Simulation of GK2A visible channel imagery and its application

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1. Introduction

Simulated satellite images are a good indicator of the state of atmosphere and cloud feature described by the fields predicted by numerical weather prediction (NWP) models. KMA has produced model-simulated images of Infrared (IR) and Water Vapor (WV) channels based on Geo-Kompsat 2A(GK2A) Since 2018. Simulated satellite images are calculated from various NWP model output fields such as Korean Integrated Model(KIM), Unified Model(UM) operated by KMA, European Centre for Medium Weather Forecasts(ECMWF) model via FTP using by Radiative Transfer for TOVs(RTTOV) model. For simulated satellite images in visible channels, we used the Method for Fast Satellite Image Synthesis(MFASIS) developed by Scheck et al.(2016) in RTTOV version 13.0. Simulated visible satellite images provide very useful information about the cloud distribution and cloud microphysical properties. This work evaluated the performance of simulation of visible satellite images using the fast RT method available in RTTOV and forecast fields of NWP models. This results are utilized for generating Day-night RGB and true-color RGB images combined by simulated visible and infrared channel images. Simulated RGB images will be expected to helpful for analyzing cloud properties more detail than simulated infrared satellite images.

2. Data and Method

❖ Input data – NWP model forecast fields

- KIM and UM: The operational global models at KMA
- ECMWF: NWP data obtained from ECMWF

	KIM	UM	ECMWF
Domain	Global	Global	Northern hemisphere
Horizontal resolution	12km	10km	0.25 degree
Vertical layer/Top	91 / ~80km	70 / ~80km	25 / 1 hPa
Forecast time (Initial time)	288 hours (00, 12 UTC) 87 hours (06, 18UTC)	288 hours (00, 12 UTC) 87 hours (06, 18UTC)	240 hours (00, 12 UTC)

❖ GK2A/AMI satellite observation

- The Advance Meteorological Imager (AMI) on GK2A has 4 visible channels and 12 infrared channels. The reflectance of satellite visible channel is used to compare with reflectance simulated by using RTTOV

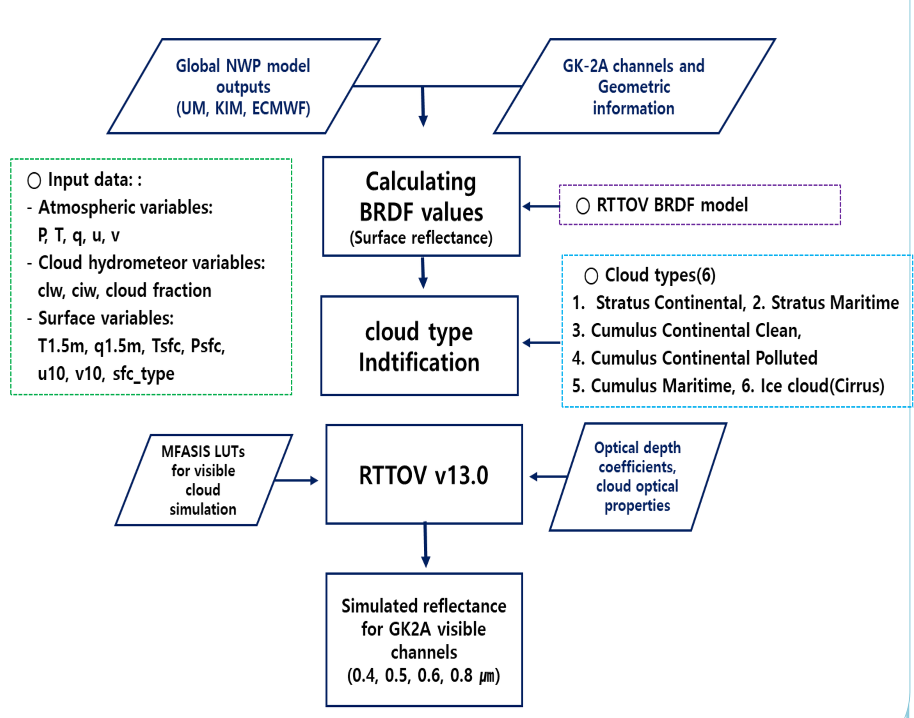
❖ Usage of MASIS LUT for visible cloud simulation

- MFASIS(Scheck et al., 2016) is a fast 1D radiative transfer model based on a look-up-table(LUT) approach. MFASIS describe relevant atmospheric properties and geometry by a minimal parameter set.
- The reflectance LUTs are precomputed for all parameter combinations using the Discrete Ordinate Method (DOM) implementation available in RTTOV

❖ Input variables for cloud simulations with RTTOV

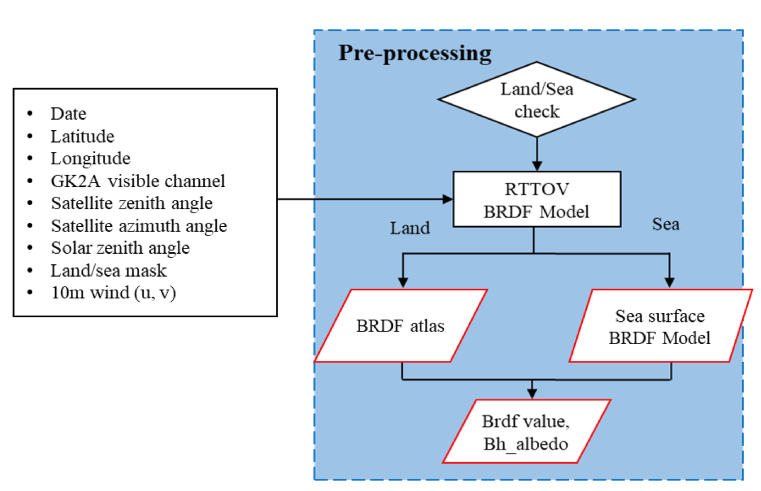
Category	Variable name	Unit
Atmospheric variables	Pressure(level) Temperature(level) Specific humidity mixing ratio(level)	hPa K kg/kg → ppmv
Surface variables	Land/Sea type Skin temperature Surface pressure Temperature at 2m Specific humidity at 2m 10 wind u-component and v-component	- K hPa K kg/kg m/s
Geometric information variables	Satellite zenith angle Satellite azimuth angle Sun zenith angle Sun azimuth angle	Degree
Cloud hydrometeor variables	Cloud liquid water profiles(clw) Cloud ice water profiles(ciw) Area cloud fraction	kg/kg kg/kg -

❖ Flowchart for simulated satellite reflectance retrieval



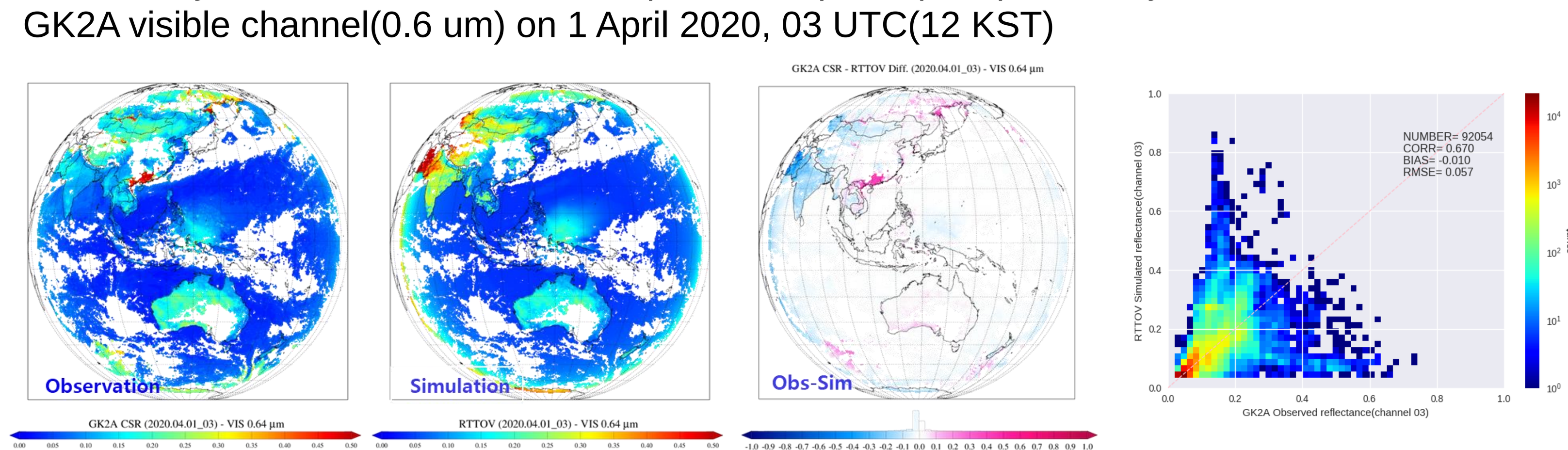
3. Retrieval of BRDF reflectance

❖ Flowchart of retrieval of BRDF relfectance



- Calculation BRDF reflectance of Land or Sea Type
  Land: BRDF atlas provides monthly climatology which returns BRDF values over land.
  BRDF atlas improved by using the C6(Collection 6) of MODIS product MCD43C1 .
  Sea: BRDF value over sea used to obtain from the internal BRDF sea surface model.
  The surface reflectance used as input for RTTOV-MFASIS are derived from RTTOV BRDF atlas(Vidot et al., 2018).

❖ Case Study: Observed vs simulated top of atmosphere(TOA) clear sky reflectance of GK2A visible channel(0.6 um) on 1 April 2020, 03 UTC(12 KST)



- Simulated TOA reflectance of GK2A visible channel show the underestimation of reflectance very close to limb. It indicate that this negative bias is mainly associated with large value of satellite zenith angle. The positive bias is due to contamination of cloud edge.

4. Cloud type indentification

❖ The conversion equation for ice cloud is:

$$IWC = qice\frac{10^2P}{R_{moist}T} \qquad R_{moist} = Rdr_y(1+\frac{1-\varepsilon}{\varepsilon}q_{h2o}) \qquad \varepsilon = \frac{M_{h2o}}{M_{dry}} \qquad R_{dry} = \frac{R}{M_{dry}}$$

- IWC : ice water content
- q_{ice} : mass mixing ratio for ice cloud
- P : atmospheric pressure in hPa
- T : atmospheric temperature in K
- R_{moist} : moist air gas constant (in $Jg^{-1}K^{-1}$)
- R_{dry} : gas constant for dry air
- qh2o : specific humidity
- M_{h2o} : 18.01528 g mol^{-1}
- M_{dry} : 28.9664 g mol^{-1}
- R : 8.3144598 J mol^{-1} K^{-1}

* The same equations are used liquid cloud, by replacing IWC by LWC

❖ Cloud types available in RTTOV v13

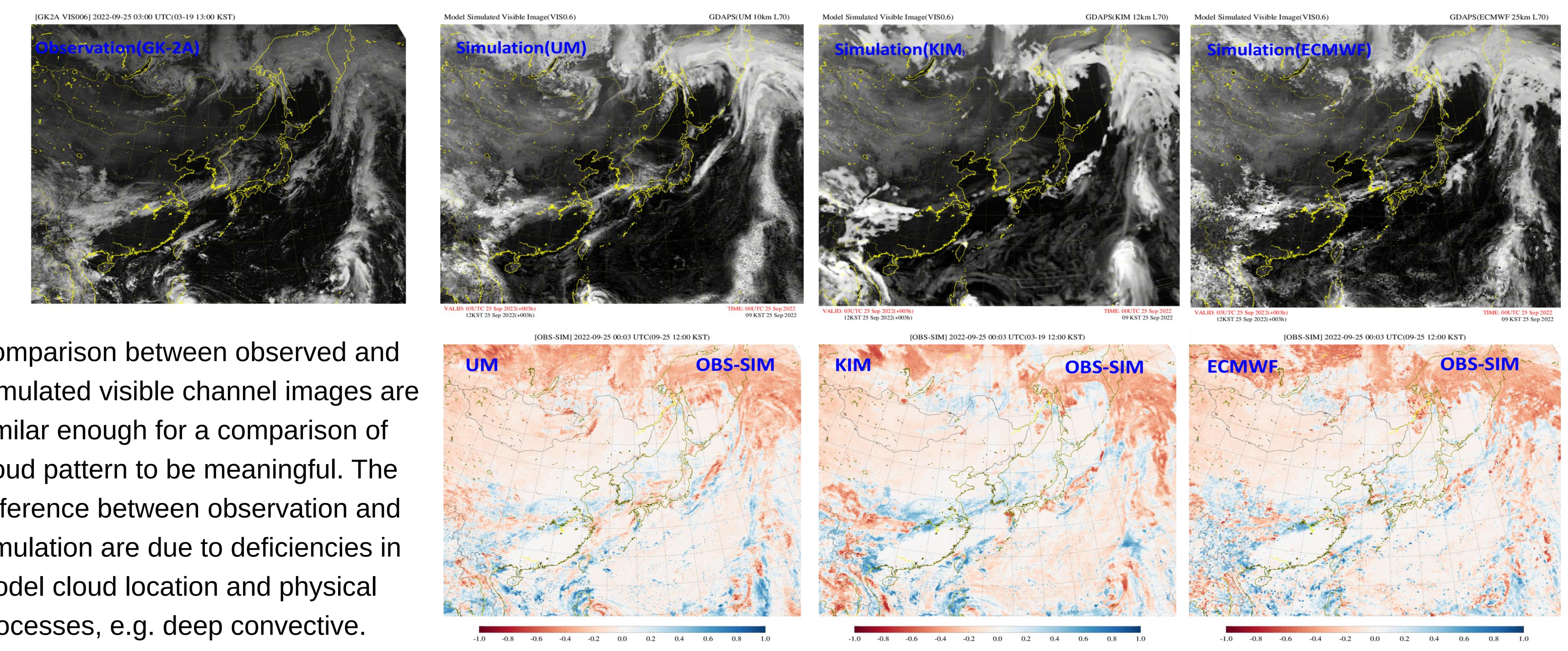
Column	Cloud type	Surface type	Threshold value
1	Stratus Continental	Land	LWC < 1 g/m³
2	Stratus Maritime	Ocean	LWC < 1 g/m³
3	Cumulus Continental Clean	Land	LWC ≥ 1 g/m³
4	Cumulus Continental Clean	-	None
5	Cumulus Maritime	Sea	LWC > 1 g/m³
6	Ice cloud(Cirrus)	Land and Sea	IWC > 6.0x10⁻⁶ and IWC < 1.969466

- In this study, the predefined cloud liquid water optical properties are based on five OPAC cloud types and ice cloud optical properties are used MFASIS LUTs trained using Baum ice cloud optical properties.
- To simulate a cloudy reflectance at visible channels, we applied the developed algorithm(Razagui et al., 2018) based on a threshold for both values of Liquid Water content(LWC) and Ice Water content(IWC).
- NWP model provide cloud information in unit of mass mixing ratio in kg/kg. We converted unit from massing mixing ratio for ice cloud/water cloud to LWC/IWC.

5. Results and its application

❖Comparison between observed and simulated visible channel(0.6μm) satellite images over East Asia

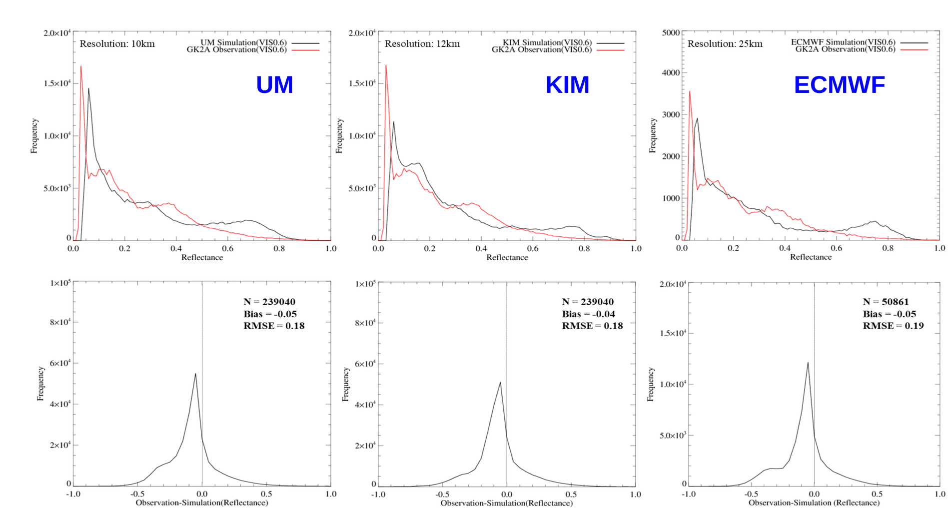
- Case: 25 September 2022, 03 UTC



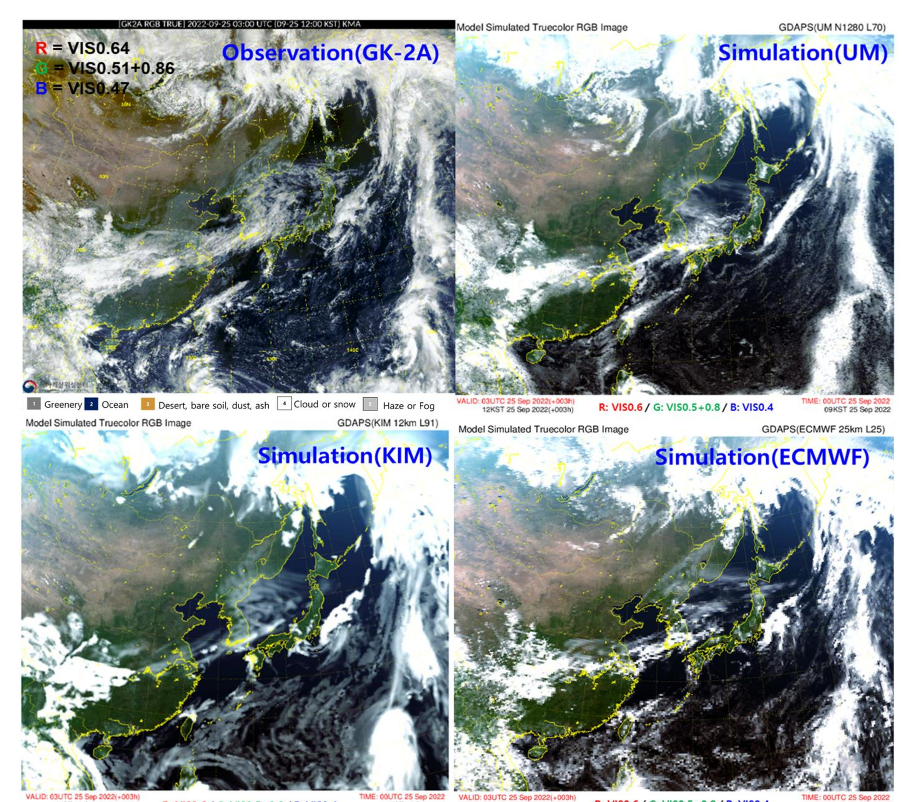
Comparison between observed and Simulated visible channel images are similar enough for a comparison of cloud pattern to be meaningful. The difference between observation and simulation are due to deficiencies in model cloud location and physical processes, e.g. deep convective.

❖ Frequency distribution of observed and simulated reflectance for visible channel(0.6μm)

The shapes of the frequency distribution for observed reflectance and simulated agree fairly well. But, for all three models(UM, KIM, ECMWF), simulated reflectance overestimates the occurrence of higher reflectance. These results are typically associated with thick cloud situation and snow cover region above 0.5 reflectance. The difference between observation and simulation show Gaussian distribution. The bias and RMSE between observed and simulated reflectance for visible channel(0.6μm) are less than -0.05 and 0.2, respectively.



❖ Application: Comparison of observed and simulated true-color RGB images.

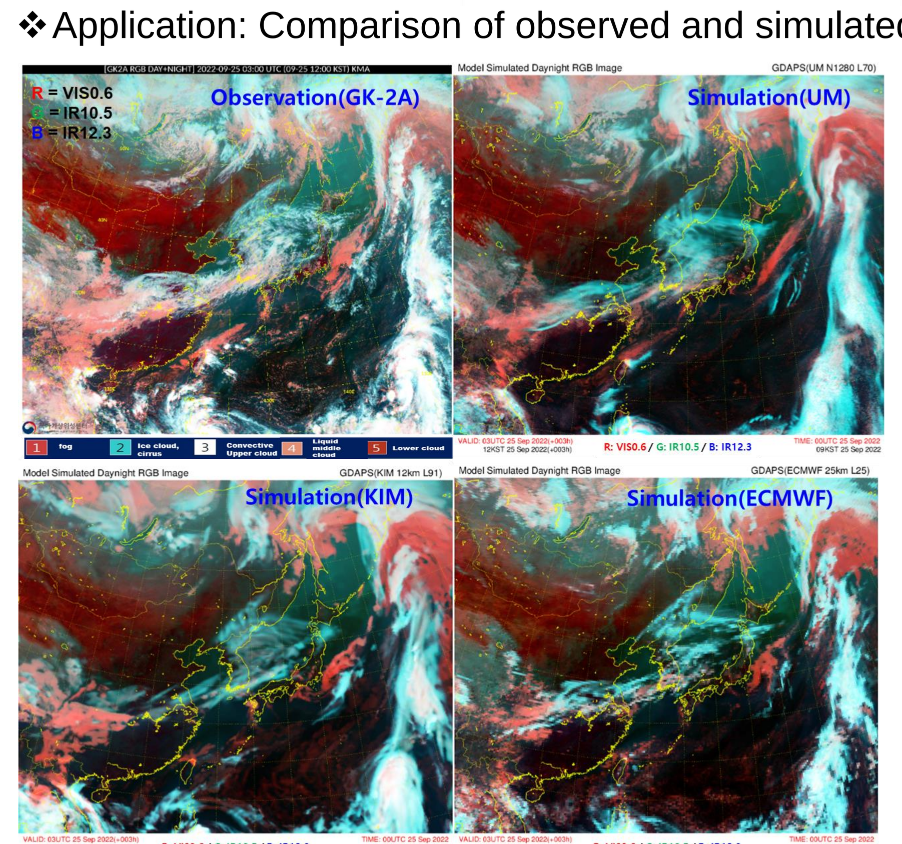


In this study, true-color RGB images obtained by combining reflectance in visible channels(R:0.6, G:0.5+0.8, B:0.4μm).

The comparison of these four images illustrates the fact that the overall agreement between simulated and observed true-color RGB images is better in middle latitude than in high latitude region.

Although the simulated true-color RGB images from the each NWP models show coarser than observed satellite images, the comparison between images can be useful in operational forecasting, to help assess the quality of analysis and very short-range NWP forecasts.

❖Application: Comparison of observed and simulated day-night RGB images



Day-night RGB images obtained by combining data in a visible channel(R0.6 μm)and two infrared channels(G:10.5, B: 12.3μm).

The interpretation of Day-night RGB image are as follows:

- Red color: fog/low-level cloud, cumulus
- Blue color: high level cloud
- White color: cumulonimbus
- Black color: ocean

To evaluate the performance day-night RGB image simulated using by RTTOV for the each NWP models(UM, KIM ECMWF), Simulated images are compare with image observed from GK2A. Overall patterns and properties of cloud in large scale are good agreement between observation and simulation.

6. Summary

- RTTOV version 13.0 based on MFASIS LUT is used to simulate visible channel reflectance observed from GK2A/AMI.
- We evaluated visible channels reflectance simulated using by RTTOV-MFASIS and forecast fields of three NWP models (KIM, UM, and ECMWF) against GK-2A observation. The simulated visible reflectance showed good results when compared with observed reflectance.
- The simulated true-color and day-night RGB images will be useful in operational forecasting, to help assess the performance of cloud simulation in very short-range NWP forecasts.

Reference

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- Scheck, Ferebeau, Buras-Schnell, Mayer(2016): A fast radiative transfer model for the simulation of visible satellite imagery, J. Quant. Spectrosc. Radiat. Transf., 175, 54-67.
- Vidot, J., Brunel, P., Dumont, M., Carmagnola, C., and Hocking, J.(2018): The VIS/NIR Land and Snow BRDF Atlas for RTTOV: Comparison between MODIS MCD43C1 C5 and C6, Remote Sens.