RRTMG setup and accuracy assessment on ERA Interim reanalysis data

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RRTM (Rapid Radiative Transfer Model) [1] is a model based on the correlated-k approach [2, pp. 127–135]. RRTMG is the version of RRTM for use in climate modeling. This version's perfomance is not as accurate as of RRTM if compared to line-by-line radiative transfer models, but takes less computational time.

Here we set up RRTMG and assess its accuracy on ERA Interim dataset. In all the scatterplots in this paper, diagonal red lines show $y = x \pm 10$ Wm^{-2} thresholds, ideally we would like to have all the error fit within this range.

1 Methodology

To compute radiation fluxes and heating rates, RRTMG requires the following input:

- layer-wise and level-wise pressure and temperature profile;
- layer-wise mixing ratios of greenhouse gases (H_2O, CO_2, O_3, N_2O, CO, CH_4, O_2);
- layer-wise cloud fraction, cloud water path, fraction of ice and efferctive radii of liquid and ice particles;
- albedo, julian day of the year, latitude and solar zenith angle (for SW only).

Almost all the data needed to run RRTM for a single atmospheric column are available in (or can be derived from) ERA Interim (ERAi). Some additional data (GHG concentrations and cloud parlictles radii) are taken from MODIS Cloud Product and a standard polar winter profile. The whole structure of the input data is shown in Fig. 1.

The idea of the validation is to compare the radiation fluxes available from ERAi with those computed with RRTMG on ERAi profiles. As a target variable we use outgoing longwave radiation (OLR) and surface solar radiation downwards (SSRD) for longwave and shortwave parts respectively.

1.1 Data

- ERA Interim with $0.75^o \times 0.75^o$ grid and 6-hourly resolution
- MODIS Cloud product, downloaded as CERES SYN1deg 3-hourly data of particles effective radii for low, mid-low, mid-high and high clouds. Available over 2000-2016. For the events beyond this range or missing values, the 2000-2016 climo (for the corresponding month) is used.
- MIPAS Model Atmospheres (2001), polar winter, available at http://eodg.atm.ox.ac.uk/RFM/atm/

After the analysis of cold air mass formation, 4 events have been chosen for the validation:

- Jan 22–28 1993 at Kugluktuk,

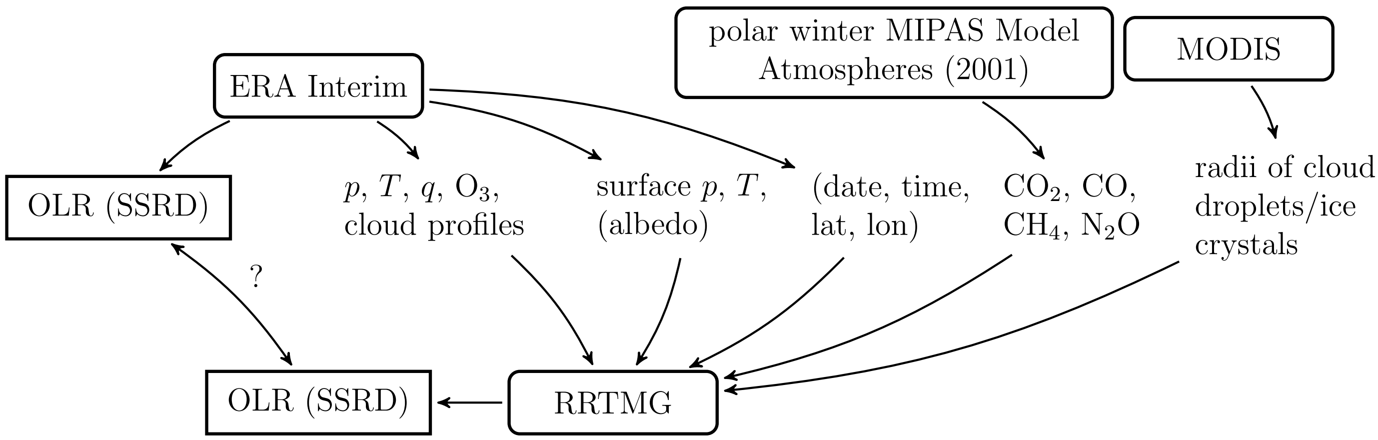

Figure 1: Schematic of the validation process. Items in brakets are used only for the SW part of the model.

- Jan 1–8 1994 at Norman Wells,
- Jan 8–15 2001 at Norman Wells,
- Dec 17–27 2005 at Fort Nelson.

All the ten stations listed in Table 1 are used in the scatterplots. For the scatterplots (Fig. 2) the whole months and all the 10 stations are used. In addition, for the SW analysis one summer month is chosen, so that the location is under polar day conditions:

- Jun 1996 at Sachs Harbour

1.2 Discrepancy sources

- From the Fig 1 one can see that the discrepancies can be partly attributed not to the RRTMG error itself, but to different input data, because we use some data from MODIS and MIPAS.
- Also, the radiation variables in ERAi are, first, a forcast (not an analysis), and are stored not as instant values, but as cumulative fluxes for 3, 6, 9 and 12 hours.

2 Longwave model validaton results

3-hourly OLR data for clear-sky/all-sky is taken from ERAi. RRTMG computes 6-hourly instant values of OLR with/without clouds based on ERAi atmospheric profiles. The goal was to achieve errors of less then 10 Wm^{-2}. Examples of OLR time series are shown in Fig. 3.

For the scatterplots in Fig. 2, we compare every other time step from ERAi to RRTMG.

For clear-sky: the mean error is of order 1 Wm^{-2} with rmse (root mean square error) of order 3 Wm^{-2}. 98.54% to 99.67% of calculations have errors of less than 10 Wm^{-2} in magnitude.

For all-sky: the mean error is of order 2 Wm^{-2} with rmse of order 8 Wm^{-2}. 77% to 92% of calculations have errors of less than 10 Wm^{-2} in magnitude.

3 Shortwave model validation

Because of the pronounced diurnal cycle in incoming solar radiation, the 6-hourly resolution is not sufficient for the validation of the SW model. Therefore, we interpolate 6-hourly data to 3-hourly resolution.

3.1 Albedo

Surface albedo is required for the SW model to set the surface emissivity. One must use 3h-resolution "forecast albedo" from ERA Interim instead of "albedo" (which is climo). The "forecast albedo" variable is in good agreement with what we tried to calculate as $(1 - \frac{\text{surface solar radiation downwards}}{\text{surface net solar radiation}})$ Unfortunately, a clear-sky SSRD is not available in ERAi, but we derive clear-sky SSRD as $\frac{\text{net surface solar radiation (clear-sky)}}{1-\text{albedo}}$.

3.2 Solar zenith angle

Another issue is solar zenith angle calculation. For the solar zenith angle computation, we use the formula A.2 from [3, pp. 347–349]:

$$\cos\theta_s = \sin\phi\sin\delta + \cos\phi\cos\delta\cos h,$$

where h is the solar hour angle, δ is the solar declination angle and ϕ is the latitude. h and δ must reflect the diurnal and annual cycles.

ERAi time steps for the atmospheric profiles are 00, 06, 12, 18 UTC hours.

ERAi time steps for the radiation variables are at 03, 06, 09, 12, 15, 18, 21, 24 UTC hours, however the radiation values which correspond to these time steps are not instant. ERAi contains cumulative radiation fluxes in $\mathrm{Jm^{-2}}$, so the derived mean values must be attributed to 01:30, 04:30, 07:30, 10:30, 13:30, 16:30, 19:30, 22:30 UTC respectively.

If one input instant time values for the solar zenith angle (SZA), the errors are reasonable during the daytime (high values of TOA incident solar radiation (TISR)), however the errors are large at sunset/sunrise time. It means that the average 3-hourly solar radiation flux cannot be attributed to an instant SZA value.

Therefore, we have tried to input an average SZA instead of an instant SZA. Here is an example of a computation attributed to ERAi cumulated TISR at 03z:

1. compute 31 values of SZA from 00z to 03z with 6 minutes time step;
2. replace the values larger than 90 (degrees) with 90;
3. take the mean.

Furthermore, a first-guess formulas for the hour and the declination angles are $h = \lambda + 360\frac{(t-12)}{24}$ and $\delta = 23.45\sin\left((\mathrm{d}-81)\frac{2\pi}{365}\right)$, where λ is the longitude, t is time of the day and d is day of the year.

However, these simple sine-like functions do not reflect the annual cycle properly. Instead, one must use more precise parameterizations, that take into account the ellipticity of the Earth's orbit. We use the parameterization adapted from:
https://en.wikipedia.org/wiki/Equation_of_time
http://www.psa.es/sdg/sunpos.htm.

With all these taken into account, the good accuracy of the final solar input computation is demonstrated by the top incident solar radiation (TISR) plots, see Fig. 4.

3.3 Results and discussion

The results for SSRD (clear sky) are shown in Figs. 5 and 6.

Even though there is a systematic bias in solar input in Fig. 4, it is not directly reflected in the results for SSRD. In Fig. 7 one can see that the correlation between biases in TISR computation and SSRD computation is not robust, it changes its sign and magnitute from one location to another, especially in winter months. Therefore, a further improvement of TISR results is not undertaken.

4 References

[1] E. J. Mlawer, S. J. Taubman, P. D. Brown, M. J. Iacono, and S. A. Clough, "Radiative transfer for inhomogeneous atmospheres: RRTM, a validated correlated-k model for the longwave," *Journal of Geophysical Research: Atmospheres*, vol. 102, no. D14, pp. 16663–16682, 1997.

[2] K.-N. Liou, *An introduction to atmospheric radiation*, vol. 84. Academic press, 2002.

[3] D. L. Hartmann, *Global physical climatology*, vol. 103. Newnes, 2015.

Table 1: Coordinates of the ten stations used in scatterplots

Station	Latitude, °N	Longitude, °W
Sachs Harbour	72.0	125.3
Inuvik	68.3	133.5
Kugluktuk	67.8	115.1
Norman Wells	65.3	126.8
Yellowknife	62.5	114.4
Fort Simpson	61.8	121.2
Fort Smith	60.0	112.0
Fort Nelson	58.8	122.6
Fort McMurray	56.7	111.2
Grande Prairie	55.2	118.9

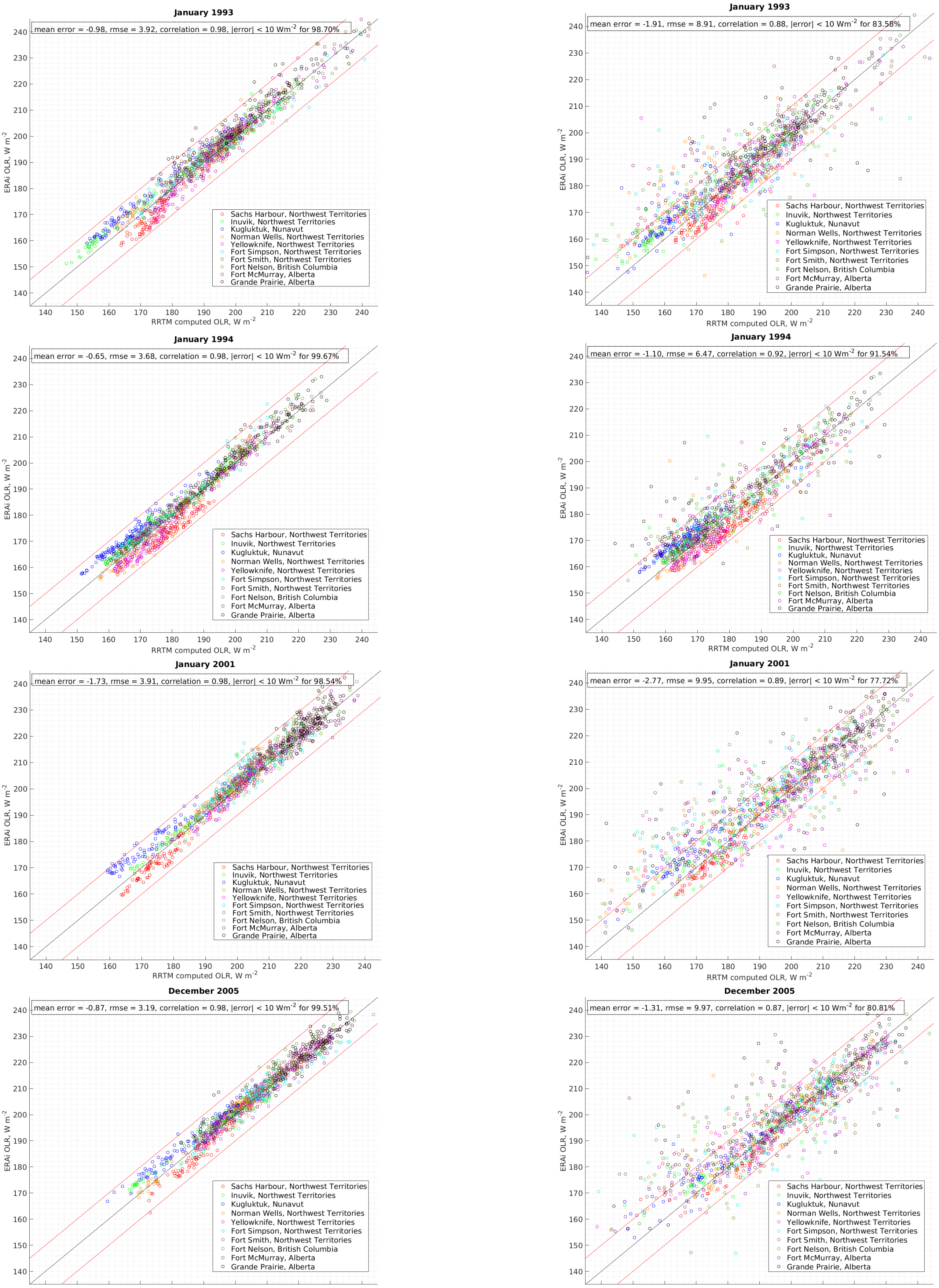

Figure 2: Scatterplots for RRTMG_LW validation. 4 months, clear-sky/all-sky cases.

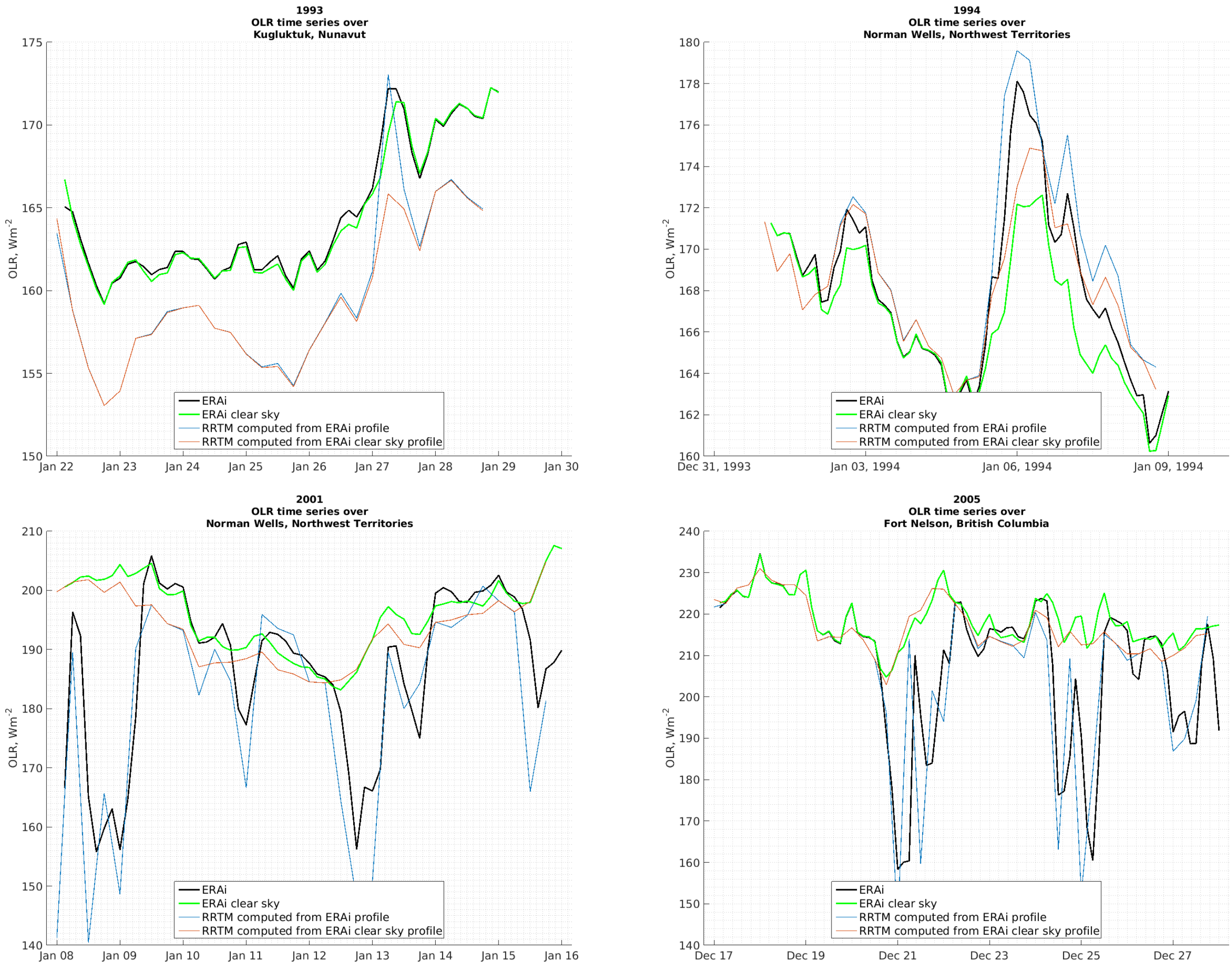

Figure 3: Examples of OLR time series, clear-sky and all-sky cases. Ideally blue and black, red and green lines would match.

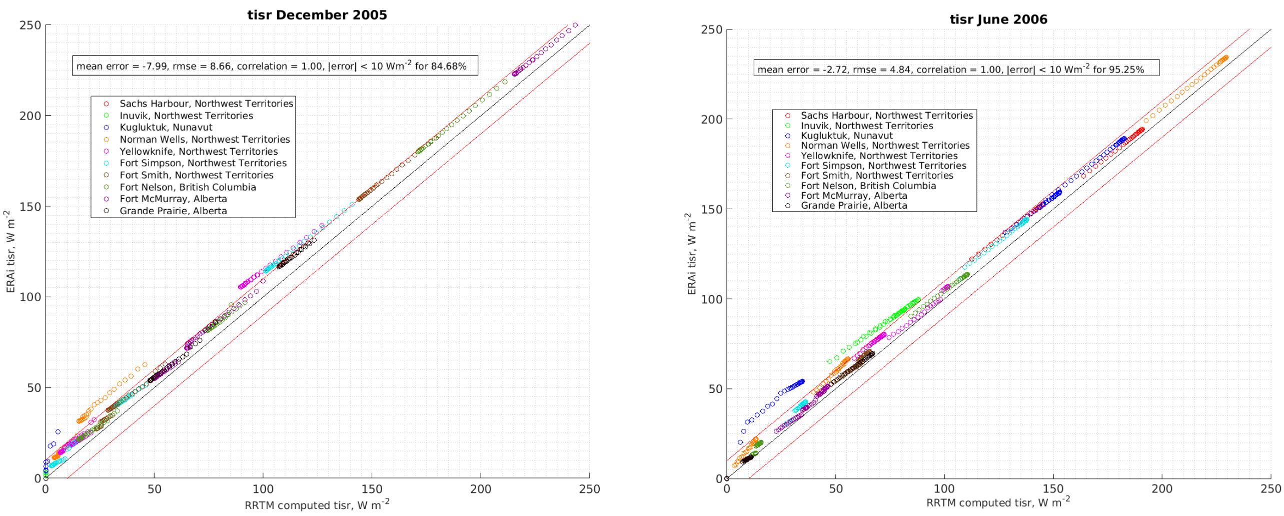

Figure 4: Scatterplots for solar geometry validation: TOA incident solar radiation, a winter and a summer cases.

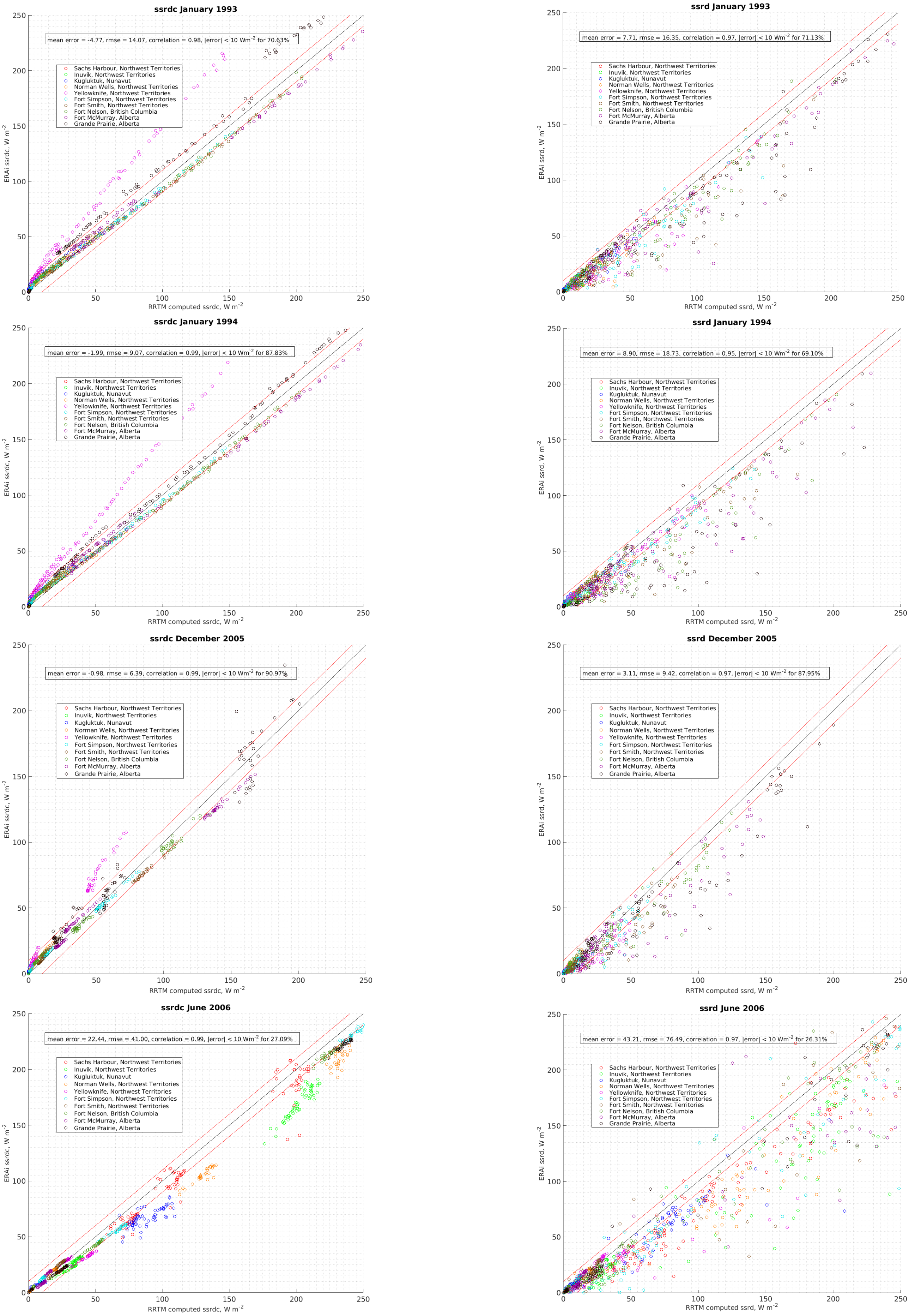

Figure 5: Scatterplots for RRTMG_SW validation: surface solar radiation downwards, clear-sky/all-sky cases. 4 months, three winter and one summer cases.

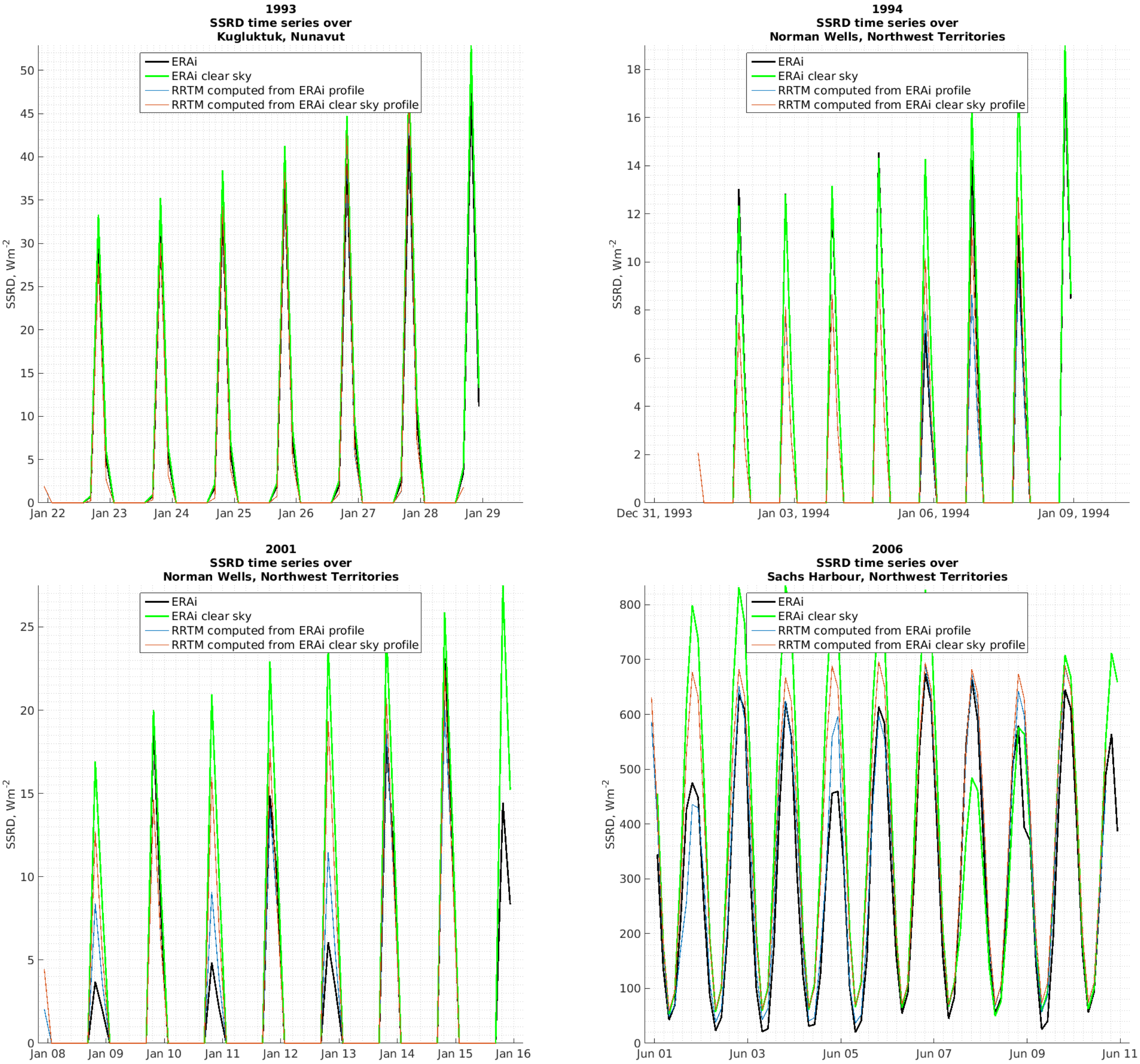

Figure 6: Examples of SSRD time series, clear-sky and all-sky cases. Ideally blue and black, red and green lines would match. 4 months, three winter and one summer cases.

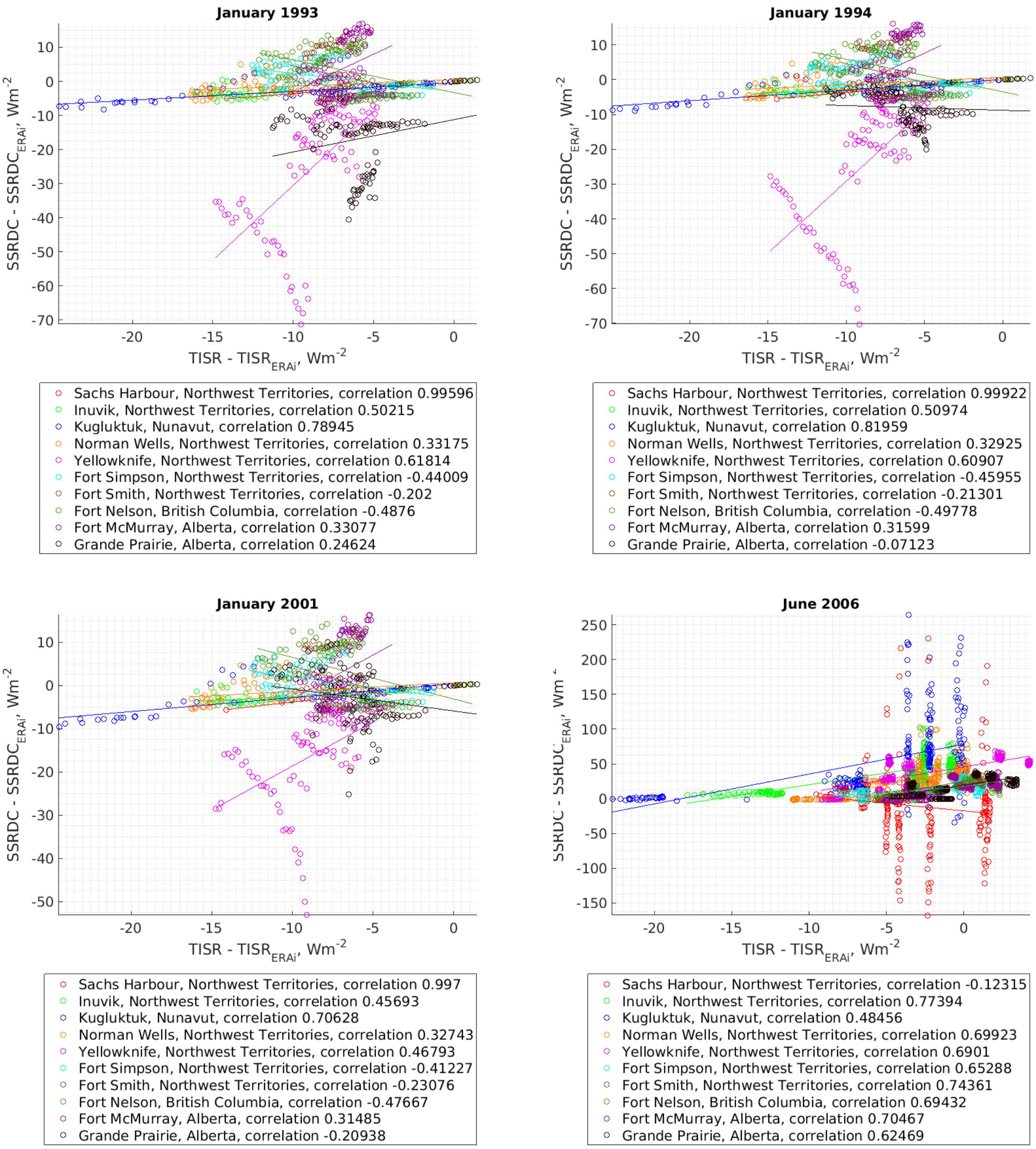

Figure 7: Correlation coefficients between TISR errors and SSRD(clear sky) errors.