Retrieval of Cloud Thermodynamic Phase Using IR Channels

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Météo France/CNRM/CEMS/Nuages

March 10, 2020

Motivations : Cloud Phase determination

State

- liquid water
- ice water
- supercooled water (liquid water below the freezing point)
- a mix between liquid water and ice water

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- infer optical and microphysical properties
- forecaster/aeronautic
- remote sensing applications

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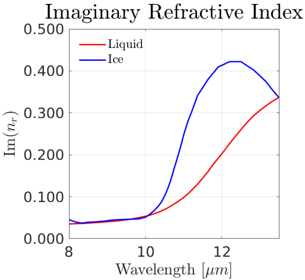
Status

- based on brightness temperature difference $(\mathrm{BT}_{\sim 8.7} - \mathrm{BT}_{\sim 10.8})$
- investigation for the new FCI radiometer on MTG is necessary
- new approach based on spectral variability of cloud absorption
- study based on simulated radiance with RTTOV

Background on retrieving cloud thermodynamic phase

Absorption of electromagnetic radiation depends on $\mathrm{Im}(n_r)$



- $\lambda \in [8.5,\ 10]$ μm: liquid water and ice absorb approximately equally
- $\lambda \in [11,\ 12.5]$ μm: ice absorbs more strongly than water.
- When **everything else being equal** (atmosphere, effective radius, . . .)

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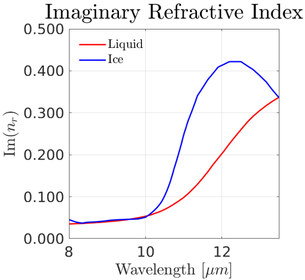

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Principle of cloud phase retrieval

$$[\mathrm{BT}_{\sim 8.7} - \mathrm{BT}_{\sim 10.8}]^{Ice} > \mathrm{BTD}_{\mathrm{thresh}} > [\mathrm{BT}_{\sim 8.7} - \mathrm{BT}_{\sim 10.8}]^{Liquid}$$

- Thresholds depend on satellite, time of the day, geolocalization, atmosphere ...
- Thresholds are set up by experience (*cf.* ATBD)
- Good enough for MSG-Seviri and other GEO (GOES-16, Himawari)
- What about MTG-FCI?

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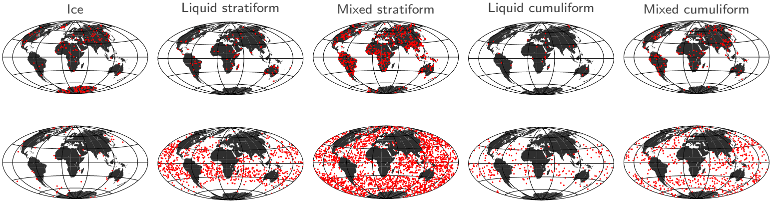
A simulation study with the ECMWF diverse profile data

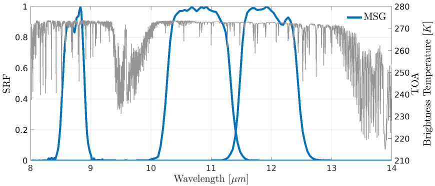
Simulation study

- Diverse profile datasets ECMWF 137 levels: 25000 profiles
- We use 4348 of realistic 1-dimensional clouds

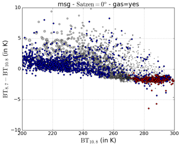


- Super fast radiative transfer code RTTOV (absorption/emission + diffusion by clouds)
- Ice cloud: parameterization Baum + Boudala (heritage from H. Le Gléau)
- GEO sensors: MSG, GOES-16, Himawari, MTG

Brightness Temperature Difference approach: MSG, GOES, Hima and MTG



- The MSG 10.8 μm band has been shifted towards lower wavelength on Himawari and MTG
- MTG is missing the 11 μm band



MSG / *vza*=0
$\lambda_1 = 8.7$, $\lambda_2 = 10.8$

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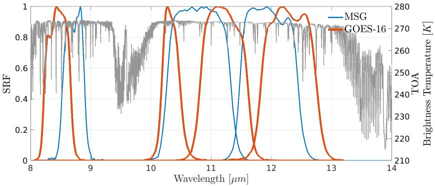

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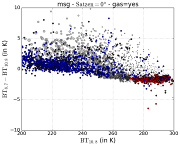

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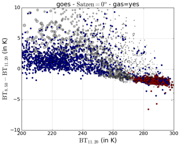

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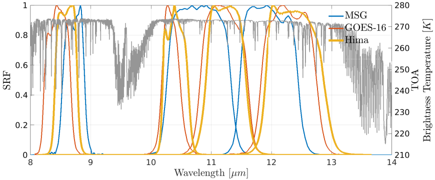

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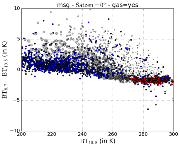

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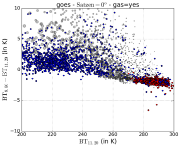

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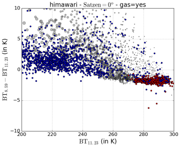

Hima / *vza*=0
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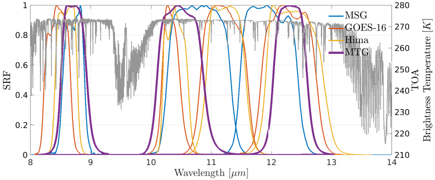

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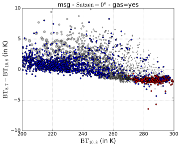

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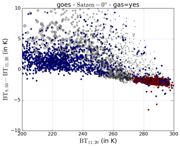

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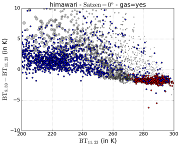

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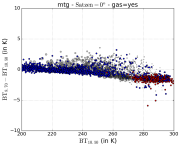

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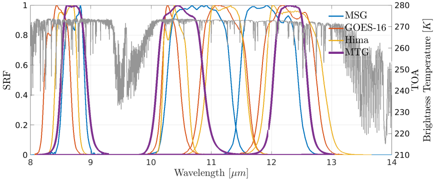

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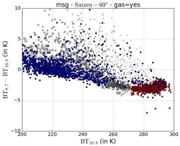

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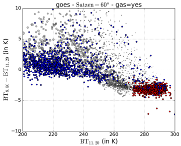

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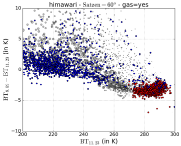

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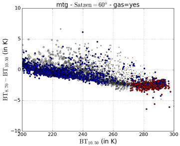

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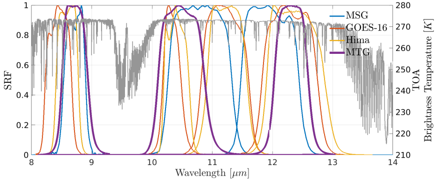

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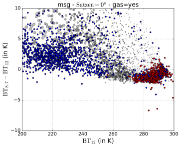

MSG / *vza=0*
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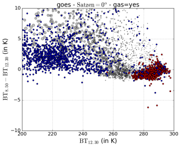

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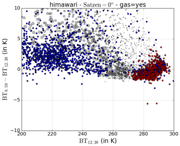

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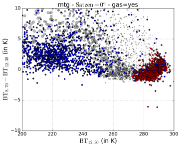

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- With the $\sim 12 - 12.4$ μm bands: significant overlap

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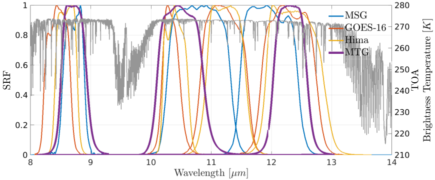

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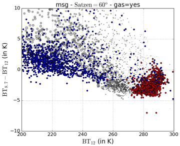

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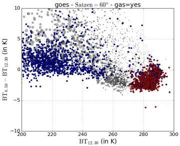

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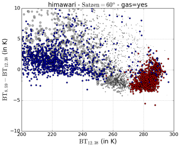

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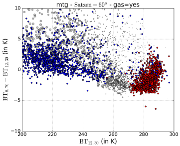

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The β-ratio approach: Theory

Relationship between cloud emissivity and cloud effective extinction coefficient (Inoue, *JMSJ*, 1984):

$$\epsilon(\lambda) = 1 - \exp\big(-\beta(\lambda) z\big)$$

Equating between 2 wavelengths (spectral bands) λ_1 and λ_2 leads to:

$$\beta' = \frac{\beta(\lambda_1)}{\beta(\lambda_2)} = \frac{\ln\left[1 - \epsilon(\lambda_1)\right]}{\ln\left[1 - \epsilon(\lambda_2)\right]}$$

From the Shwarzschild equation we can solve for the effective cloud emissivity ϵ:

$$\epsilon(\lambda) = \frac{\mathcal{R}_{\mathrm{obs}}(\lambda) - \mathcal{R}_{\mathrm{clr}}(\lambda)}{\underbrace{\left[\mathcal{T}_{\mathrm{ac}}(\lambda) B(\lambda, T_{\mathrm{eff}}) + \mathcal{R}_{\mathrm{ac}}(\lambda)\right]}_{\mathcal{R}_{\mathrm{blk}}(\lambda)} - \mathcal{R}_{\mathrm{clr}}(\lambda)}$$

- $\mathcal{R}_{\mathrm{obs}}$: RTTOV-DOM (Discrete Ordinate Method for diffusion)
- $\mathcal{R}_{\mathrm{clr}}$: Clear sky (absorption/emission)
- $\mathcal{R}_{\mathrm{blk}}$: Blackbody radiation transmitted to TOA + Above cloud emission

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The β-ratio approach: Simulations for all GEO

The β-ratio computation

$$\beta'(\lambda_1, \lambda_2) = \frac{\ln\left[1-\epsilon(\lambda_1)\right]}{\ln\left[1-\epsilon(\lambda_2)\right]}$$

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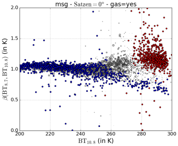
- β-ratio is more sensitive to cloud phase (removal of clear sky effect)



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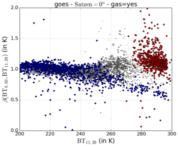

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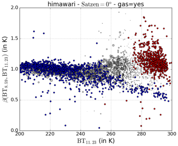

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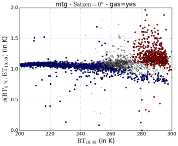

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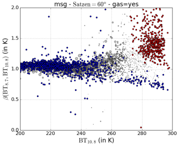

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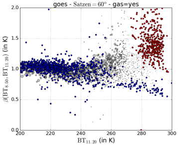

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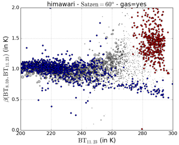

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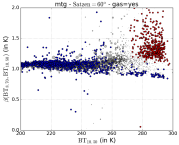

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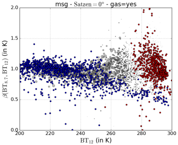

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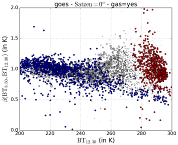

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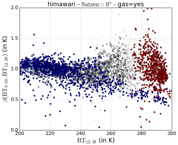

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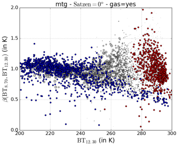

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- Sensitivity to IR band $\sim 12 - 12.4\ \mu$m

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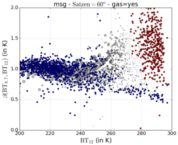
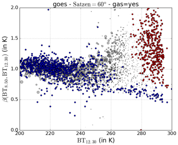


MSG / *vza=60*
$\lambda_1 = 8.7$, $\lambda_2 = 12$



GOES / *vza=60*
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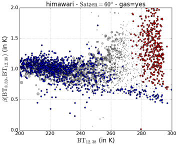
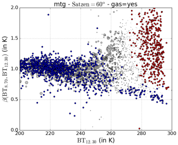


Hima / *vza=60*
$\lambda_1 = 8.6$, $\lambda_2 = 12.38$



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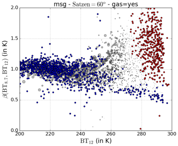

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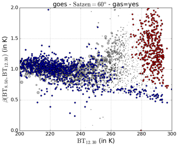

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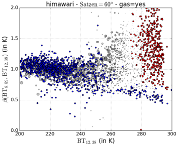

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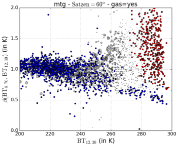

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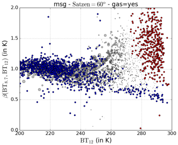

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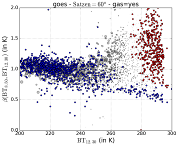

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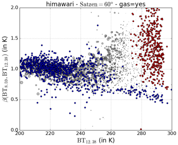

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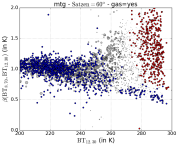

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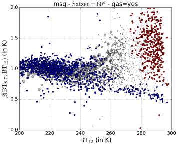

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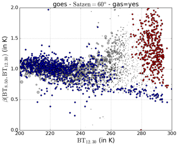

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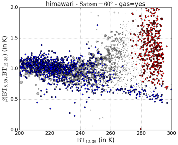

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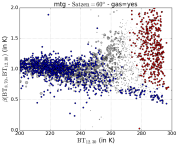

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- Classification algorithm: Logistic Regression/SVM using multiple predictors

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Conclusions and Perspectives

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  - remove the effect of gaseous absorption from observed radiances
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4 - MTG data

- When available ...
- Probably more tuning required
- Final algorithm ...