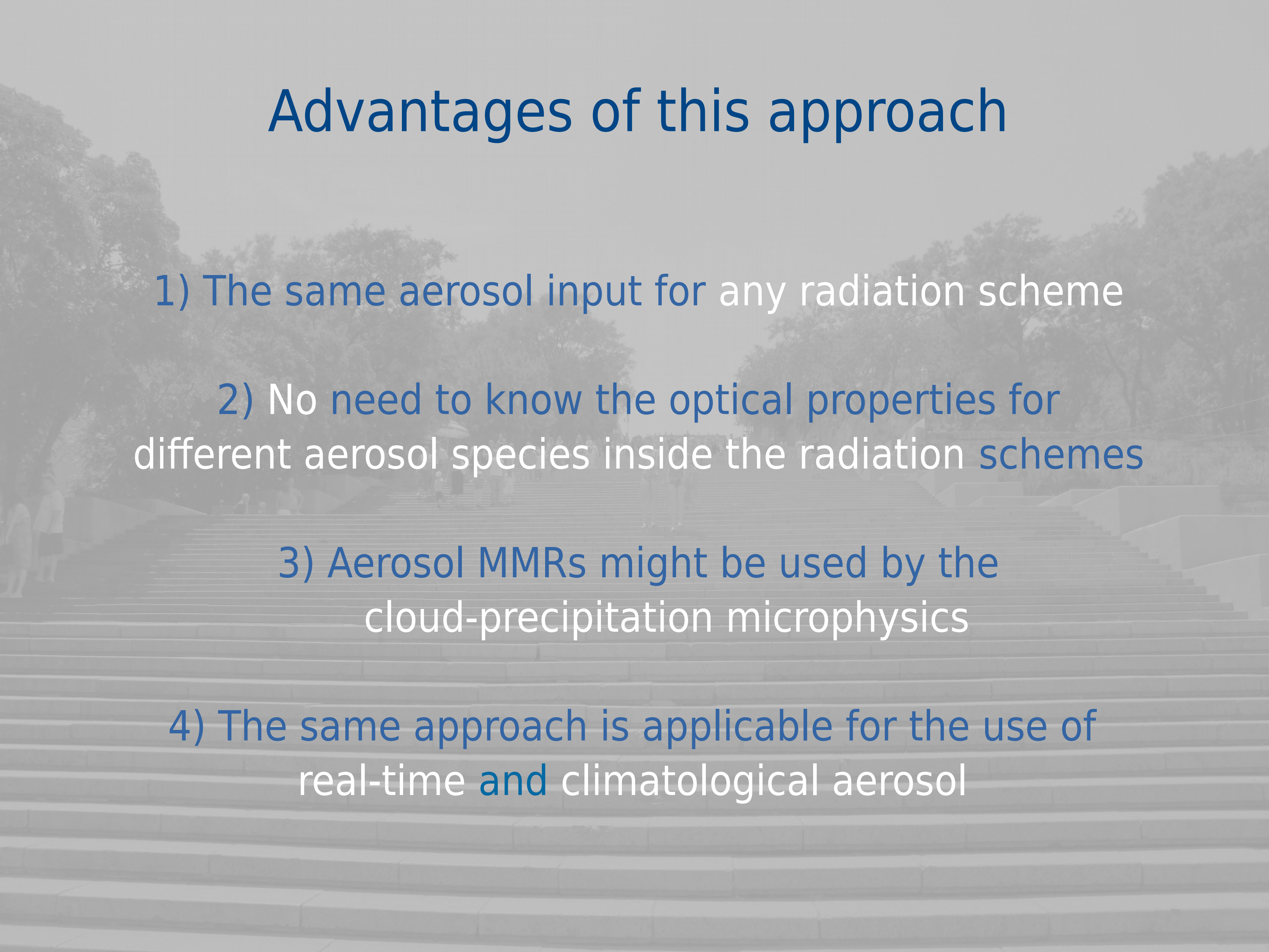
Obtain the predefined IOPs (from ECMWF)

Obtain the vertically integrated (2D) climatological
or 3D near-real-time MMRs (from ECMWF)
For 2D climatology, apply the prescribed vertical distributions → 3D MMRs

Combine 3D MMRs and prognostic humidity fields
at each time step, gridpoint and level
with the prescribed IOPs to obtain
AOD, SSA and SSA of the aerosol mixture

Renew the 3 radiation schemes to use these fields for calculation
of the aerosol transmission at each gridpoint and level

Advantages of this approach



1) The same aerosol input for any radiation scheme

2) No need to know the optical properties for different aerosol species inside the radiation schemes

3) Aerosol MMRs might be used by the cloud-precipitation microphysics

4) The same approach is applicable for the use of real-time and climatological aerosol

Practical steps within the forecast

Climate generation:

Read 2D monthly aerosol MMR fields and write to m-climate files

or

Boundary preparation:

Obtain 3D near-real-time MMR fields via horizontal boundaries

Setup:

Read aerosol optical properties from RADAIOP ascii file
into ME, SSA, ASY run-time arrays

Every time step:

(Vertical structure of MMRs for climatology)
Combination of IOPs with MMRs and humidity
→ 3D optical properties depending on (wavelength, klon, klev)
for input to radiation schemes
Radiative transfer calculations

```
src/arpifs/
├── c9xx
│   └── incli0.F90
├── climate
│   └── updcli.F90
├── control
│   └── cprep1.F90
├── fullpos
│   ├── fpiniphy.F90
│   ├── hpos.F90
│   ├── sufprfpds.F90
│   └── sufptr2.F90
├── module
│   ├── surface_fields_mix.F90
```

```
src/aladin
└── c9xx
    ├── ebicli.F90
    └── eincli9.F90
```

```
├── module
│   ├── surface_fields_mix.F90
│   ├── yoaiop.F90
│   ├── yoerad.F90
│   ├── yomafn.F90
│   ├── yomlun.F90
│   └── yomphy.F90
├── namelist
│   ├── namafn.nam.h
│   |------namcli.nam.h
│   └── namphy.nam.h
│   ├── suaersn.F90
│   └── suecrad.F90
└── setup
    ├── su0phy.F90
    ├── suafn1.F90
    ├── suafn2.F90
    ├── suafn3.F90
    ├── suaiop.F90
    └── su_surf_flds.F90
```

```
├── phys_dmn
│   ├── apl_arome.F90
│   ├── aplpar.F90
│   └── mf_phys.F90
├── phys_radi
│   ├── aeropt.F90
│   ├── aero_rt6.F90
│   ├── radaer.F90
│   ├── suaersn.F90
│   └── suecrad.F90
```

Later:

ecrad
acraneb2
hlradia
- modifications of several subroutines to use new aerosol IOPs

Data from Alessio → HIRLAM-ALADIN climate/prescribed

MMRclim_gbst_2003-2011.nc → mmr.cams.m01_GL
macc_opt_43R1.nc → const/rrtm_const/RADAIOP

Data directly from CAMS

3D real-time aerosol for radiation and cloud microphysics

Gracias por su atención!

EFFECTIVE RADIUS FOR WATER CLOUDS:

$$r_{e,water}^3 = k r_v^3 \tag{1}$$

The parameter k is different for marine and continental clouds.

The cloud condensate content (CCC = liquid + ice water content, in kgm^{-3}) in the cloud is connected to r_v by

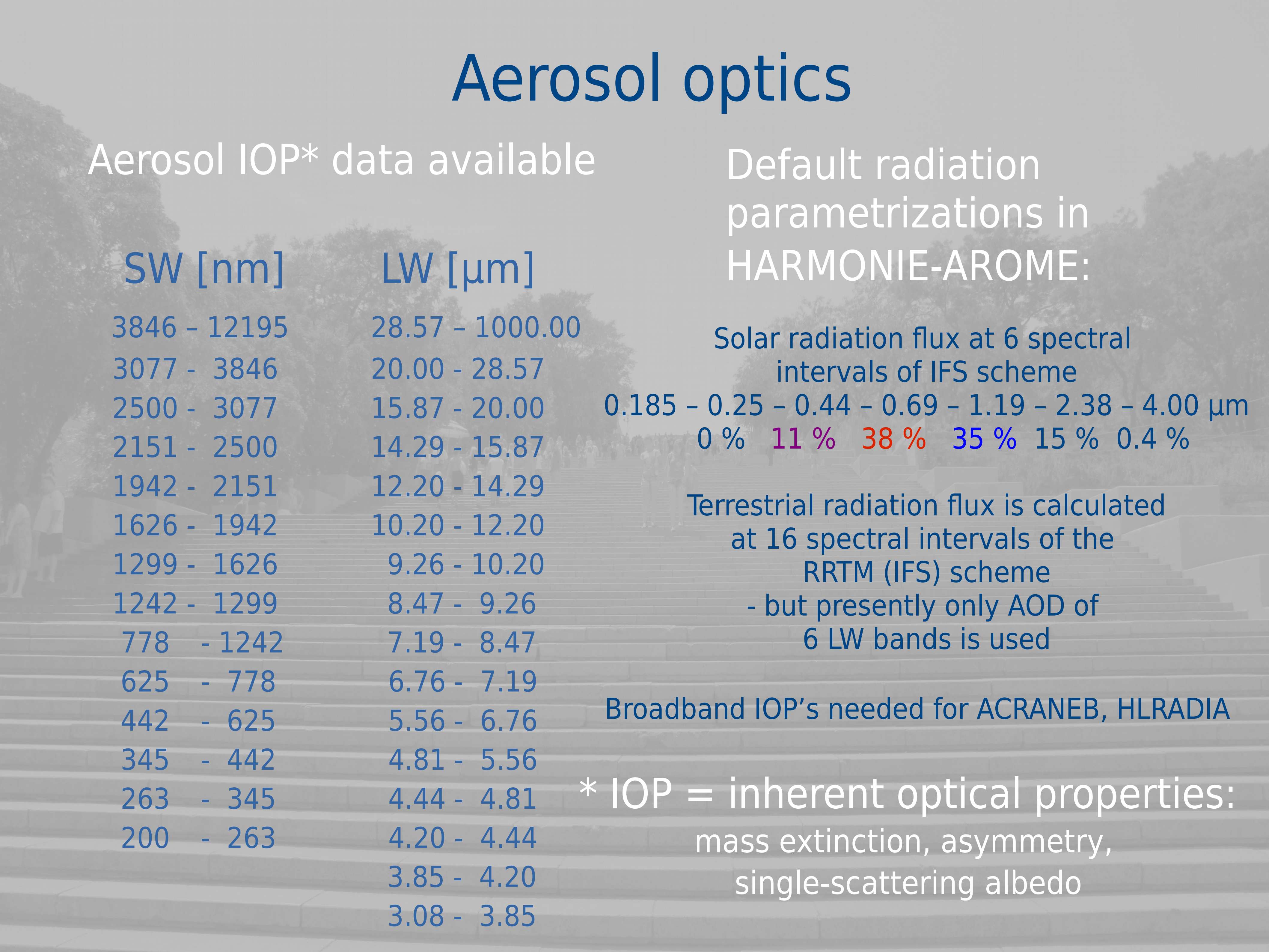
$$CCC = \frac{4\pi}{3} \rho_\ell N r_v^3 \tag{2}$$

where ρ_ℓ=1000 kg m^{-3} is the density of liquid water and N the number concentration of the cloud droplets.

Combining (1) and (2) yields

$$r_{e,water} = \left(\frac{3CCC}{4\pi \rho_\ell k N} \right)^{1/3} \tag{3}$$

Aerosol optics



Aerosol IOP* data available

SW [nm]	LW [µm]
3846 – 12195	28.57 – 1000.00
3077 - 3846	20.00 - 28.57
2500 - 3077	15.87 - 20.00
2151 - 2500	14.29 - 15.87
1942 - 2151	12.20 - 14.29
1626 - 1942	10.20 - 12.20
1299 - 1626	9.26 - 10.20
1242 - 1299	8.47 - 9.26
778 - 1242	7.19 - 8.47
625 - 778	6.76 - 7.19
442 - 625	5.56 - 6.76
345 - 442	4.81 - 5.56
263 - 345	4.44 - 4.81
200 - 263	4.20 - 4.44
	3.85 - 4.20
	3.08 - 3.85

Default radiation parametrizations in HARMONIE-AROME:

Solar radiation flux at 6 spectral intervals of IFS scheme

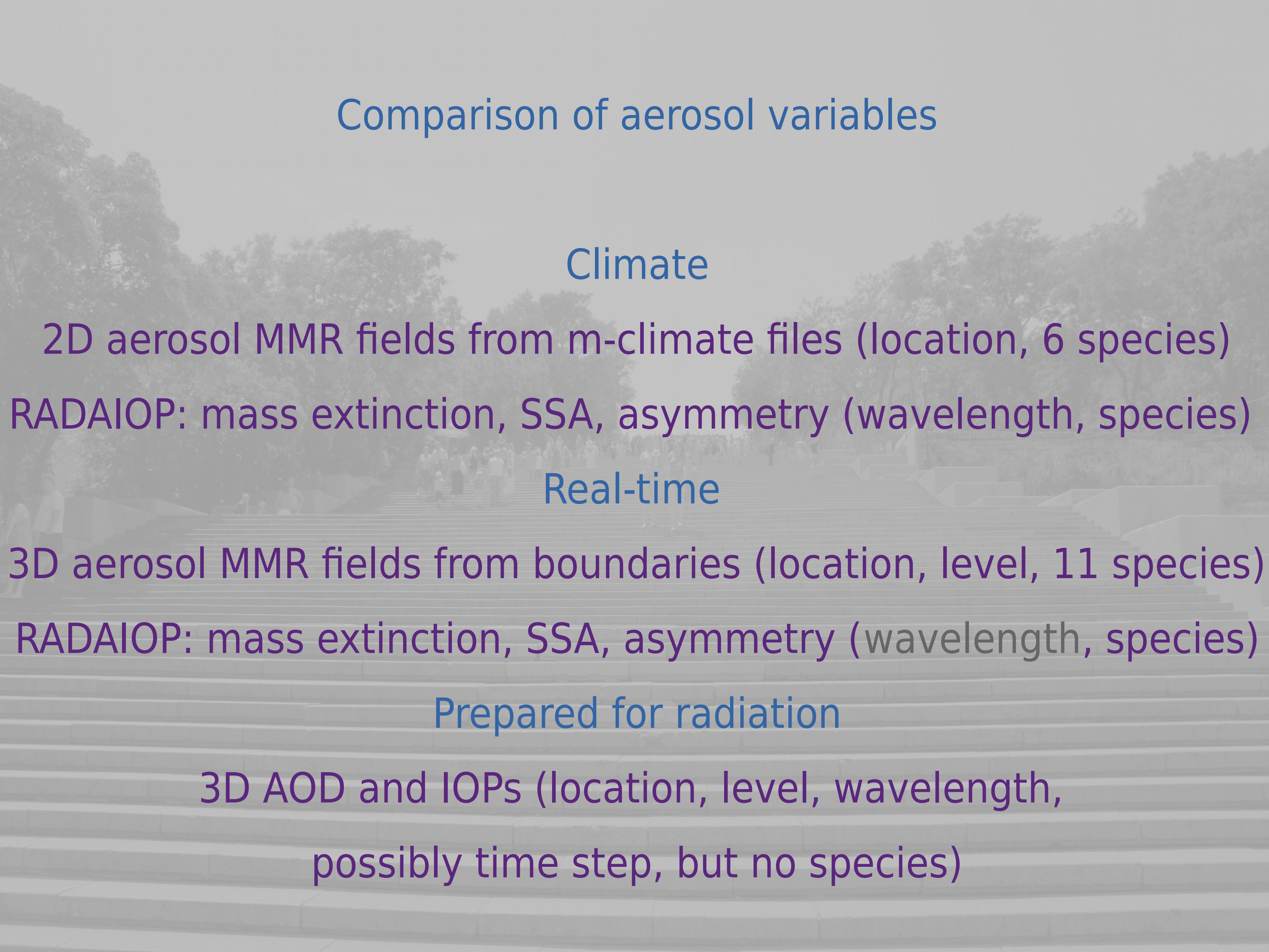
0.185 – 0.25 – 0.44 – 0.69 – 1.19 – 2.38 – 4.00 µm
0 % 11 % 38 % 35 % 15 % 0.4 %

Terrestrial radiation flux is calculated at 16 spectral intervals of the RRTM (IFS) scheme
- but presently only AOD of 6 LW bands is used

Broadband IOP’s needed for ACRANEB, HLRADIA

* IOP = inherent optical properties:

mass extinction, asymmetry, single-scattering albedo



Comparison of aerosol variables

Climate

2D aerosol MMR fields from m-climate files (location, 6 species)

RADAIOP: mass extinction, SSA, asymmetry (wavelength, species)

Real-time

3D aerosol MMR fields from boundaries (location, level, 11 species)

RADAIOP: mass extinction, SSA, asymmetry (wavelength, species)

Prepared for radiation

3D AOD and IOPs (location, level, wavelength,
possibly time step, but no species)

Input to radiation schemes

Currently

3D AOD converted from 2D by radaer

Prescribed optical properties (2x6 or 2 wavelengths, 6 species)

Used by future radiation

3D AOD and IOPs (location, level,

14/16 or 6/6 or 1/1 wavelengths)

ECRAD v.s. IFSRAD cy27, hlradia, acraneb