ACRANEB2 radiation transfer scheme

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1. Basic facts about ACRANEB

ACRANEB is an economical radiative transfer scheme used in model ALADIN since 1990s. It splits electromagnetic spectrum into single shortwave and single longwave interval and thus must deal with broadband optical saturation for gases and clouds, as well as with non-random spectral overlaps between various absorbing species. ACRANEB employs several simplifying assumptions like:

- plane-parallel atmosphere composed of homogeneous layers
- multiple scattering accounted for by delta-two stream approximation combined with adding method
- simple treatment of cloud geometry assuming random or maximum-random overlaps between cloud layers
- aerosols and earth's surface treated as grey bodies
- absorbing gases H_2O, O_3 and CO_2+ (composite of CO_2, N_2O, CO, CH_4 and O_2, i.e. most important radiatively active gases with constant mixing ratios with respect to dry air)
- optical saturation based on idealized optical pahts
- non-homogeneous gaseous optical paths treated by Curtis-Godson approximation applied to Malkmus formula with empirical broadband correction
- longwave computations using NER (Net Exchanged Rate) formalism with bracketing

Key ACRANEB design feature is update of cloud optical properties at every model timestep, in order to have full feedback between radiation and clouds.

3. Some 3D results

Comparison with RRTM/FMR – summer day with frontal passage

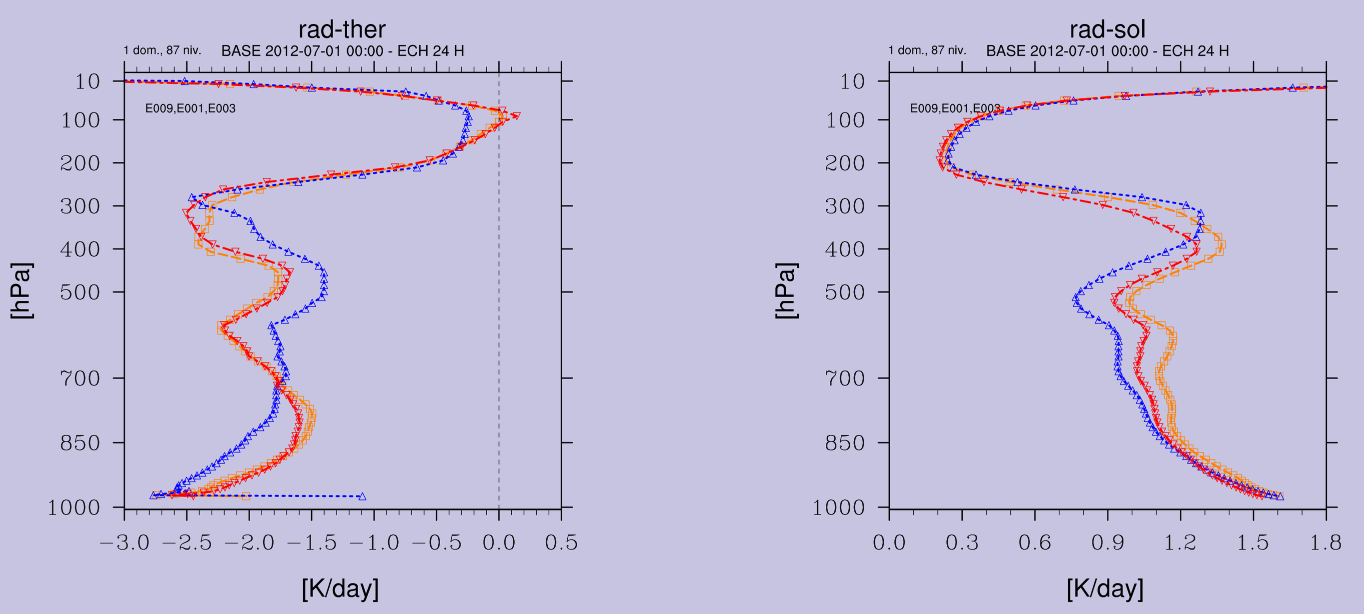

Figure 1: Longwave (left) and shortwave (right) domain averaged heating rates obtained from 24 hour ALARO integrations with different radiation schemes: red – RRTM/FMR reference; blue – ACRANEB; orange – ACRANEB2. RRTM/FMR scheme used cloud inhomogeneity factors 1 and options `NLIQOPT=2`, `NICEOPT=3`.

Verification of global radiation – 15 day summer convective period

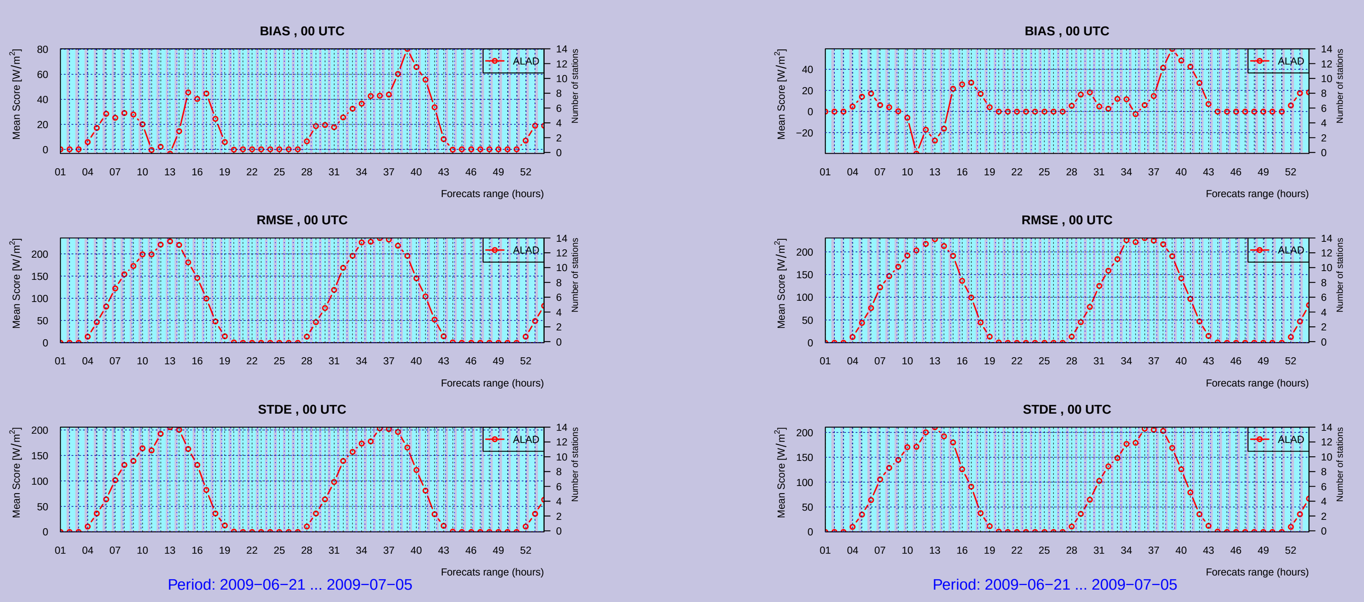

Figure 2: Basic scores of 1 hour global radiation verified against 14 Czech stations for each forecast lead time: left – ACRANEB; right – ACRANEB2. It can be seen that ACRANEB2 nicely reduces systematic error, but impact on RMSE is negligible since random error dominates.

6. Future challenges

ACRANEB2 baseline version reached mature stage and is ready for routine usage. Still, there are some issues which should be addressed sooner or later:

1. Activation of ACRANEB2 scheme with ALARO-0 settings increases bias of some model parameters on some levels. Likely reason are broken error compensations tuned for old ACRANEB. New physics tuning compatible with improved radiation scheme still has to be found.
2. True bracketing weights change with introduction of clouds, but they are taken from clearsky computation. Parameterization of cloud influence on them would enable use of statistical model and thus cheaper code.
3. Importance of spectral correlation between cloud and water vapor shortwave absorption has to be evaluated. If significant, its tractable parameterization will be needed.

2. Main novelties introduced by ACRANEB2

ACRANEB2 shares its basic assumptions with ACRANEB, but it improves several issues:

- Broadband gaseous transmissions were refitted against more up-to-date reference based on HITRAN 2008 line data [1]. Semi-empirical treatment of longwave water vapor e-type continuum was replaced by [2] and shortwave ozone continuum absorption was taken from [3]. Functional form of the fits was improved, revising temperature dependency of broadband Malkmus coefficients and shape of empirical correction accounting for secondary saturation. CO_2+ composition was updated to average atmospheric concentrations from year 2010 and CO was omitted due to its negligible influence in both shortwave and longwave spectral intervals.
- It was realized that longwave gaseous transmissions must be functions of two temperatures – layer temperature T and temperature of emitting body T_e. Common assumption $T_e = T$ turned to have strongly detrimental effect on longwave heating rates for typical atmospheric profiles. Implementation of $T_e \neq T$ compatible with NER scheme was achieved via linearization of Planck weights with respect to T_e around $T_0 = 255.8\,\mathrm{K}$.
- Non-random broadband spectral overlaps of all gaseous pairs were parameterized. While in shortwave band their impact is negligible, in longwave band they become significant.
- Increased cost of the new gaseous transmissions was reduced by their intermittent update in longwave band. Hourly update is sufficient for keeping required accuracy and making the cost affordable.
- Statistical model delivering bracketing weights for NER scheme was reformulated. It improves EBL (Exchange Between Layers) estimate when adjacent exchanges are excluded from EBL computation. However, accurate inclusion of clouds requires adjacent exchanges to be included in EBL flux and thus prevents use of statistical model.
- In order to bypass problem from the previous point, costly exact computation of bracketing weights is applied intermittently. It was shown that their 3 hourly update is accurate enough, while reducing the cost dramatically. It also removes problem with dependency of statistical fit on vertical resolution.
- Optical properties of ice clouds were refitted against more modern reference [4], since the old ice clouds [5] turned to be too thick. Water clouds use the same reference [6] as before. Optical saturation of shortwave cloud absorption was rederived using the same kind of formula as for secondary gaseous saturation. Computation of effective cloud optical depth in case of maximum-random overlaps between cloud layers was revised.
- Broadband saturation of Rayleigh scattering was parameterized, using reference data [7]. Parameterization relies on dominant role of primary scattering and takes the same shape as for saturation of shortwave cloud absorption. Correlation between Rayleigh scattering and gaseous absorption is ignored.
- Dependency of direct surface albedo on sun elevation given by heuristic Geleyn's formula was generalized by introducing proportion of Lambertian reflection. Setting this proportion to 0.6 greatly improves reflective properties of land and snow with respect to references [8,9].
- ACRANEB2 code was modularized and computation of direct surface albedo was moved to APLPAR (it applies only in ISBA case). Interfacing with SURFEX scheme was cleaned, ensuring consistent use of single shortwave interval and correct exchange of albedos and shortwave surface fluxes.

4. CPU cost

Efficiency of various radiation transfer schemes and intermittent strategies was evaluated for 24 hour ALARO integrations on operational CHMI domain ($\Delta x = 4.7\,\mathrm{km}$, 87 levels, $\Delta t = 180\,\mathrm{s}$). Their relative CPU cost with respect to integration using ACRANEB radiation scheme with statistical model and without any intermittency is given in table below:

radiative scheme	update frequency			relative CPU cost
	clouds	gases	bracketing weights	
RRTM/FMR	3 min	3 min	–	2.40
RRTM/FMR	1 h	1 h	–	1.03
ACRANEB	3 min	3 min	3 min	1.49
ACRANEB	3 min	3 min	3 min, statistical fit	1.00 (reference)
ACRANEB2	3 min	3 min	3 min	5.42
ACRANEB2	3 min	1 h	3 h	1.07 (baseline)

It can be seen that proposed ACRANEB2 baseline configuration (last row) increases integration user time by roughly 7%. These results are valid for NEC SX-9 platform with OpenMP parallelization using 8 threads.

5. Availability

ACRANEB2 baseline version entered official ARPEGE/ALADIN cycle 40t1, where it is available under both APLPAR and APL_AROME via new physics-dynamics interface INTFLEX. On APLPAR side it can be used both with ISBA and SURFEX surface schemes, while on APL_AROME side SURFEX is the only option. For backward compatibility, old ACRANEB was preserved under APLPAR. ACRANEB2 baseline version was backphased to cycle 38t1 locally at CHMI, where it is being extensively validated in the framework of ALARO-1 prototype.

7. References

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