First results and future plans for ecRad radiation in Météo-France models

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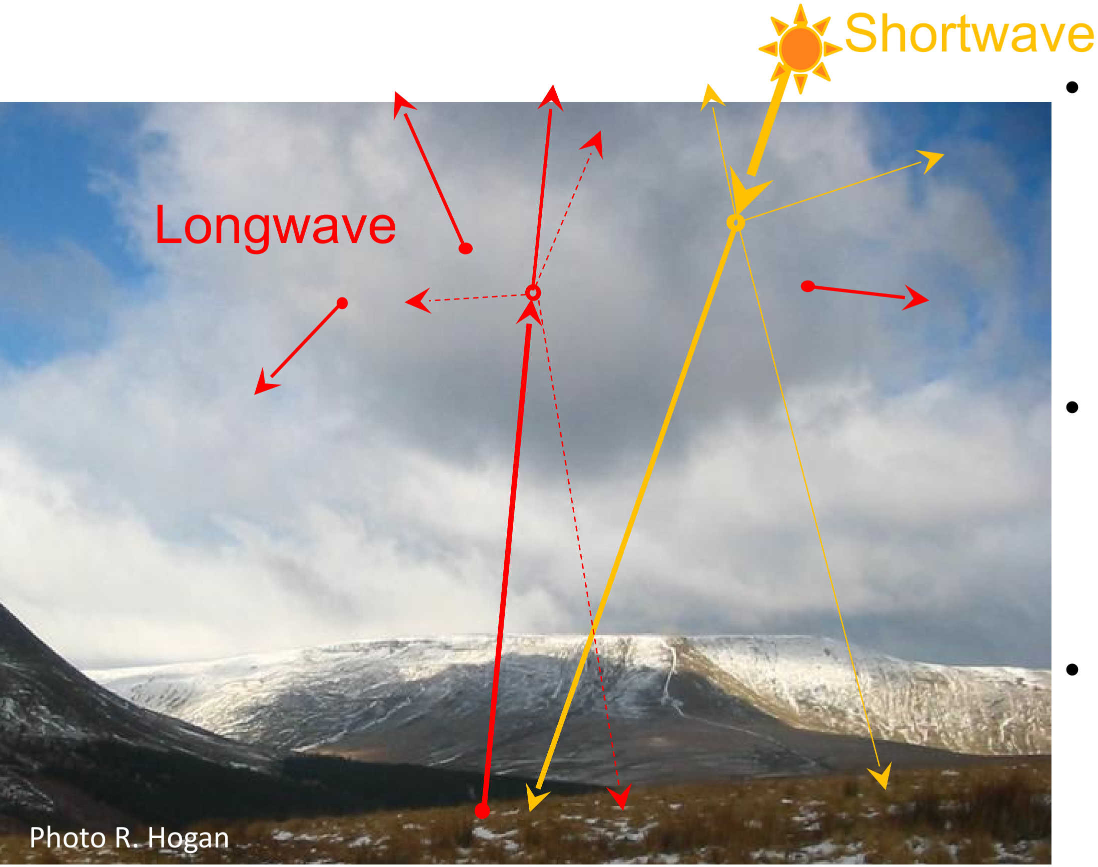
Overview

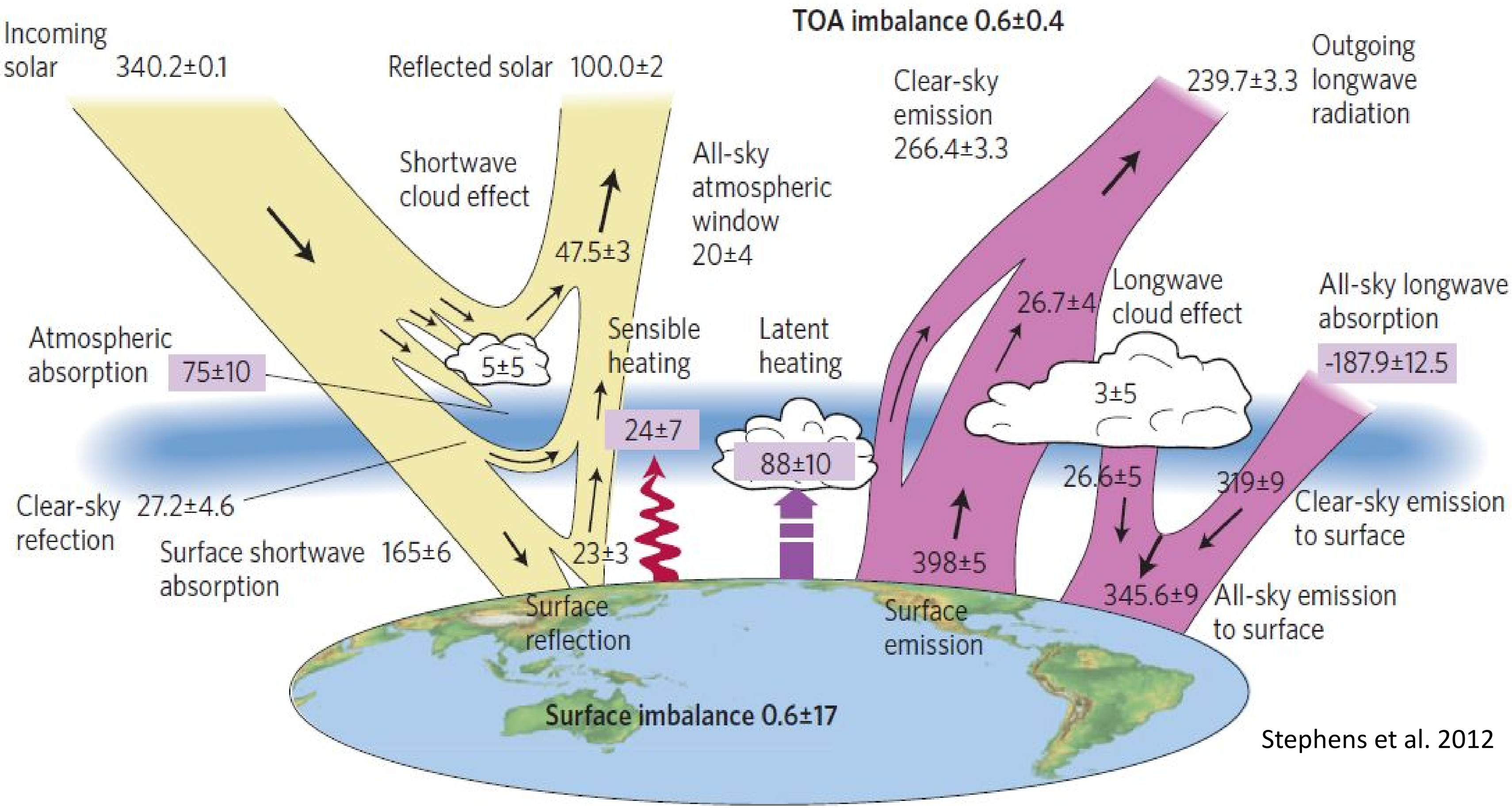
- Radiation: sources and impact
- Radiation scheme ecRad, settings on ice optics and cloud geometry
- Radiation tasks and research questions
- Model status: Meso-NH, AROME, ARPEGE, ARPEGE-Climat
- 3D physics work
- Summary

Radiation sources



- Photons emitted by sun (visible/shortwave) and Earth system (infrared/longwave) interact with surface, atmospheric gases, aerosol, cloud water or ice particles
- Described by electromagnetic **Maxwell equations** and quantum mechanics, BUT can‘t treat every photon and atmospheric particle!
- Have to capture bulk effect of each component - simplifications for practical calculation

Radiation budget drives climate and weather



Stephens et al. 2012

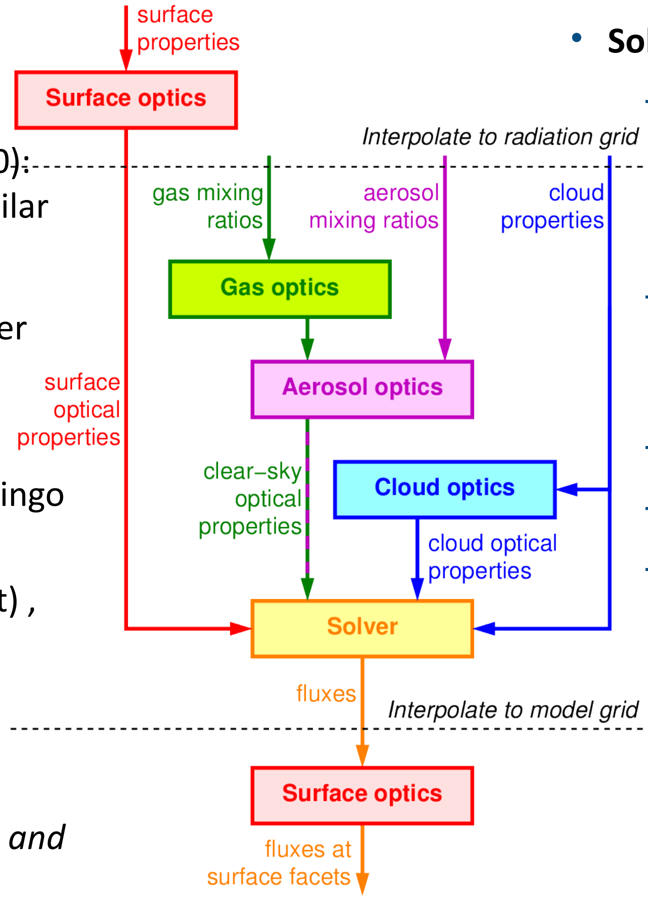
Models tuned to top-of-atmosphere radiative fluxes (directly observable), ideally bias < 1W/m²

New modular radiation scheme ecRad (Hogan & Bozzo 2018)

- **Gas optics:**
  - RRTMG (Iacono et al. 2008)
  - ecCKD (Hogan & Matricardi 2020): Fewer spectral intervals but similar precision
- **Aerosol optics:** variable species number and properties (set at run-time)
- **Cloud optics:**
  - **liquid:** SOCRATES (MetOffice), Slingo (1989), Mie calculation
  - **ice:** Fu 1996, 1997, 1998 (default) , Yi et al. 2013, Baran et al. 2014, Baum et al. 2014

From ecRad 1.6: user can choose hydrometeor number + add optics

- *Surface: Consistent treatment of urban and forest canopies*



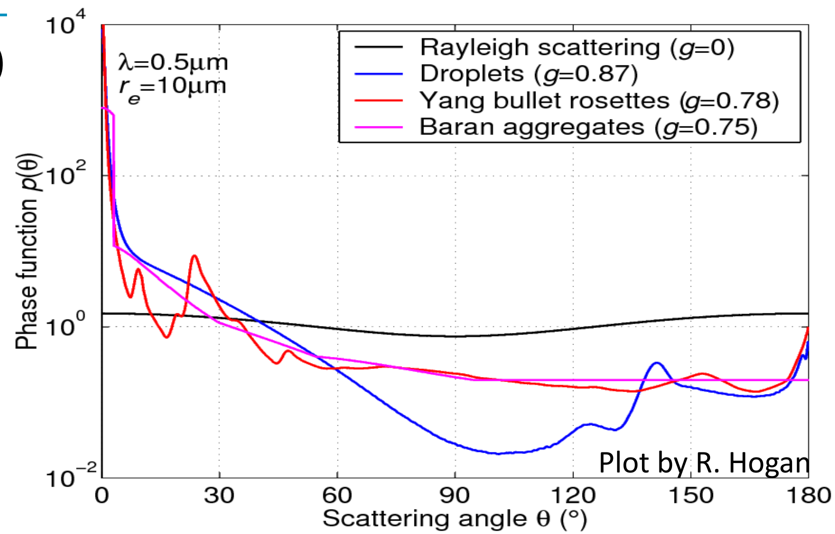
- **Solvers** for radiative transfer equations:
  - **McICA** (Pincus et al. 2003), **Tripleclouds** (Shonk & Hogan, 2008) or **SPARTACUS** (Schäfer et al. 2016, Hogan et al. 2016)
  - SPARTACUS makes ecRad the only global radiation scheme that can do sub-grid **3D** radiative effects
  - Longwave scattering optional
  - Can configure **cloud overlap**
  - **Cloud inhomogeneity**: can configure width and shape of PDF

Implemented in ARPEGE, AROME and Meso-NH (update in progress)

Ice particle shape and effective radius

- **Ice particle shape** assumptions (liquid: spherical)
- Fu ice optics (Fu 1996, 1998, default): hexagonal columns

- Alternative ice optics in ecRad: Yi (Yi et al. 2013), Baran (Baran et al. 2014), Baum (Baum et al. 2014): ice habit mixtures



- Mixture of particle sizes in clouds
- Parametrised **effective radius**

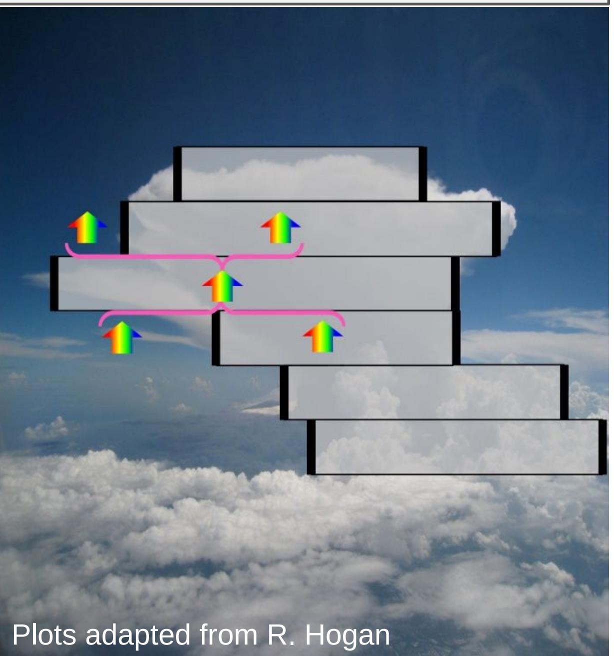
  = mean radius weighted by number, area, scattering efficiency of each particle size
- Definition needs to agree with optics
- Consistency with microphysics?

Radiation solvers and sub-grid cloud geometry

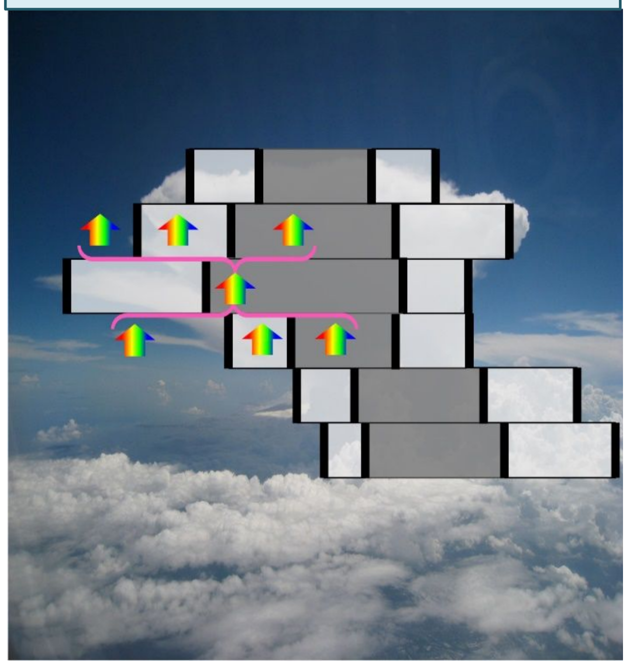
Simplify by treating **only vertical** dimension explicitly.

Deterministic:

Two-stream solver: solve in **cloudy / clear regions**, partition at layer boundaries according to **overlap**

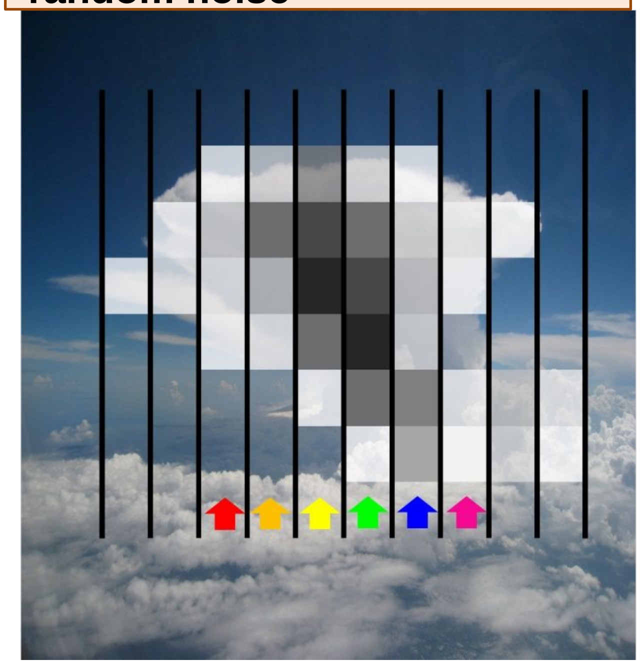


Tripleclouds/SPARTACUS (ecRad)**:** similar; 3 regions: **clear, thin cloud, thick cloud** cloud **inhomogeneity**



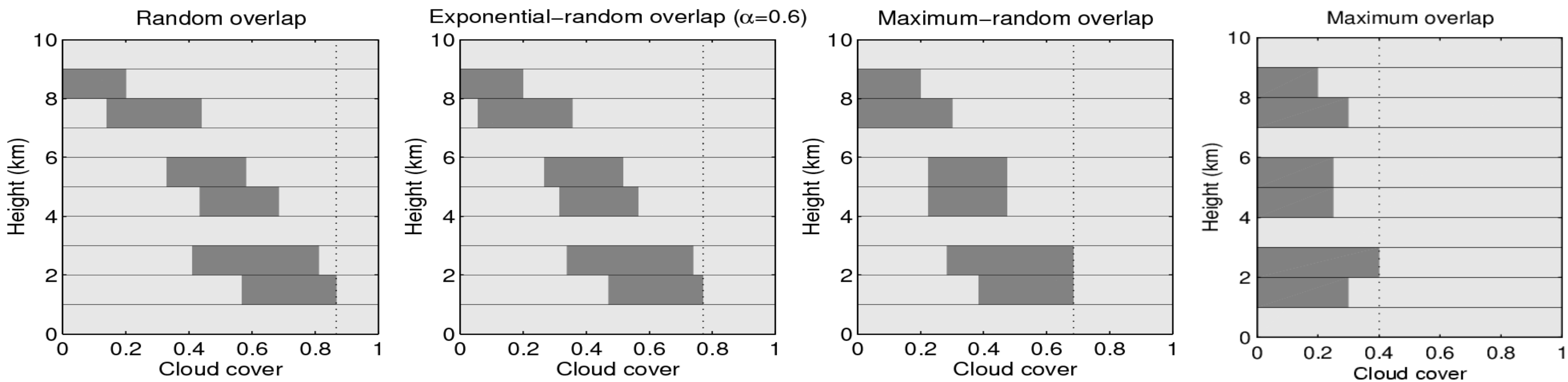
Stochastic:

McICA (ecRad)**:** draw **random clouds in sub-columns** for overlap + inhomogeneity; **distribute spectral intervals** in 1 sub-column each **fast, random noise**



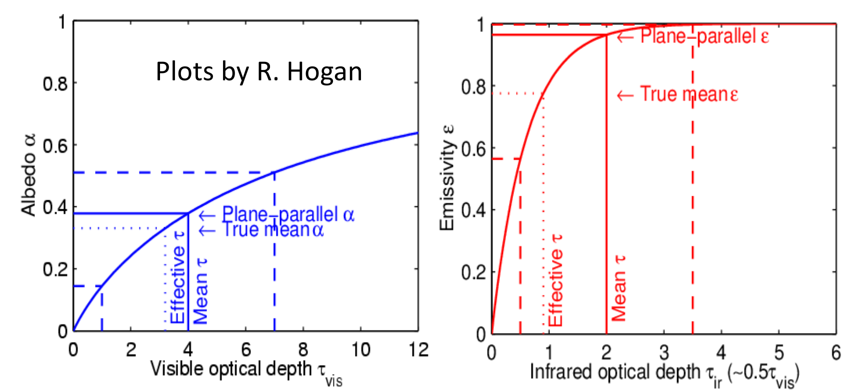
Plots adapted from R. Hogan

Cloud geometry uncertainties

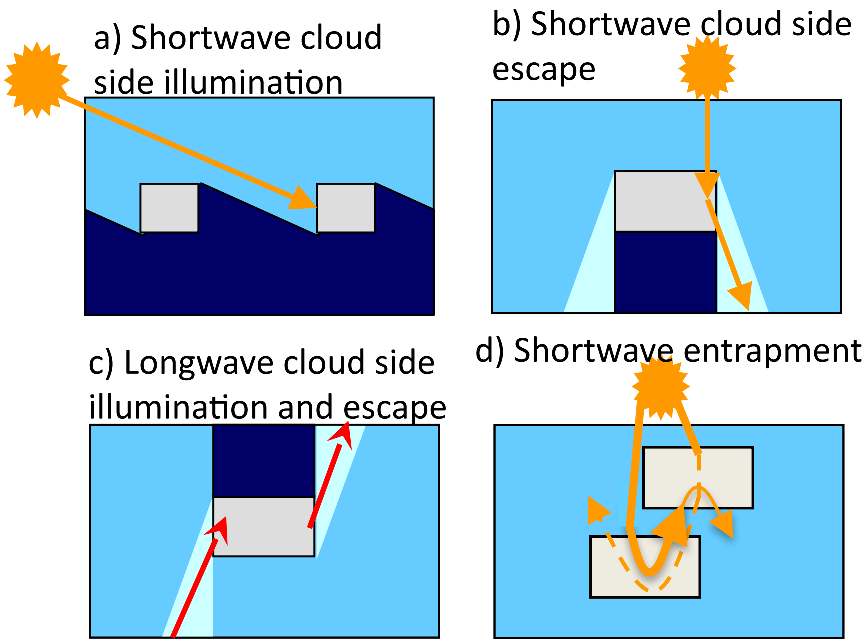


Adapted from Hogan & Illingworth 2000

- For given layer clouds, **cloud overlap** decides total cloud cover
- Observations: **exponential-random overlap,** decorrelation length 2 km (Hogan & Illingworth 2000) to 100-600 m (Neggers et al. 2011) - **Should depend** on cloud type
- Reflectivity and longwave emissivity **non-linear functions** of optical depth: need **horizontal cloud variability** (fractional standard deviation FSD = standard deviation / mean optical depth)
- Should also depend on cloud type, resolution



3D cloud effects



- **Shortwave cloud side illumination** increases cloud reflectivity, **cloud side escape** decreases cloud reflectivity
- **Longwave cloud side illumination and escape** increase cloud effect
- **Shortwave entrapment** decreases cloud reflectivity
- Similar effects at complex surfaces (trees / mountains / buildings)
- **Usually neglected, SPARTACUS** solver in ecRad can treat them (Schäfer et al. 2016, Hogan et al. 2016, 2019), cost x4

Further uncertainties: surface coupling: albedo, emissivity, one- or multi-level coupling
Cloud and aerosol input

Radiation tasks and research questions

- Radiation in 4 models (Meso-NH, AROME, ARPEGE, ARPEGE-Climat): same ecRad version
- Evaluate global and local radiation balance and model performance, optimise ecRad settings + input, especially clouds + aerosol properties, cloud geometry
- Use French pyranometer observations (Magnaldo et al. 2023 for AROME), also DWD, BSRN, highly instrumented sites (SIRTA, Meteopole-Flux), measurement campaigns, satellite data for evaluation
- Keep ecRad updated and contribute to ecRad development, e.g.:

  - better consistency between radiation, microphysics and aerosols: collaboration ICCARE project, LAERO Toulouse

  - 3D radiation effects of clouds, mountains, trees, buildings: SPARTACUS (sub-grid) and resolved 3D methods
- Collaborations with ECMWF, ACCORD consortium, ecRad developers and users, coordination of radiation work at CNRM and other French laboratories (DEPHY group), research projects on particular questions

Radiation + aerosol status in AROME/ARPEGE, Meso-NH

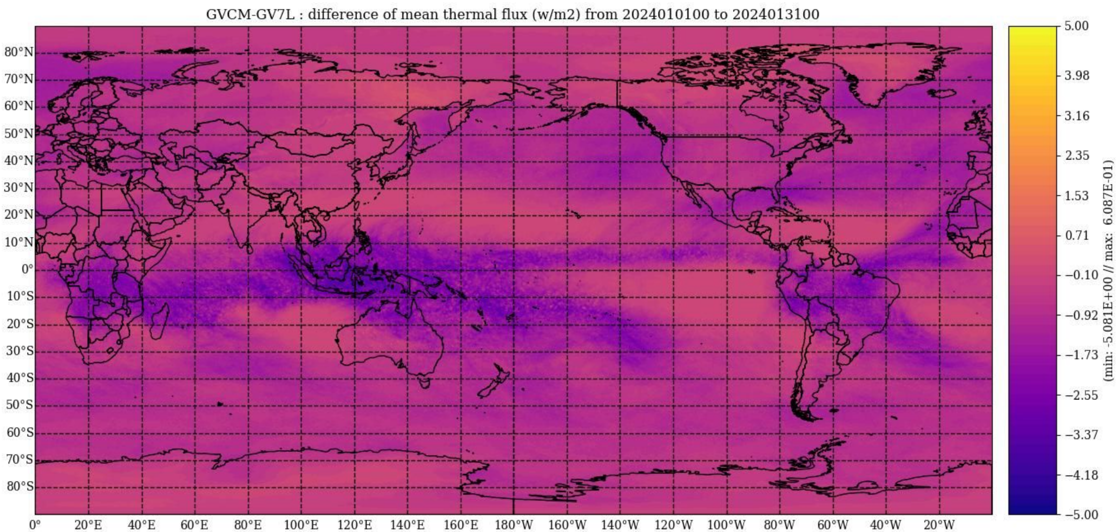
	OPER(CY46T1)			E-Suite (CY48T1)			E-SUITE (CY49T1) (under development)		
	SW	LW	Aerorols	SW	LW	Aerosols	SW	LW	Aerosols
AROME	Fouquart-Morcrette	RRTM	Tegen 2D clims (6 var)	ecRad (SRTM McICA)	ecRad (RRTM McICA)	CAMS 3D clims (11 var)	ecRad (SRTM McICA)	ecRad (RRTM McICA)	CAMS 3D clims (11 var)
ARPEGE	SRTM					Tegen 2D clims (6 var)			Tegen 2D clims (6 var)

- **Tests AROME:** ecRad some improvement, near-real-time CAMS aerosol for improves dust outbreaks
- **Plans:** further tests of radiation options, reduced radiation grid (with DMI)

- Plan to test ecRad versus ACRANEB2 radiation scheme (with Ján Mašek, CHMI)

- **Status Meso-NH**: new implementation + update to ecRad 1.6.1 ongoing, reduced radiation grid (V. Masson)

Evaluation of ecRad settings in ARPEGE (with Y. Bouteloup, P. Chambon)

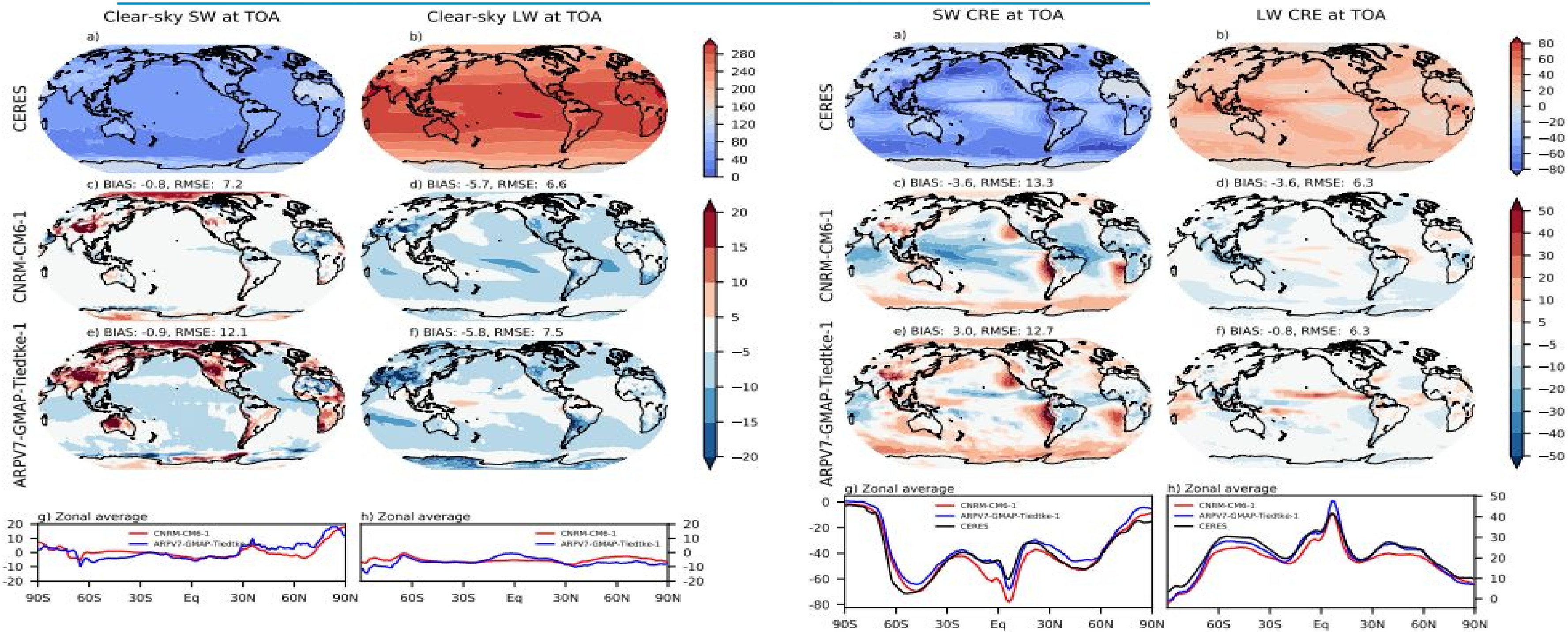


Effects in downward TOA LW flux
in ARPEGE Cy48t1 with ecRad (McICA solver)

Yi ice optics – Fu ice optics

- Tested: Radiation solver McICA vs. Tripleclouds; Cloud geometry: vertical cloud overlap, horizontal inhomogeneity measured by fractional standard deviation (FSD)
- Effects of up to 5 W/m², especially in ITCZ, will evaluate against CERES data
- Also test: ecCKD gas optics, parametrised decorrelation length / cloud FSD
- Will do similar evaluation for AROME, Meso-NH on limited domains

First tests with ARPEGE-Climat (T. Drugé, R. Roehrig)



Errors in TOA clear-sky radation and cloud radiative effect (CRE) vs. CERES data (top) in shortwave and longwave for ARPEGE-Climat 6.3 (2nd line), ARPEGE-Climat 7 using ecRad (work in progress, 3rd line) and zonal averages (4th line). Plots by T. Drugé

- ecRad + new ARPEGE version increases clear-sky SW land – sea contrast / bias
- ecRad: Clouds less reflective in SW (esp. tropics), LW CRE overestimated for some tropical clouds
- Needs analysis / tuning.

3D radiation: fully calculated by htrdr Monte Carlo method

Atmosphere (Villefranque et al, 2019), vegetation, urban (Caliot et al. 2022), ongoing evaluation in mountains;
Used for evaluation of radiation options, Future plan: online in model?

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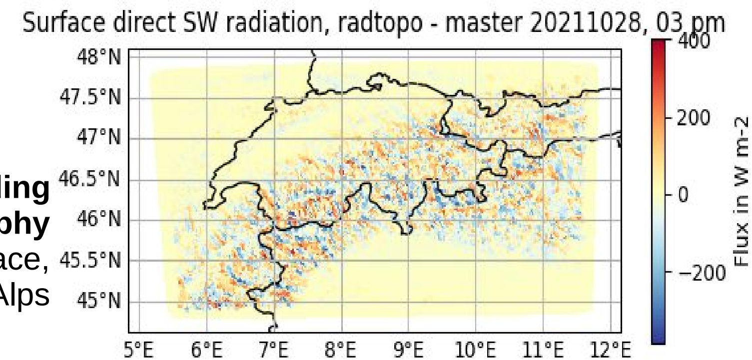
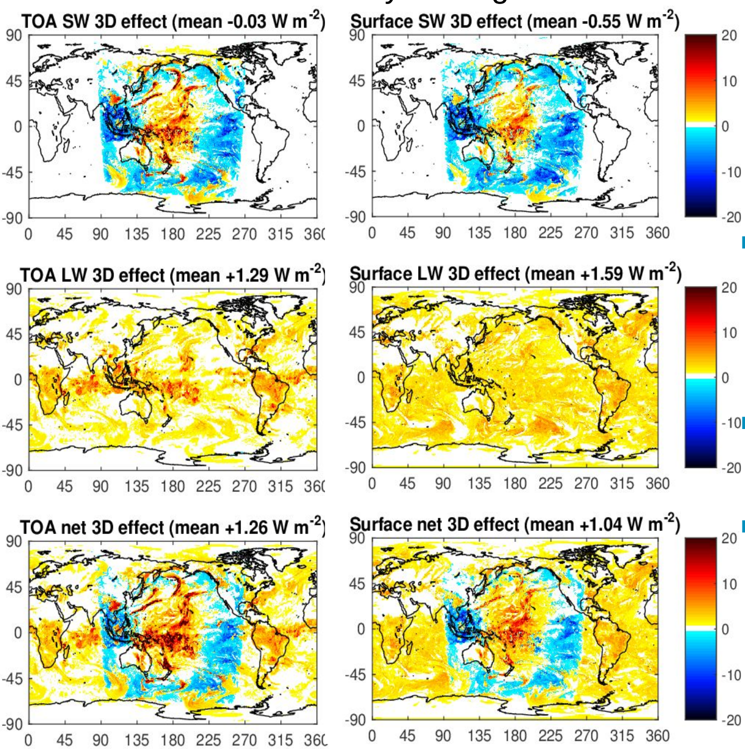
3D radiation and physics in NWP / climate models

- Currently: cloud and vegetation 3D effects ignored; approximate corrections for 3D orography slope angle, shadowing, longwave skyview (ORORAD, Rontu et al. 2016)

3D effects of **including shadowing by orography** on SW direct flux at surface, in ICON model, western Alps



Instantaneous 3D cloud effects in Era5 field, 01.04.2000 0 UTC. Plots by R. Hogan

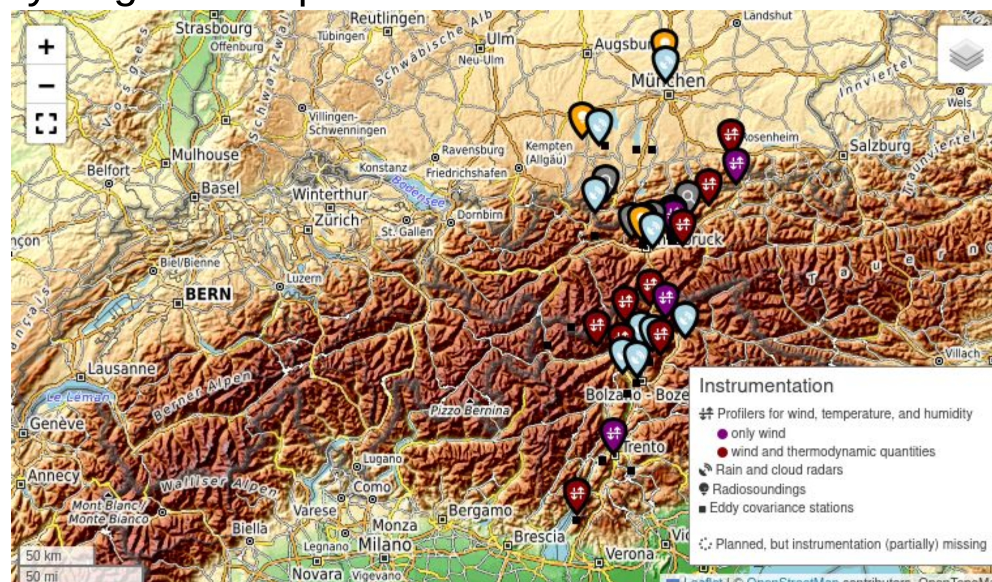


- In ecRad: SPARTACUS (Schäfer et al. 2016, Hogan et al. 2016, 2019) approximates sub-grid 3D for clouds, vegetation, urban; now in MesoNH, AROME, ARPEGE, coupled to TEB urban scheme (Schoetter et al 2024); depends on good geometry estimates;
- Global 3D cloud effects: 1 W/m² (Hogan et al. 2019), partial compensations; some SPARTACUS biases in LW (ongoing work)
- Resolved 3D approximation POMART3D (R. Hogan, ECMWF, ongoing): tilted column + layerwise diffusion, implementation planned in < 1 year

Planned work on 3D radiation and physics in mountains

- Investigate 3D versus 1D model physics (radiation, turbulence, surface interactions) at high resolution in complex terrain
- Use and develop 1D and 3D physics options in AROME and Meso-NH
- Collaborate with TEAMx project (https://www.teamx-programme.org)
  Sept. 2024 – Sept 2025 with focus on complex terrain, energy fluxes, boundary layer
- Utilise high density of radiation and energy flux and eddy covariance observations and model comparisons in TEAMx, synergies with partners

Planned locations in TEAMx campaign of atmospheric profilers, rain and cloud radars, radiosoundings, eddy covariance stations (incl. radiative flux). https://www.teamx-programme.org/observational-campaign/



Summary

- ecRad available and being tested in AROME, ARPEGE, ARPEGE-Climat, Meso-NH
- New Meso-NH ecRad implementation + ecrad 1.6 version update ongoing
- Workflow for consistency between models
- 3D radiation: SPARTACUS sub-grid 3D, ongoing work for resolved 3D

- Ongoing: evaluation, optimisation of settings, consistency with other parametrisations
- Planned project: 3D physics in mountains

Thank you for your attention!

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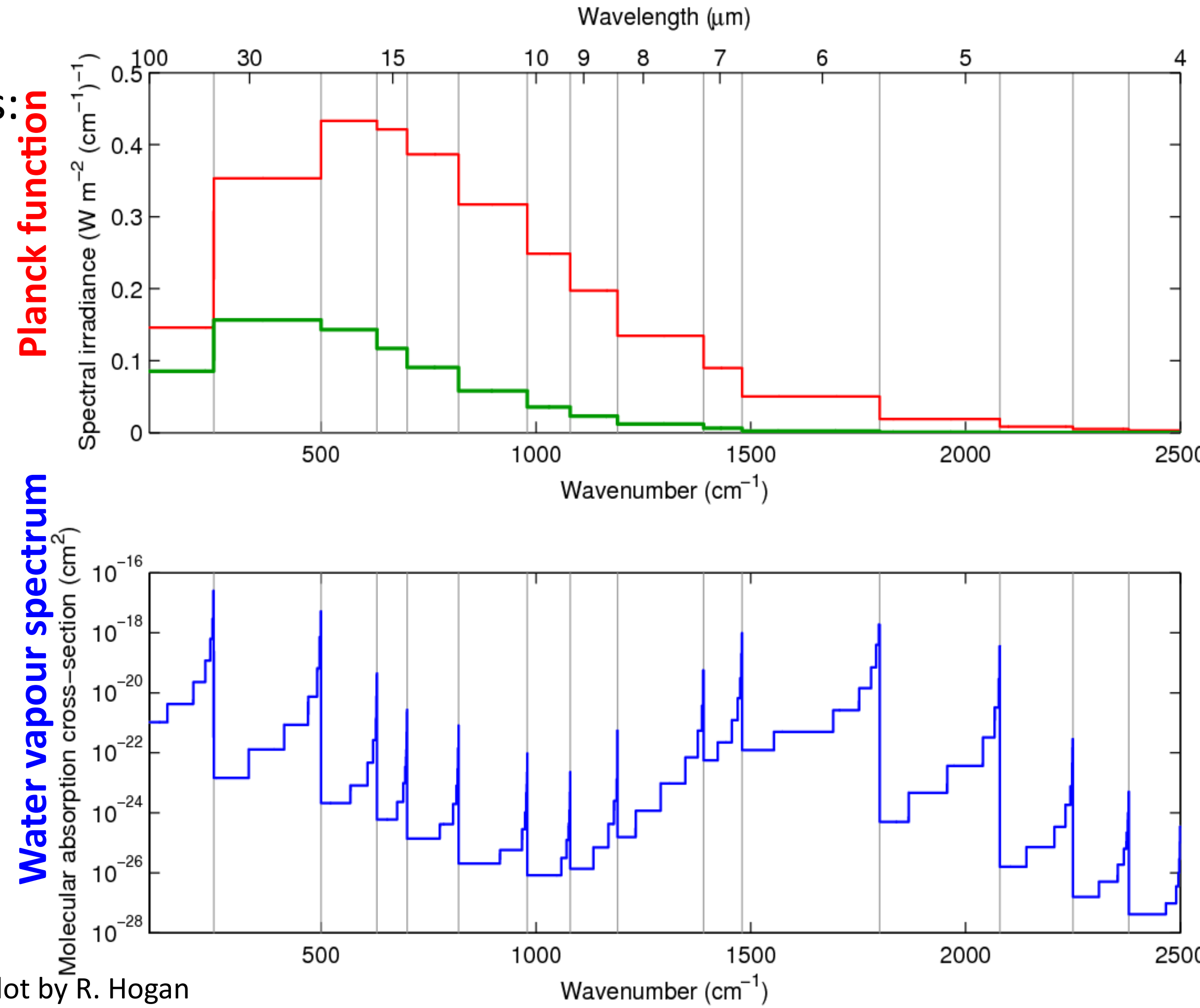
Current RRTMG gas optics

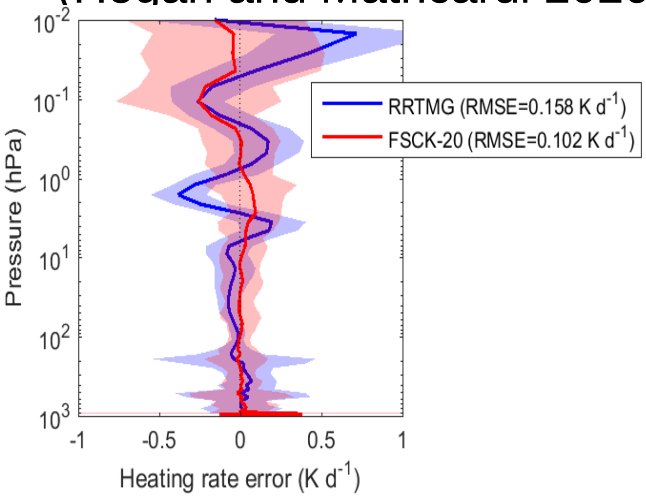
- Approximate Planck function, cloud+aerosol optics on bands: in RRTMG 14 SW + 16 LW
- Re-order in band by gas absorption, approximate on g-points → > 200 g-points
- Determines spectral dimension and code structure of most radiation schemes (incl. older ecRad versions)



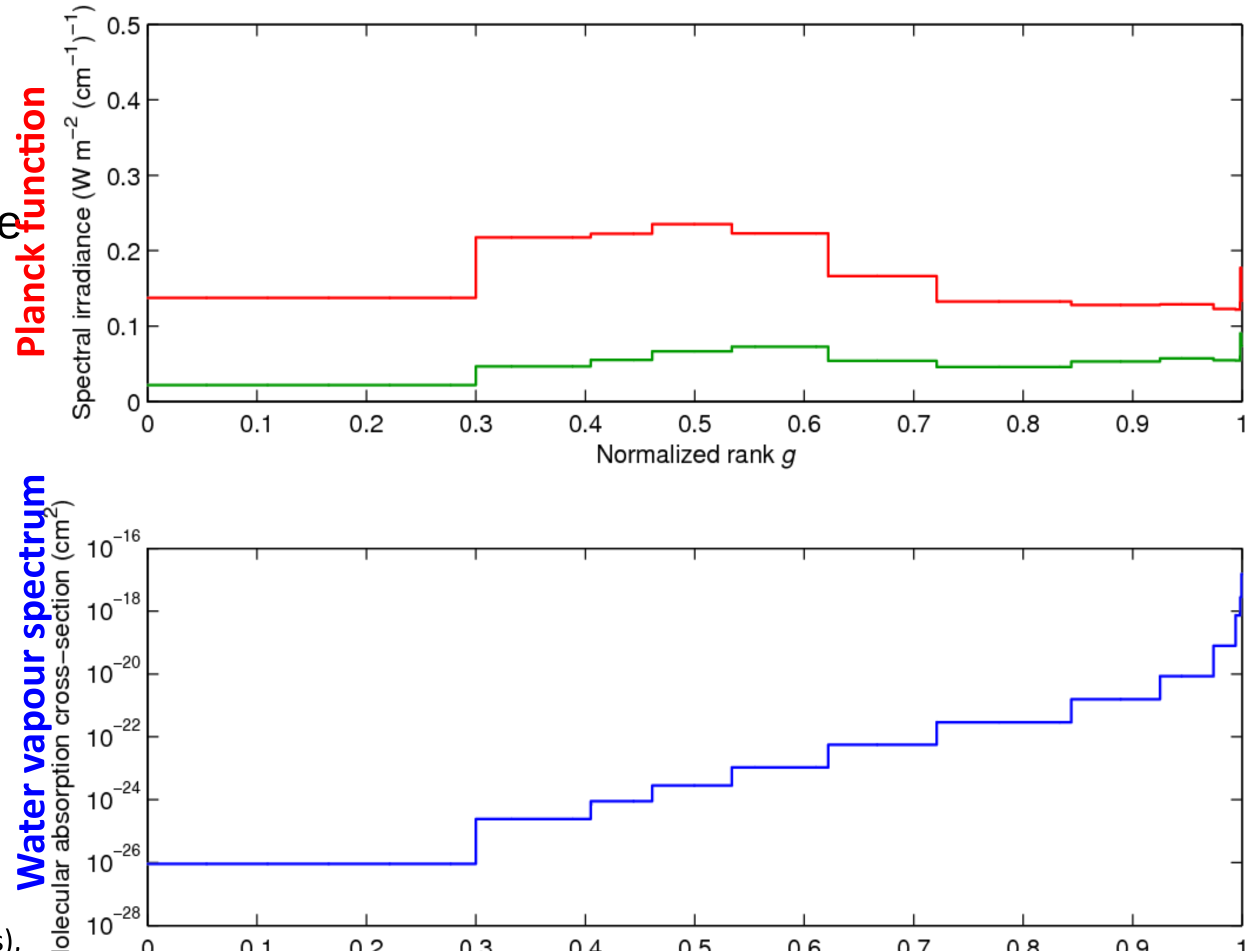
Plot by R. Hogan

ecCKD gas optics: full-spectrum correlated-k-method (Hogan 2010)

- Re-order whole spectrum, average Planck emission, cloud + aerosol optics interpolated onto chosen bands, more options available
- With 64 g-points: cheaper, more precise that RRTMG (Hogan and Matricardi 2020)



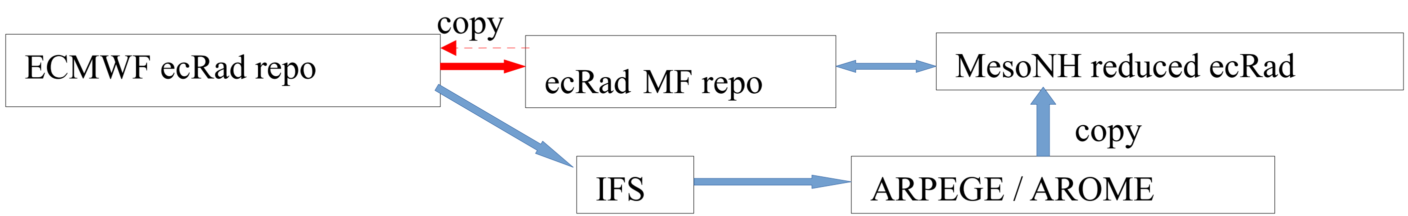
ecRad longwave heating rate error (50 test profiles), RRTMG (blue) and ecCKD gas optics (red)



Plots by R. Hogan

Implementation of ecRad in Meso-NH (consistent with ARPEGE/AROME, IFS)

Workflow:

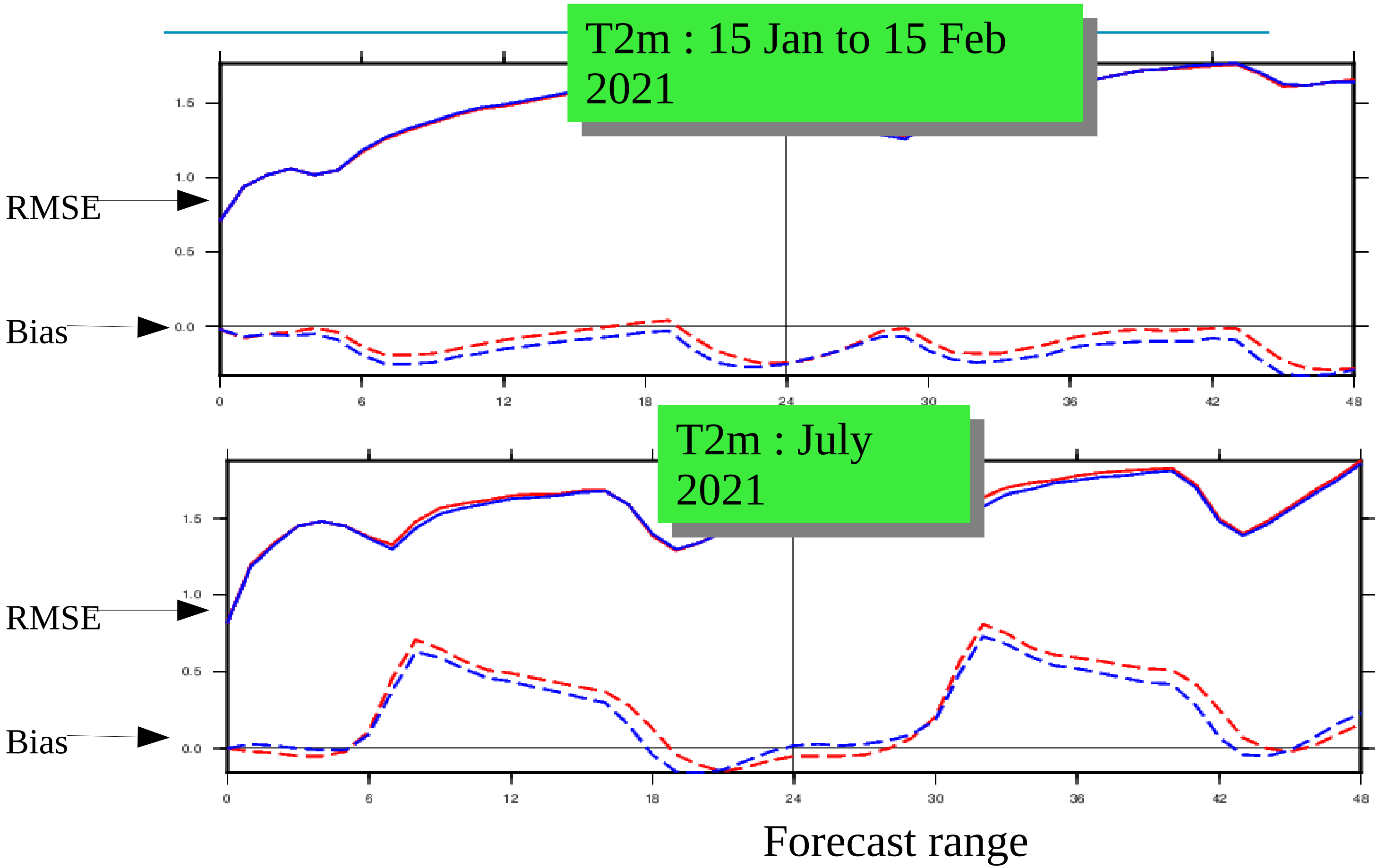


New cleaner implementation of ecRad and update to version 1.6.1 ongoing
Plan to include ecRad in Meso-NH as external library (also at ECMWF for IFS): easier, cleaner code, automated conversion offline ↔ online versions of ecRad (implementation ongoing)

Scientific options:
- Cloud optical properties accounting for particle shape distribution, habit: liquid (E. Jahangir), ice (M. Taufour)
- CAMS aerosol climatology
- Spectral emissivity

- Reduced radiation grid (implemented by V. Masson)

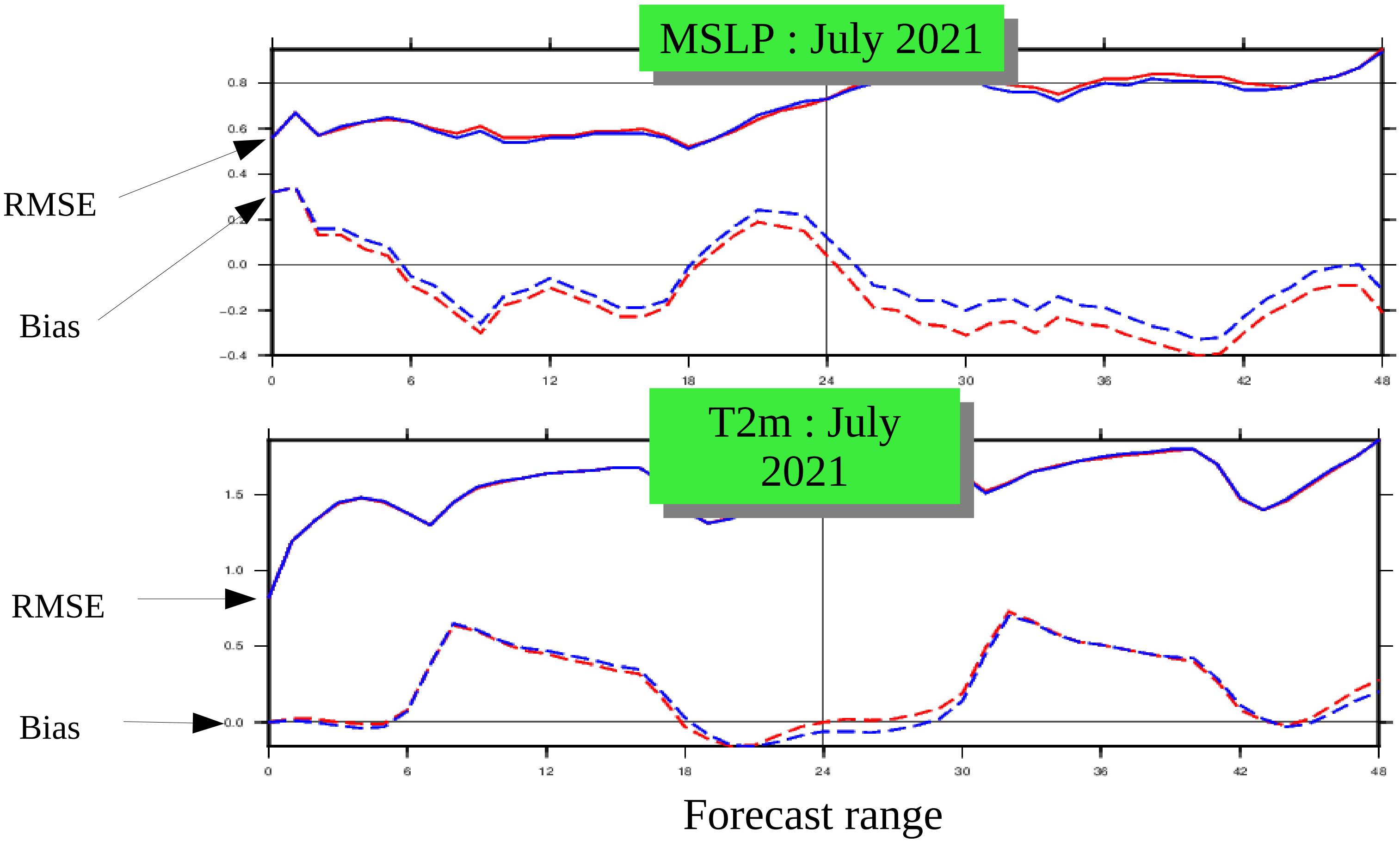
Comparison ecRad versus Operational



→ ecRad scores close to Operational, slight improvement

→ new optical properties also tested, little impact on scores (not shown)

Aerosol impact : ecRad+CAMSAERO versus ecRad



New CAMS aerosol climatologies available in ecRad:

2D in CY46T1,

3D in CY48T1

→ In July, improvements on surface pressure with CAMS Aerosol Climatology