TRUTHS for Climate:

Session4: Scientific supporting elements

Scheduled: FRIDAY 28th June, 13:30 – 15:30

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SESSION: SCIENTIFIC SUPPORTING ELEMENTS

The introductory talks (and discussions) will cover:

1. Summary of key barriers limiting the exploitation of TRUTHS data (e.g.)
    - utilising UV-VIS-SWIR for retrievals / in data assimilation
    - (F)RTM and uncertainties
    - achieving spectral consistency
    - cloud classification and modelling
    - atmospheric correction (for surface reflectance)
    - solar spectral irradiance modelling and spectral calibration

The objectives of the facilitated discussions are:

1. Determine the research areas to foster till 2030 to accelerate products uptake and maximise benefits from Day-1
2. Establish a framework to support the radiative transfer modelling needs by identifying the required:
    - RTM code development for different communities/needs
    - Intercomparison and validation studies
3. Define validation campaign requirements

Introductory Talks

1) Yves Govaerts (Rayference), “RTM, going for the 1% uncertainties. challenges and opportunities”
2) Antonis Gkikas (Athens Academy), “Aerosol-related uncertainties in short-wave RT modelling”
3) Richard Bantges (Imperial College London & NCEO), “Candidate Fast Radiative Transfer Codes for UV-VIS-SWIR”

Review of RT Models

Credit: Maddie Stedman (NPL/Imperial-NCEO)

Activities addressed:

1. Tools – review of current RT codes; capabilities and developments required. Preliminary simulations for suitable example case study (informed from climate model predictions/sensitivities task).

National Physical Laboratory

Model	Spectral Resolution	Speed	Open Source?	Wavelength range	Method
RTTOV	Satellite bands (can do hyperspectral) GOME-2 report says gas absorption coefficient file trained at GOME-2 wavelength grid.	Fast	Available to licensed users free of charge	240 nm - 100 µm	Uses coefficients based on LBLRTM line-by-line datasets. “In practice one really needs to account for Rayleigh multiple scattering in the UV (below ~400-500 nm), for both clear-sky and cloud/aerosol cases. RTTOV enables this via the slow-but-accurate DOM (Discrete Ordinates Method) solver. It is possible that the MFASIS-NN solver in RTTOV (fast neural-network-based parameterisation of DOM for VIS channels) could be extended to the UV to support faster simulations for sensors such as GOME-2 and TRUTHS but this would require some work and so would need to be discussed within the NWP SAF team.” James Hocking, Met Office.
PC-RTTOV	Satellite bands (can do hyperspectral)	Very fast	Available to licensed users free of charge	IR (developed for IASI/IASI-NG)	Principal component based method. Developed specifically for IASI/IASI-NG. “PC-RTTOV uses "standard" RTTOV radiances as predictors for the PC scores of the full spectrum. In theory PC coefficients could be trained on suitable RTTOV radiances (either fast clear-sky radiances with Rayleigh single-scattering, full multiple-scattering with DOM, or parameterised multiple scattering with MFASIS-NN), and then the PC simulations would require running simulations configured in the same way as the training for a subset of the sensor channels.” James Hocking, Met Office
PCRTM-solar	1 cm-1 to a few nm “8 nm version developed for CLARREO RS”	Very fast compared to standard line-by-line models	N	300 - 2500 nm	Principle components selected during a training process – typically number of PCs needed < number of instrument channels. Principal component analysis is a dimensionality reduction method that is used to reduce the dimensionality of large data sets, by transforming a large set of variables into a smaller one that still contains most of the information in the large set.
LibRadtran	<0.1 nm	Method dependent	Y	120 nm - 100 µm	Multiple 1D RT solver options for underlying method, including DISTORT, polRadtran, MYSTIC (1D), and others. The atmosphere is discretised with 50 horizontal layers. Within libRadtran V2, the gaseous transmission relies on representative wavelengths parametrisation (REPTRAN) - assumes that spectrally integrated radiances can be approximated by weighted means of radiances at so-called representative wavelengths.
MODTRAN	0.2 cm−1, < 0.5 nm		N	200 nm – 100 µm	Atmospheric "narrow band model" algorithm – includes statistical & LBL options. 30 year heritage,
6SV	1 nm		Y	400 - 2500 nm	Basic RT code used for calculation of lookup tables for the atmospheric correction of satellite and airborne sensors. Based on the method of successive orders of scatterings approximations. The atmosphere is divided into 30 horizontal layers.
Eradiate	1 nm (for now – likely to be developed to higher resolution	Method dependent – focus is accuracy rather than speed	Y	280 nm to 2400 nm (can be extended)	Multiple options, including 3D & Line-by-line simulation. Uses Monte Carlo ray tracing method used to solve the radiative transfer equation – main focus is accuracy. Aims at achieving an accuracy better than 1% on the simulation of satellite images. Currently beta software.
CRTM	Satellite bands	Fast	Y	Visible to microwave (UV under development)	Uses the specific sensor response functions convolved with a Line-by-Line Radiative Transfer Model (LBLRTM) to return accurate representation of satellite radiances. Fast, 1D radiative transfer model used in numerical weather prediction, calibration/validation, etc.
ARTDECO	Docs state that hyperspectral sensors are excluded		Available to licensed users free of charge for non-commercial use	200 - 50 µm	Atmosphere discretised with 50 horizontal layers. Implements three 1D RTE solvers (vector Monte Carlo ray tracing, DISORT and adding-doubling approximation) alongside an input data library to compute Earth atmosphere radiances and radiative fluxes as observed by passive sensors.
DISAMAR	High resolution wavelength grid for model running & output at 0.2 nm	Slow – line by line	Y https://gitlab.com/KNMI-OSS/disamar/disamar	270-2400 nm	Line-by-line. Simulates spectrum of Earth-reflected sunlight as measured by an instrument & can apply retrieval algorithms to that. BRDF surface is not yet implemented (Lambertian only).

Fast radiative transfer codes – capabilities & developments – (1) RTTOV

- Capabilities:
  - Spectral range: 0.24 to 100 µm
  - Spectral resolution: specific satellite bands (hyperspectral capability)
  - Slow for Rayleigh multiple-scattering in UV (< 400-500 nm)
- Developments (EUMETSAT NWP SAF team):
  - v14 (Q3/4 2024) – enhanced VIS/IR cloud optical properties definitions; heterogenous surfaces; sea surface solar BRDF
  - v14.x (Q1 2026) – aerosol optical properties (size); enhanced/efficient cloud overlap options; tools for generating scattering property files
- Options:
  - Fast neural-network-based parameterisation of DOM for VIS only, "MFASIS-NN" solver in RTTOV extension to UV? Currently outside of scope of NWP SAF team.

Fast radiative transfer codes – capabilities & developments – (2) PC-RTTOV

- Capabilities:
  - Very fast Principal Component-based version of RTTOV
  - Spectral range: IR only, developed for IASI/IASI-NG
- Developments (EUMETSAT NWP SAF team):
  - None currently relevant
- Options:
  - Build PC training set covering UV-VIS using the fast neural-network-based parameterisation of DOM "MFASIS-NN" if extended to the UV. Currently outside of scope of NWP SAF team.

Fast radiative transfer codes – capabilities & developments – (3) PCRTM-solar

- Capabilities:
  - Very fast Principal Component-based version based on MODTRAN
  - Spectral range: 300 – 2500 nm
- Developments (Xu Liu, NASA LaRC):
  - Polarisation inclusion in PCRTM-solar based on VLIDORT (Spurr, R.; JQSRT 2006)
- Options:
  - Adapt / Build PC training set covering UV-VIS for TRUTHS-specific channels / range based on VLIDORT -> 2-4% improvement, Xu Liu 2024 (pers. comm.))
  - Clouds are still to be included, and aerosol models to be updated.
  - Surface BRDF data being worked on.

Jet Propulsion Laboratory
California Institute of Technology

EMIT EARTH SURFACE MINERAL DUST SOURCE INVESTIGATION

EMIT
- Imaging spectrometer
- 380-2500 nm (@7.4 nm sampling, ~ 285 bands)
- ~ 60 m spatial resolution
- On ISS until early 2026

EMIT look-up table (LUT) generated by PCRTM:
- It only takes 2.2 hours for with 35 CPU cores for PCRTM to generate a LUT more than 9 million EMIT spectra entries
- Wide range of observation geometries, surface elevations, & atm. conditions

Validating EMIT L2 product using the PCRTM LUT
- One granule of EMIT L1 data were simulated using the PCRTM generated LUT
- EMIT L2 product were used as input
- Good agreement for the granule with more than 1.6 million spectra

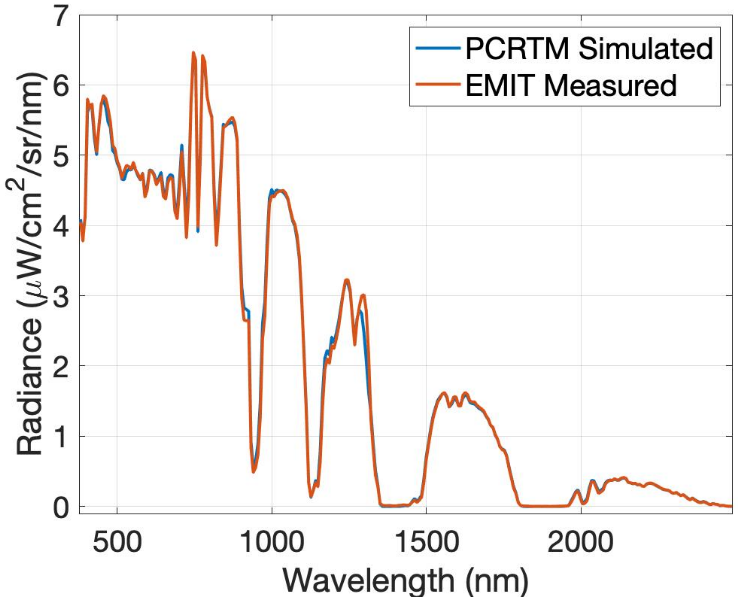
JPL SBG team (Phil and David) are testing the LUT using ISOFIT retrieval algorithm on EMIT data

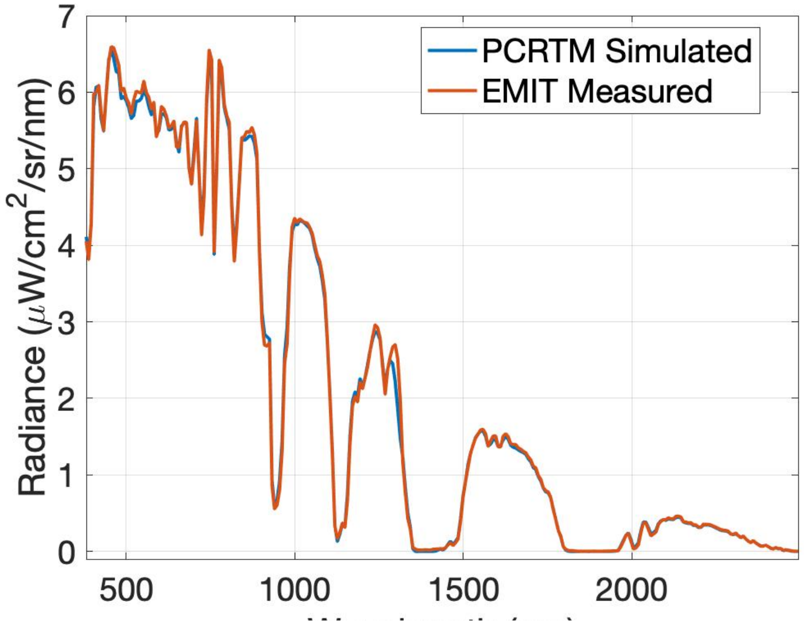
The PCRTM can be used for high fidelity SBG simulator
- With fast speed of PCRTM, we can generate high fidelity SBG data cubes with different instrument characterizations
  - Observation geometry on different satellite platforms
  - Different spectral resolution and spectral coverage
  - Different random and systematic noises

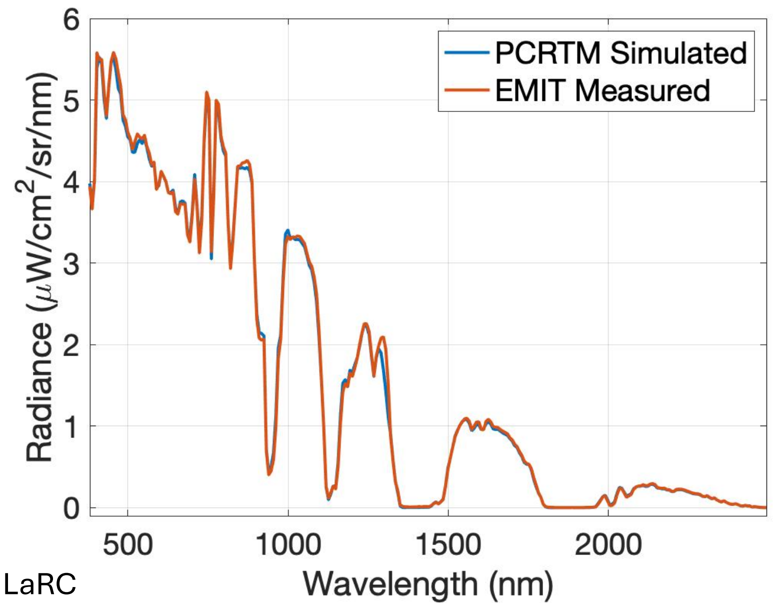
PCRTM has been proven to be a good tool for spectral calibration of hyperspectral sensors (OMPS, HYSICS, AIRS etc)

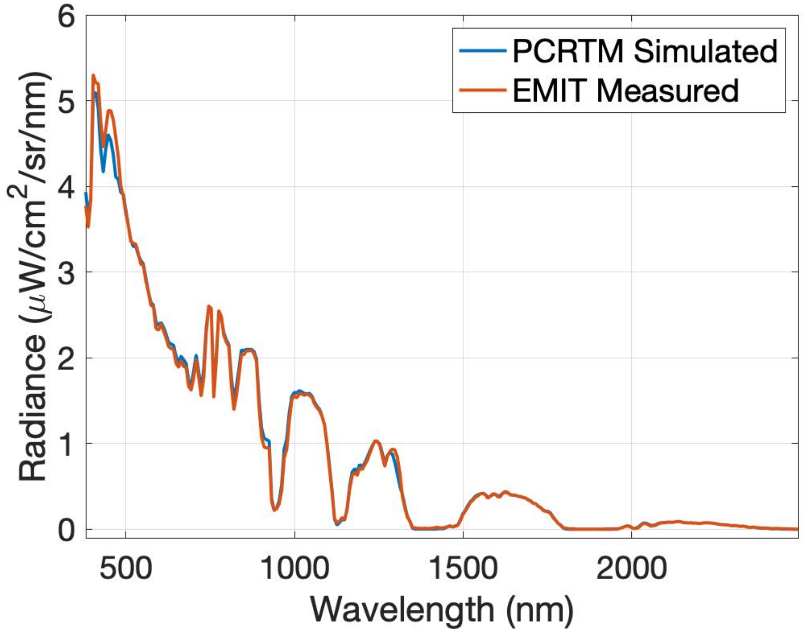
Courtesy: Xu Liu, NASA LaRC (modified)

Examples of PCRTM simulated and EMIT observed spectra





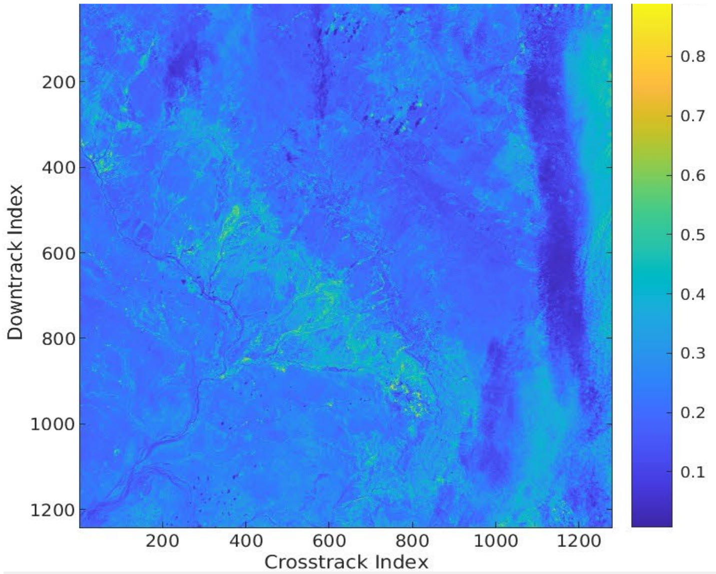


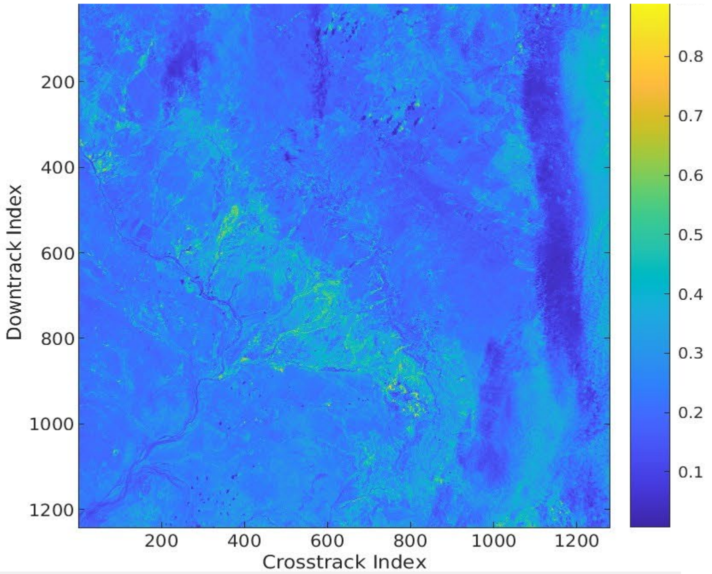


Courtesy: Xu Liu, NASA LaRC

PCRTM simulated spectra agree all well with EMIT observation at different wavelengths and 1.6 million pixels

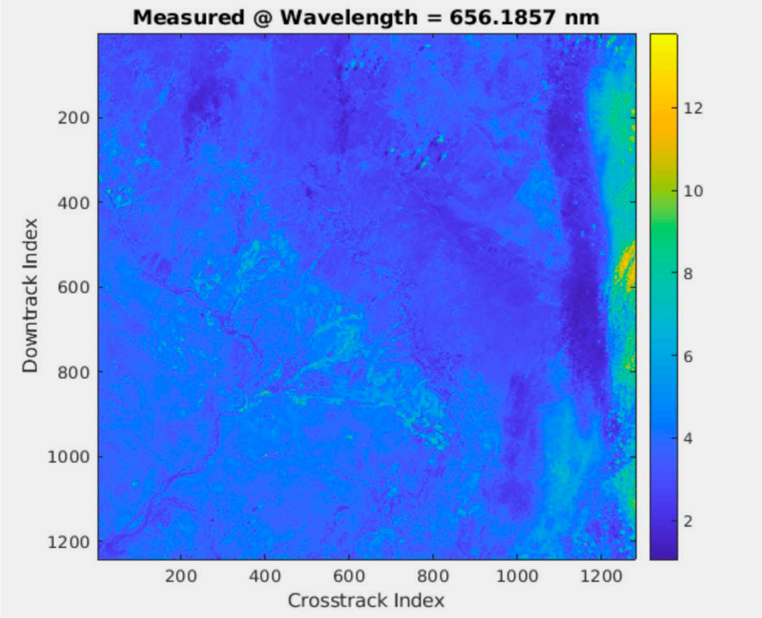
EMIT observed radiance at 2078.5 nm

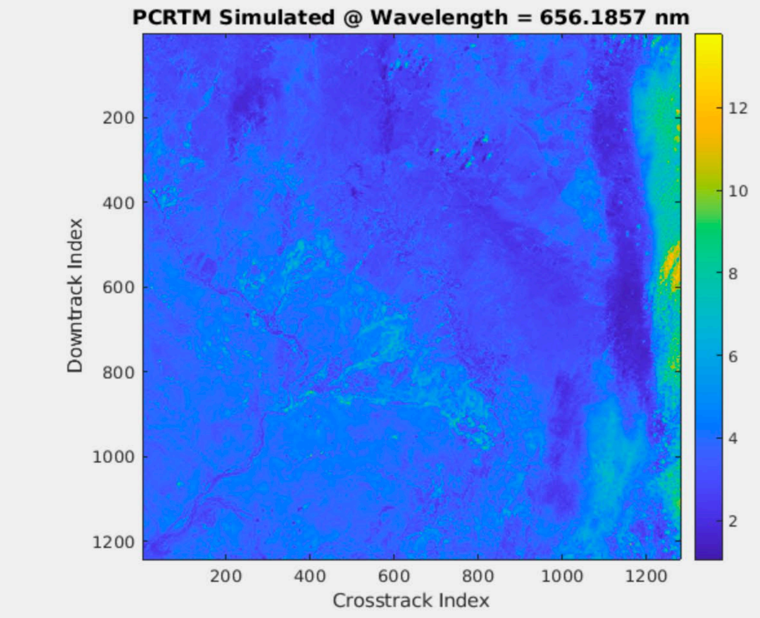




PCRTM simulated radiance at 2078.5 nm using EM L2 product as input

EMIT observed radiance at 656.2 nm

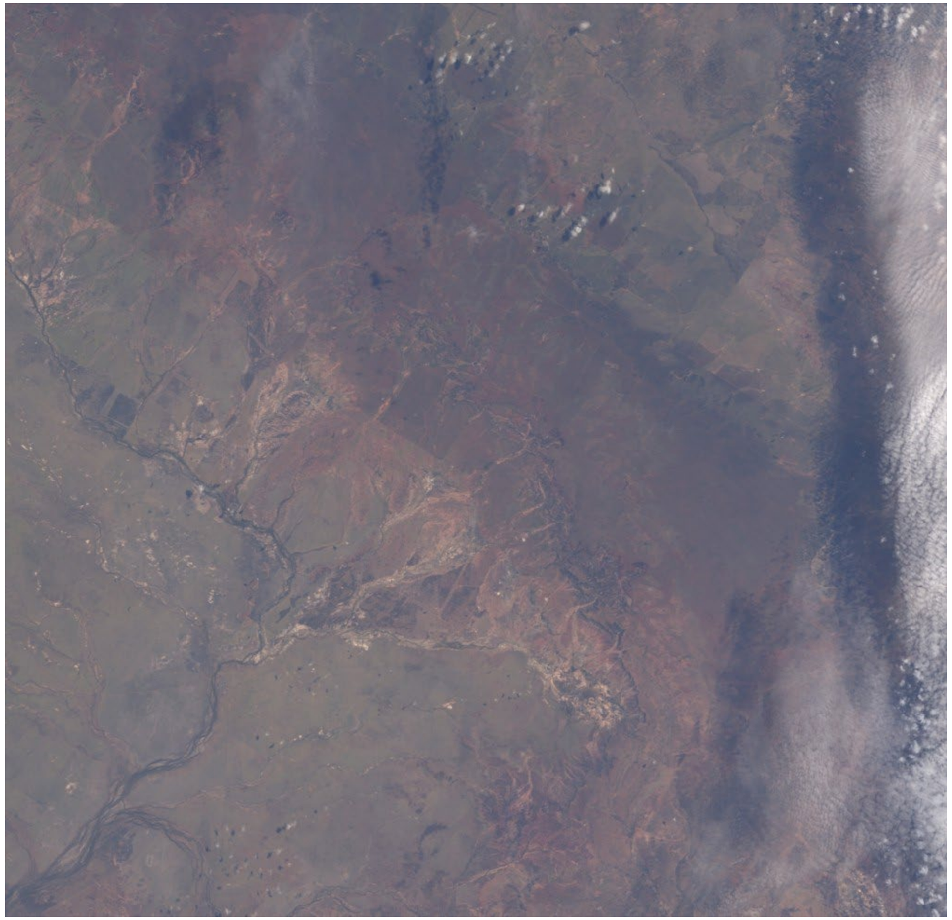




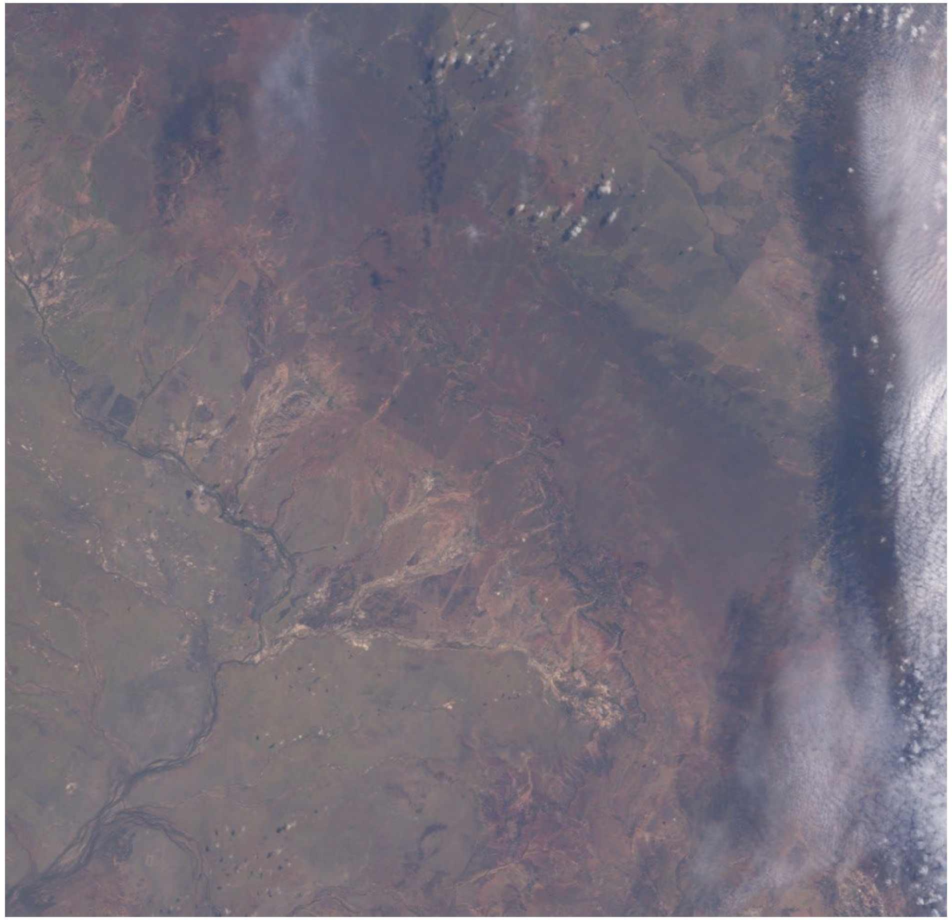
PCRTM simulated radiance at 656.2 nm using EM L2 product as input

Courtesy: Xu Liu, NASA LaRC

PCRTM Simulated RGB image and spectra agree well with EMIT L1 observations (indicating high EMIT L2 product quality)



EMIT RBG Image



PCRTM Calculated EMIT RBG Image

Courtesy: Xu Liu, NASA LaRC