EUMeTrain Water Vapour Event Week 2022

12-15 November 2022

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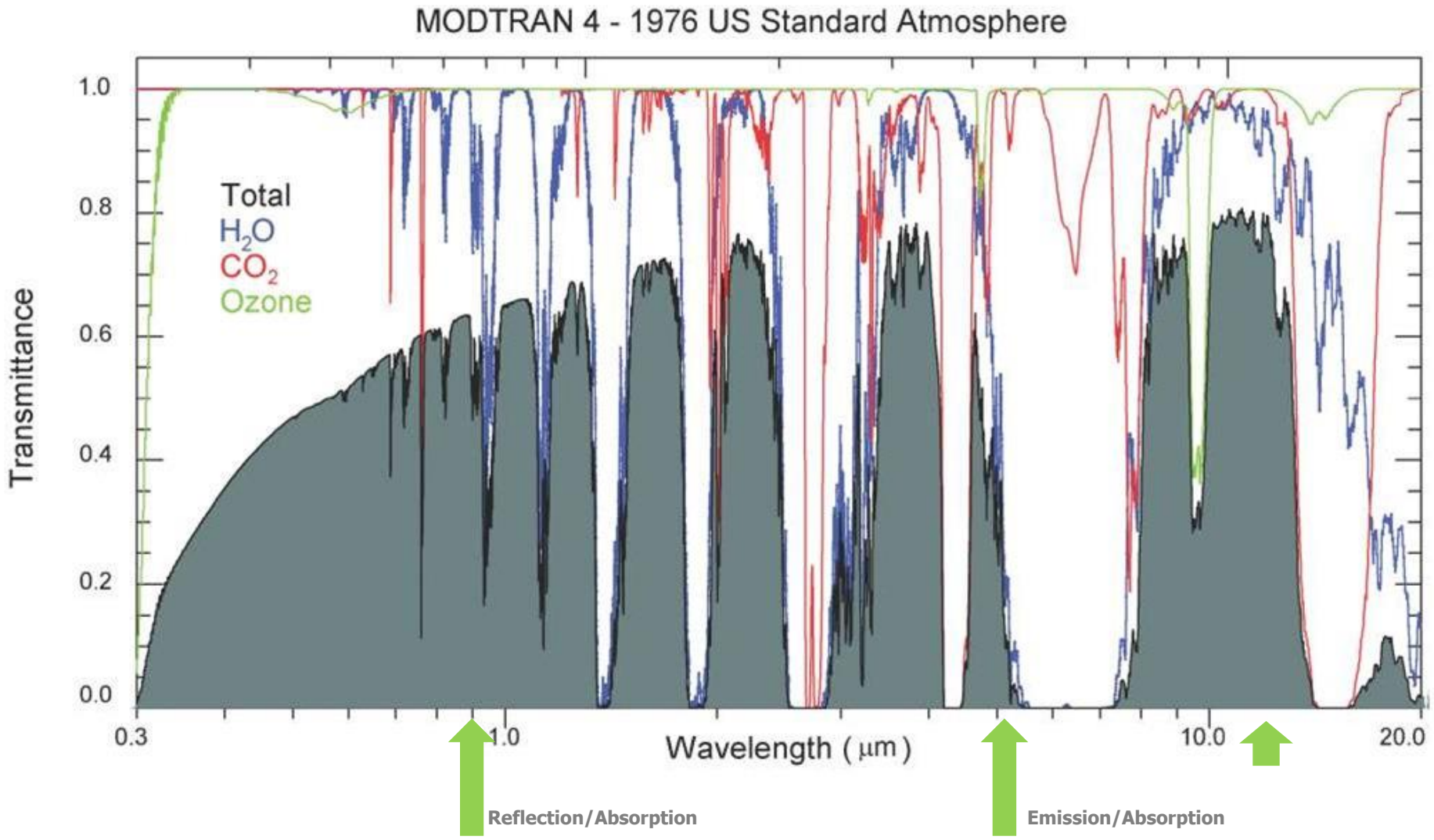
Talk Outline

- Basic Principles (quick!)
- EUMETSAT TCWV products from optical imagers
- TCWV NIR (0.9 μm) challenges and potential solutions
- Outlook

Water Vapour absorption bands



FCI and METimage

Supporting channels bring information on surface Albedo and Aerosol

Measures WV abs. NEEDs support

Measure WV abs./Emi. NEEDs support

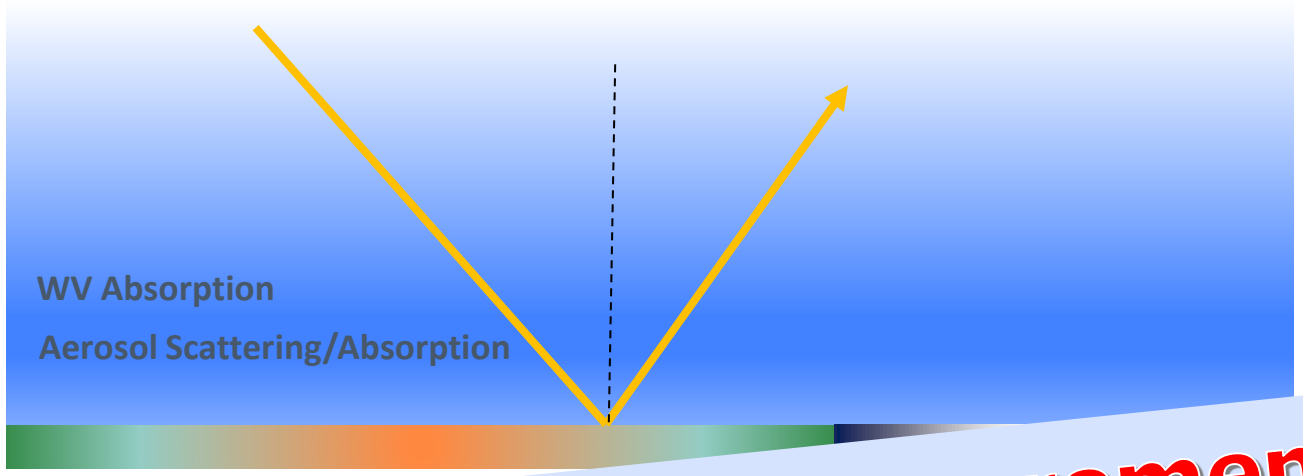
Supporting channels bring information on surface and Atmospheric temperature

MTG FCI	λ_C (µm VII)	EPS-SG METimage	Comments
■	0.44	■	Window
■	0.55	■	Window
■	0.67	■	Window
	0.75	■	O_2 continuum
	0.76	■	O_2 A-band
■	0.86	■	Window
■	**0.91**	■	**H_2O absorption**
■	1.24	■	Window
■	**1.37**	■	**H_2O absorption (Cirrus)**
■	1.63	■	Window
■	2.25	■	Window
■	3.74	■	Window
	3.90	■	Window
	4.05	■	Window
■	**6.72**	■	**H_2O absorption**
■	**7.32**	■	**H_2O absorption**
■	8.54	■	Window
■	10.8	■	Window - **H_2O 'contamination'**
■	12.01	■	Window - **H_2O 'contamination'**
■	13.33	■	CO_2 absorption band (temperature)

0.91 channel: solar transmission measurement

METimage channels

λ_C (µm)	Comments	
0.44	Windows channel	**3. Aerosol Scattering**
0.55	Window channel	
0.67	Window channel	**2. Surface Reflection**
0.75	O_2 continuum	
0.76	O_2 A-band	
0.86	Window channel	**2. Surface Reflection**
0.91	**H_2O absorption channel**	**1.**
1.24	Windows channel	**2. Surface Reflection**
1.37	**H_2O absorption channel**	
1.63	Windows channel	
2.25	Windows channel	
3.74	Windows channel	
3.90	Windows channel	
4.05	Windows channel	
6.72	**H_2O absorption channel**	
7.32	**H_2O absorption channel**	
8.54	Windows channel	
10.8	Window channel	
12.01	Window channel	
13.33	CO_2 absorption band	

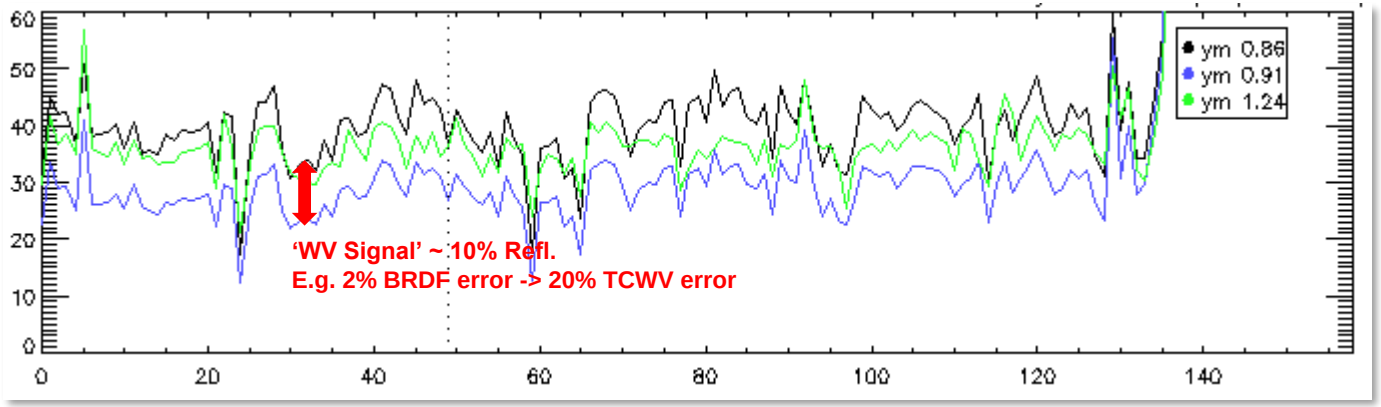


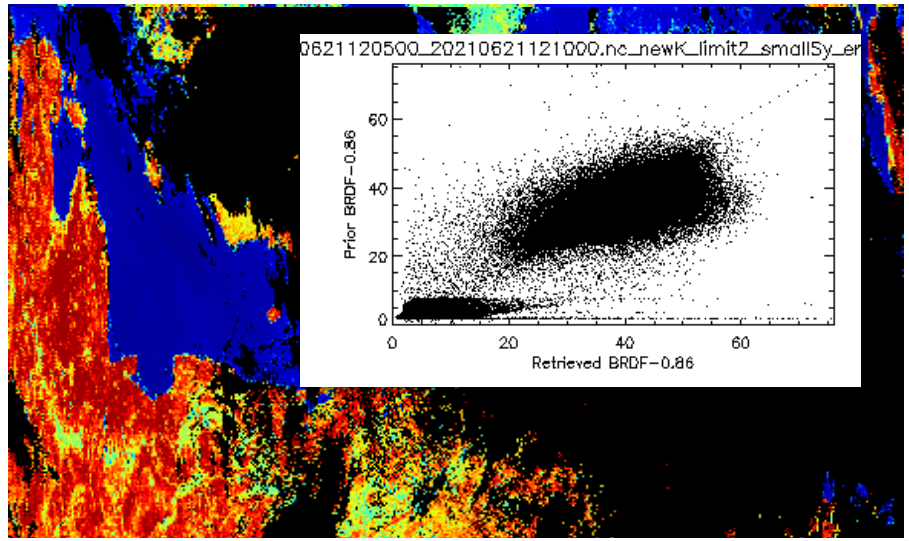
Absorption measurement!
Doesn't matter where the WV is..
Just that most is near the surface

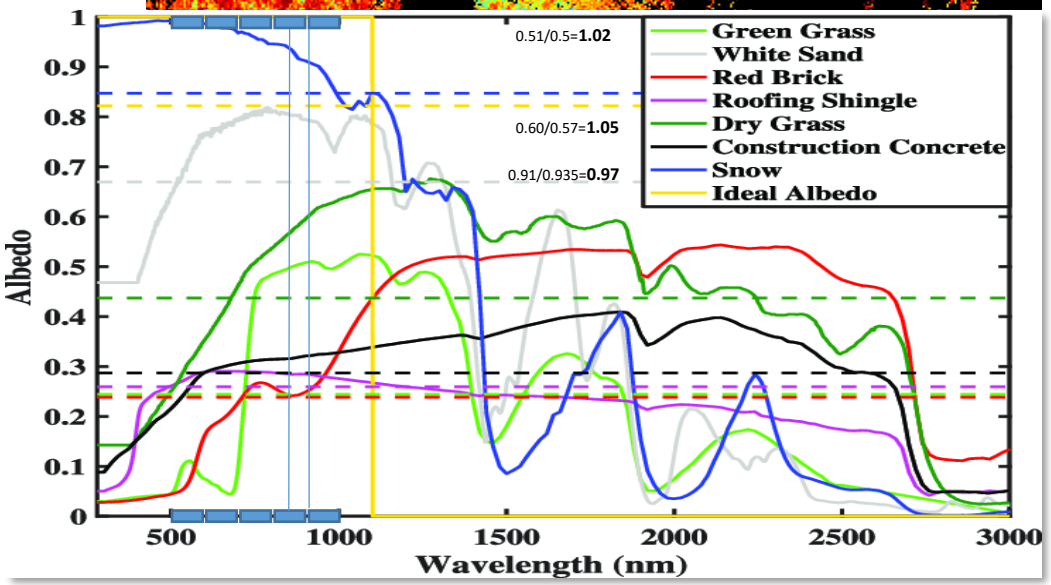
- Zenith angles (absorption path length)
- Presence of aerosols in the atmosphere
- Relative azimuth (through BRDF)

0.91 channel: solar transmission measurement

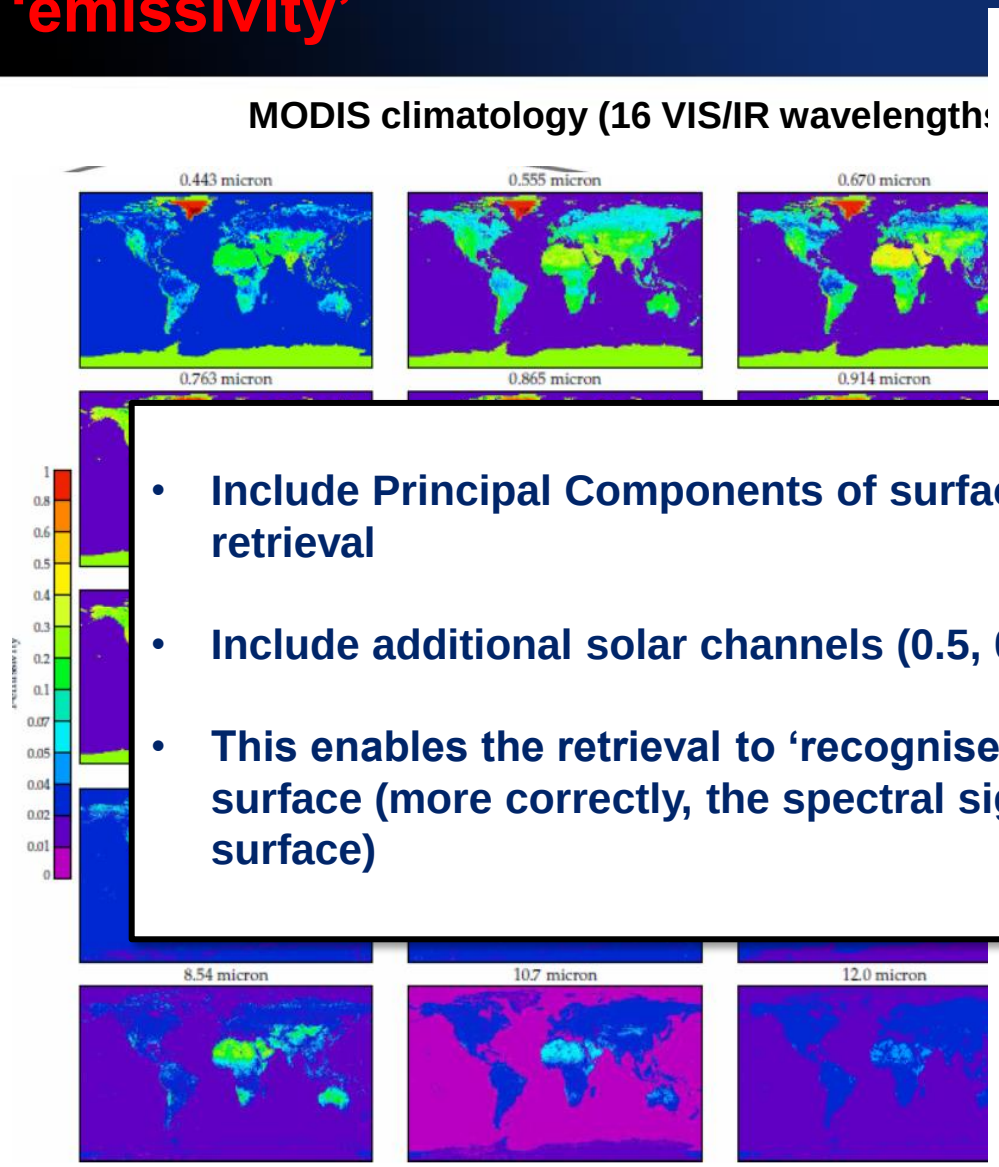
- Surface reflectance (BRDF) at 0.91 μm?
  1. Assume = 0.86 μm & Take from Climatology/map
     - Very large error
  2. Assume = 0.86 μm but take from measurements
     a) 'Implicitly': as in Reflectance ratio RGB/Product
     b) 'Explicitly': estimate as part of Retrieval
     c) Error in assumption ~0 – 5% absolute?
     d) Effect on estimated/visualised TCWV is amplified







Proposed solution: RAL External Study: TPW from METimage: PCs of 'emissivity'



- Include Principal Components of surface BRDF in the retrieval
- Include additional solar channels (0.5, 0.6, 0.7, 1.24,..)
- This enables the retrieval to 'recognise' the type of surface (more correctly, the spectral signature of the surface)

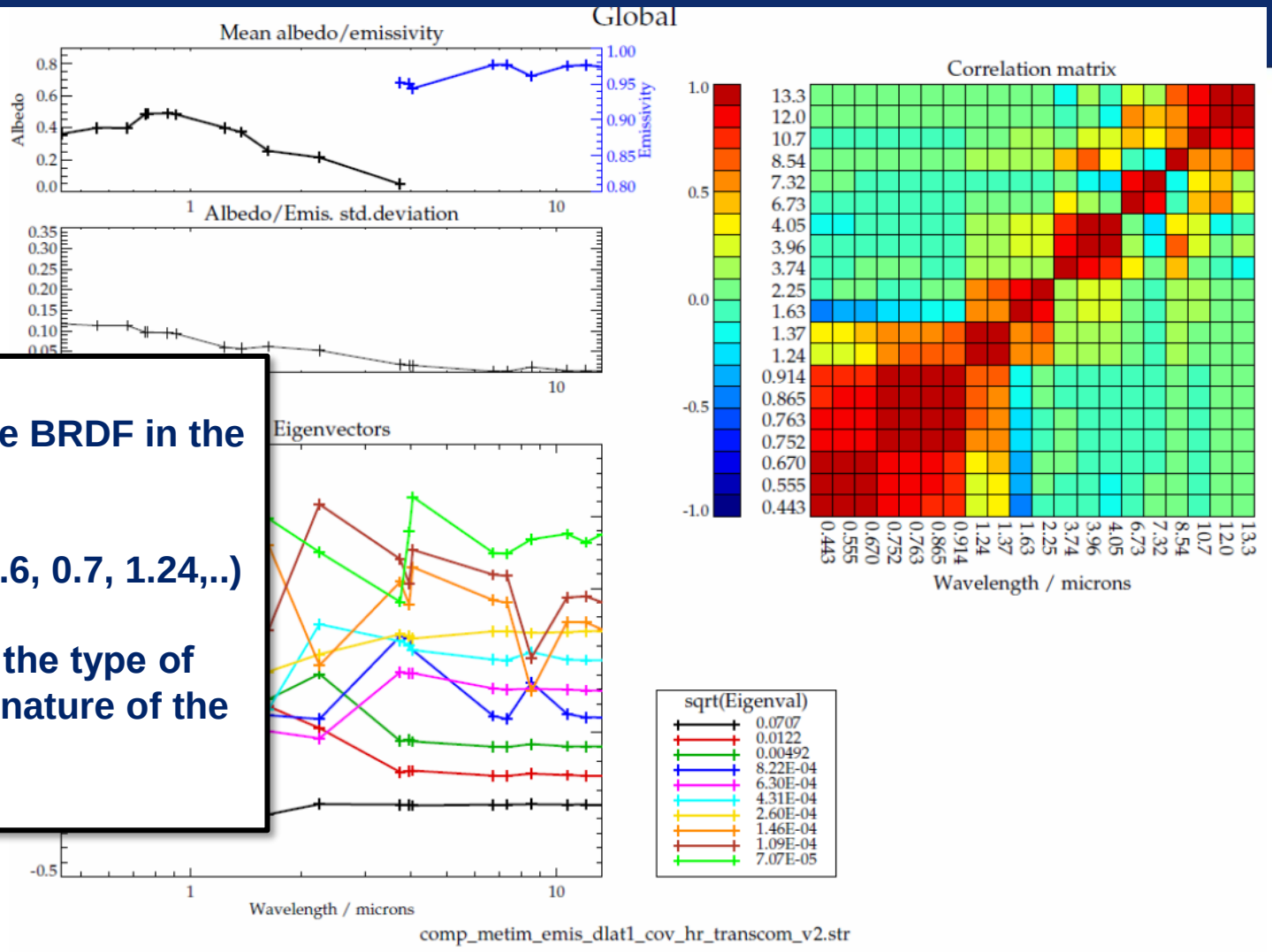


Figure 3-5: Surface emissivity covariance (global)

.. The other effects..

- View Zenith and Solar zenith angles (absorption path length)

- Presence of aerosols in the atmosphere

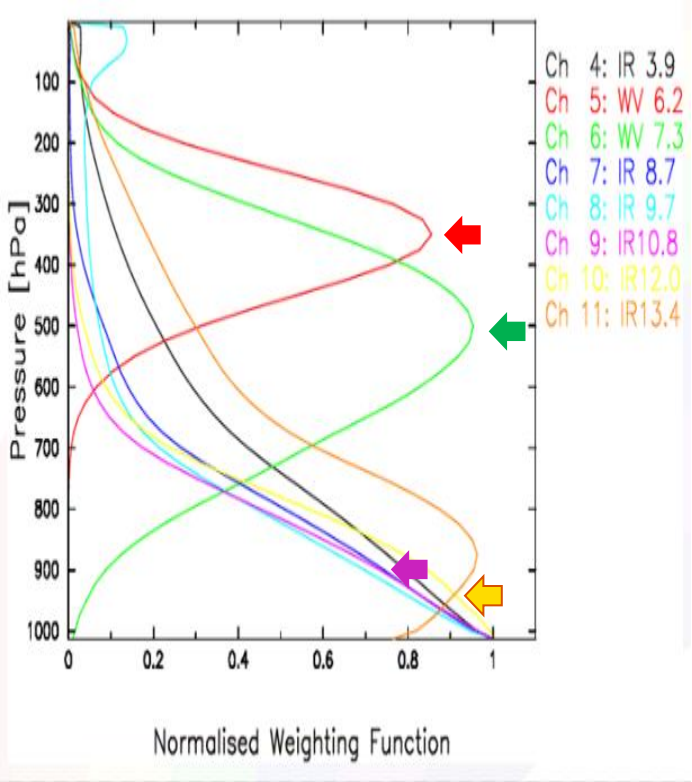
- Relative azimuth

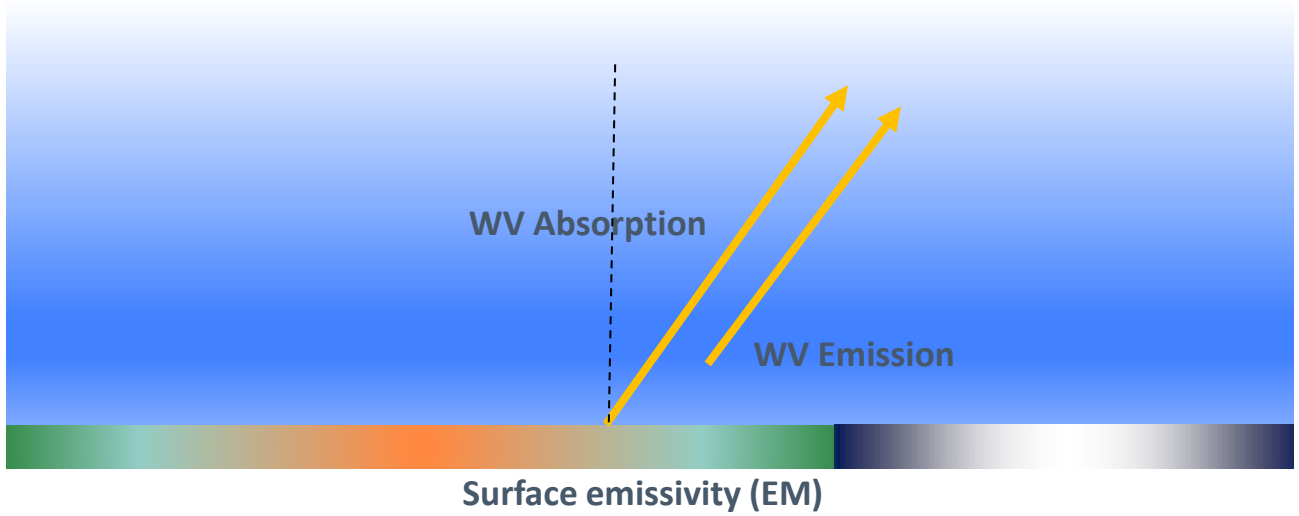
- Use of fast RTM (RTTOV-12): models the effect of the angles

- Use of CAMs aerosol forecasts + RTTOV-12
- Include estimate of aerosol AOD

- Use of MODIS BRDF information

TIR channels: thermal emission/transmission measurement





4.05	Window
6.72	**H_2O absorption channel**
7.32	**H_2O absorption channel**
8.54	Window
10.8	Window- **H_2O 'contamination'**
12.01	Window- **H_2O 'contamination'**
13.33	CO_2 absorption band

Clear-sky water vapor measurement in the thermal IR part of the spectrum are affected by:

- Atmospheric & surface temperature
- Vertical distribution of WV
- View Zenith (absorption path length)
- Surface emissivity

- E.g. R/S, hyperspectral sounder, Forecast
- E.g. R/S, hyperspectral sounder, Forecast
- RT modelling RTTOV-12
- Emissivity (MODIS) maps but small effect

Retrieval methodology

Measurement cost + **Prior cost**

$$J(x) = [F(x) - y_m]^T \cdot S_y^{-1} \cdot [F(x) - y_m] + (x - x_a)^T \cdot S_a^{-1} \cdot (x - x_a)$$

Cost Minimisation
(likliehood maximisation)

Fast RTM on state x
(RTTOV-12)

Measurements

Measurement error

Prior

Prior error

Prior from a forecast enables an accurate as possible specification of features (e.g. vertical profile) that cannot be extracted from imager measurements but have a non-negligible effect on them.

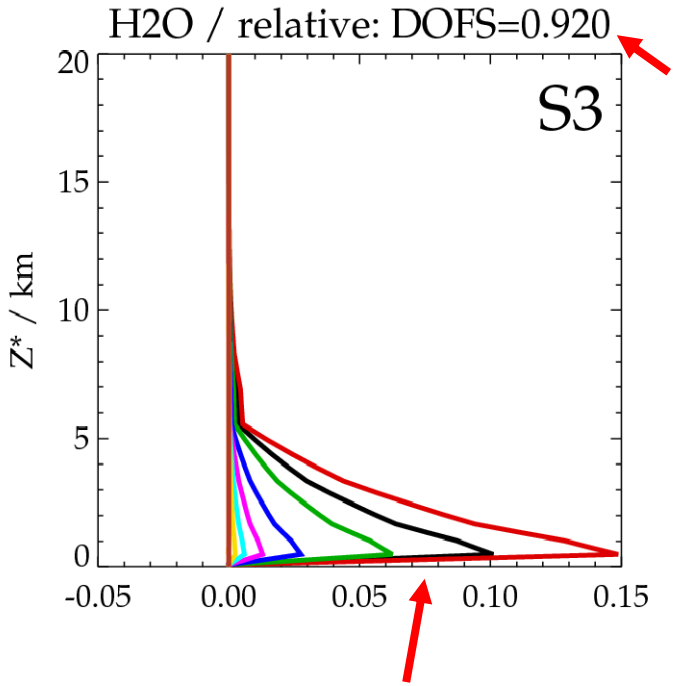
The prior error can be set:

- Realistically (representing the true prior error – gives statistically best result over large samples)
- Overlarge – reduces the prior impact on the product (even to zero) without losing the benefit of vertical structure

Comparison NIR and TIR retrievals of TCWV

Sensitivity to the vertical profile (‘Averaging Kernels’) and

NIR

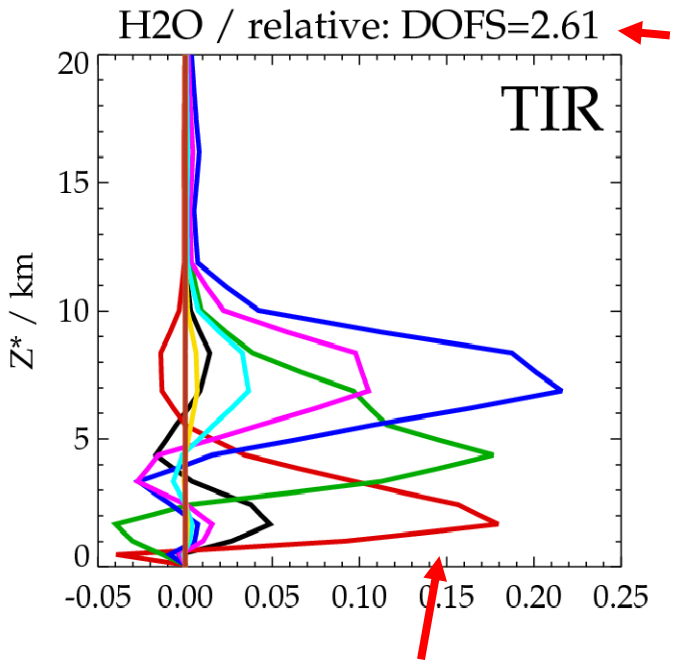


Total column only

Land +
Sunglint
Low level aerosol??

Sensitivity to lowest level moisture

TIR



2-3 Layers

Land + Sea

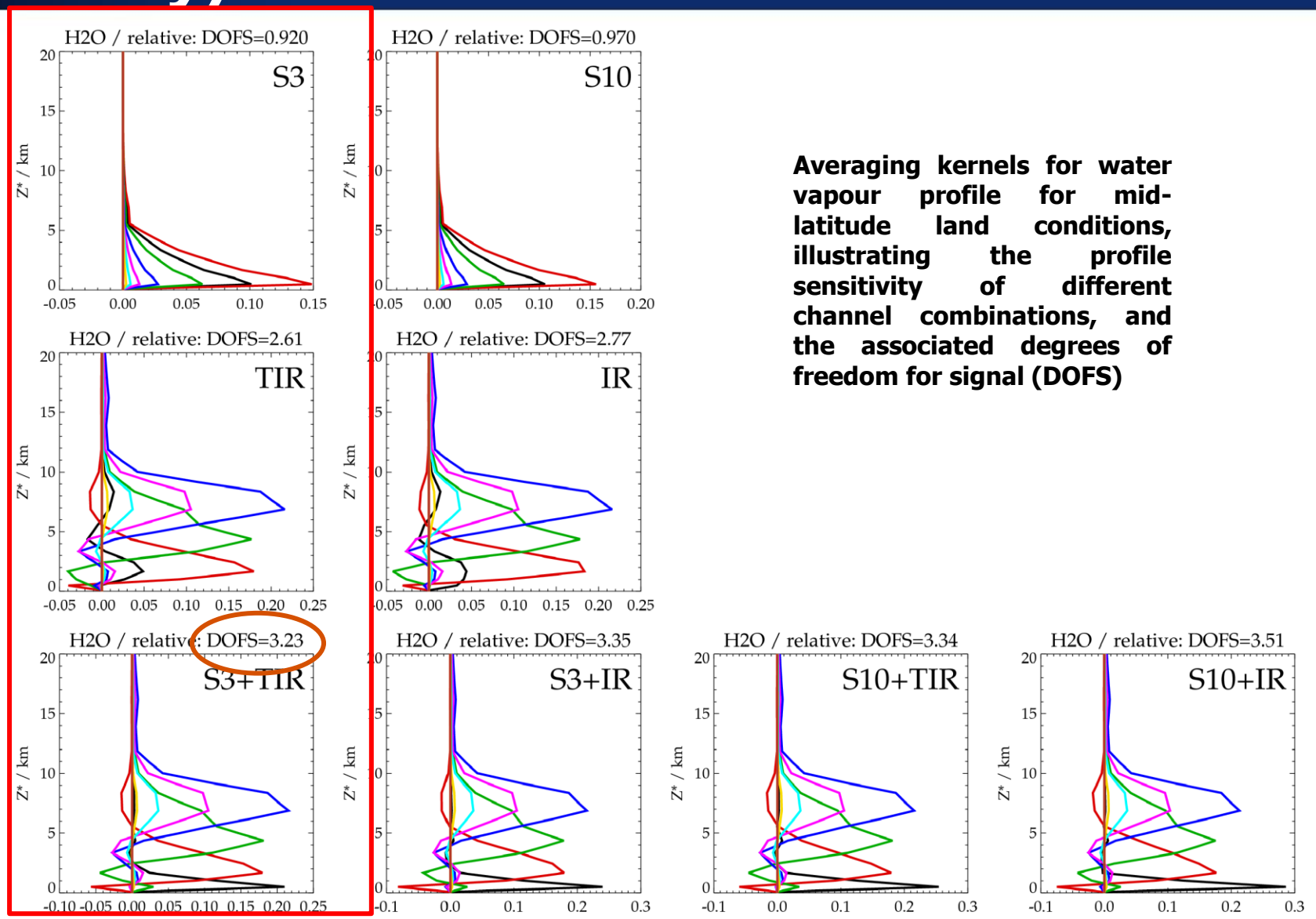
Lack of Sensitivity to lowest level moisture

Comparison NIR and TIR retrievals of TCWV (RAL/STFC study)

Solar channels only

Thermal channels only

Solar plus Thermal channels



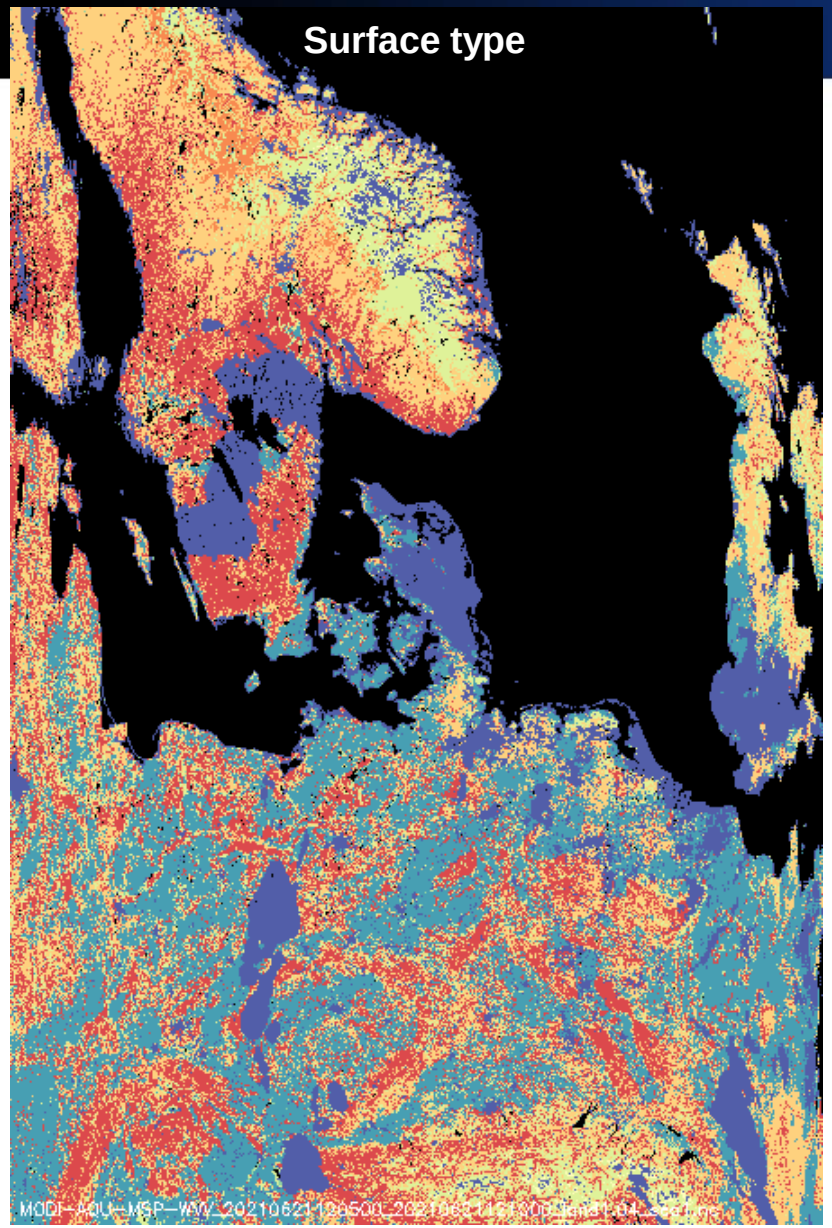
Averaging kernels for water vapour profile for mid-latitude land conditions, illustrating the profile sensitivity of different channel combinations, and the associated degrees of freedom for signal (DOFS)

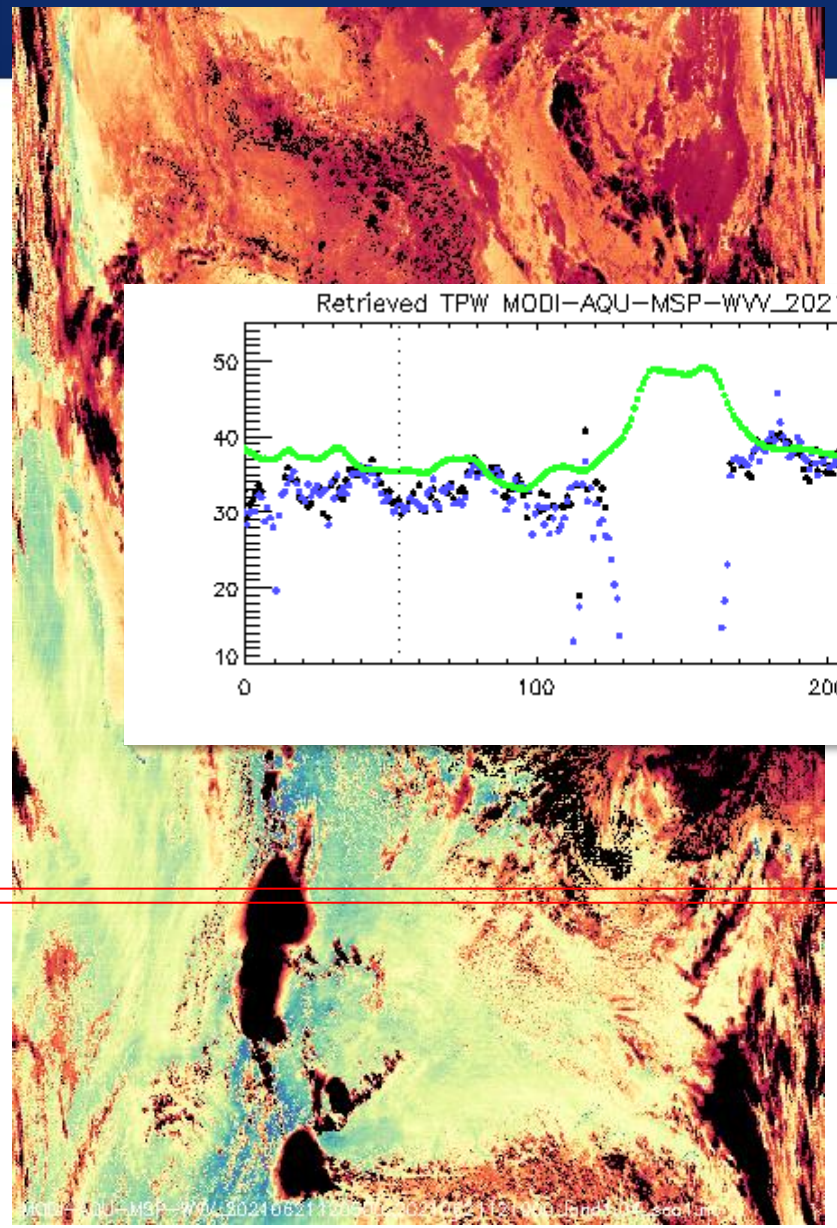
Example results

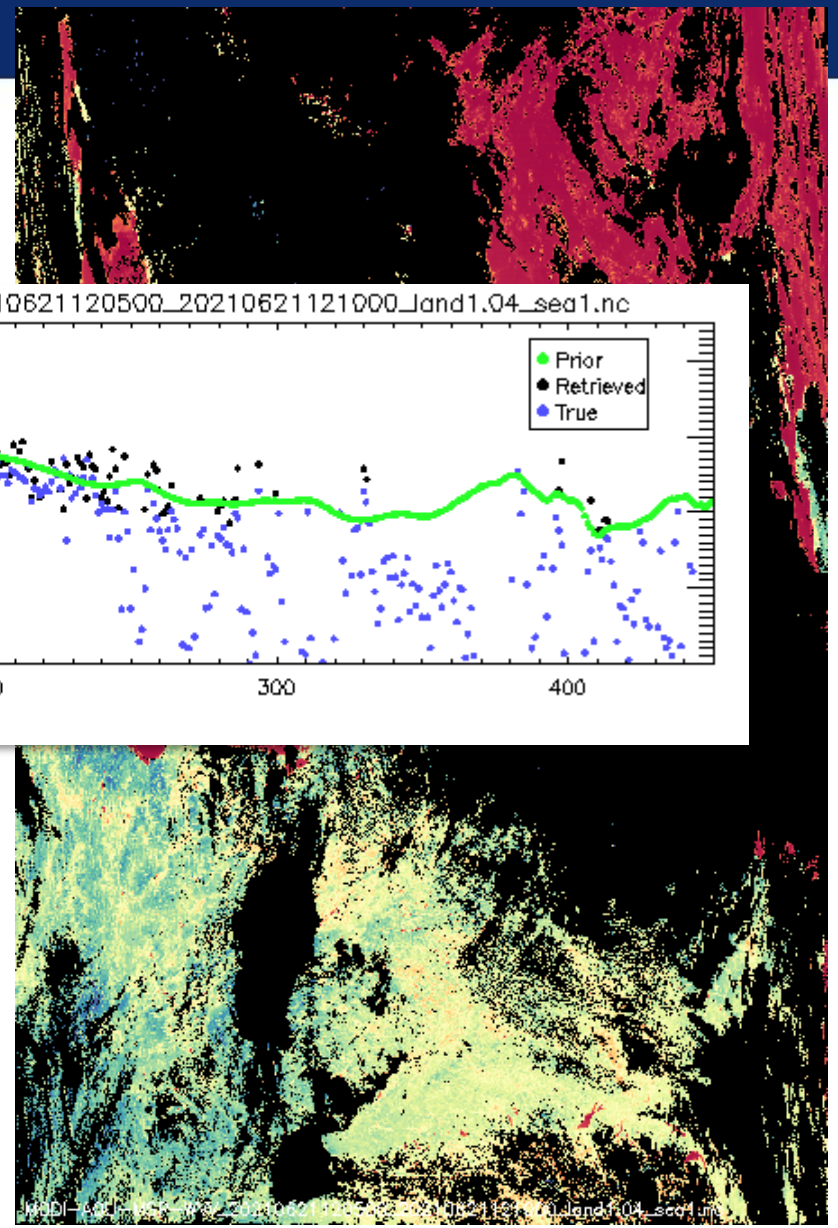
- Showing only NIR product
- Prior: ECMWF 6-12h forecast, MODIS BRDF
- ‘Truth’ is MODIS L2 NIR product

2021 June 21 12:05 MODIS AQUA

MODIS L2

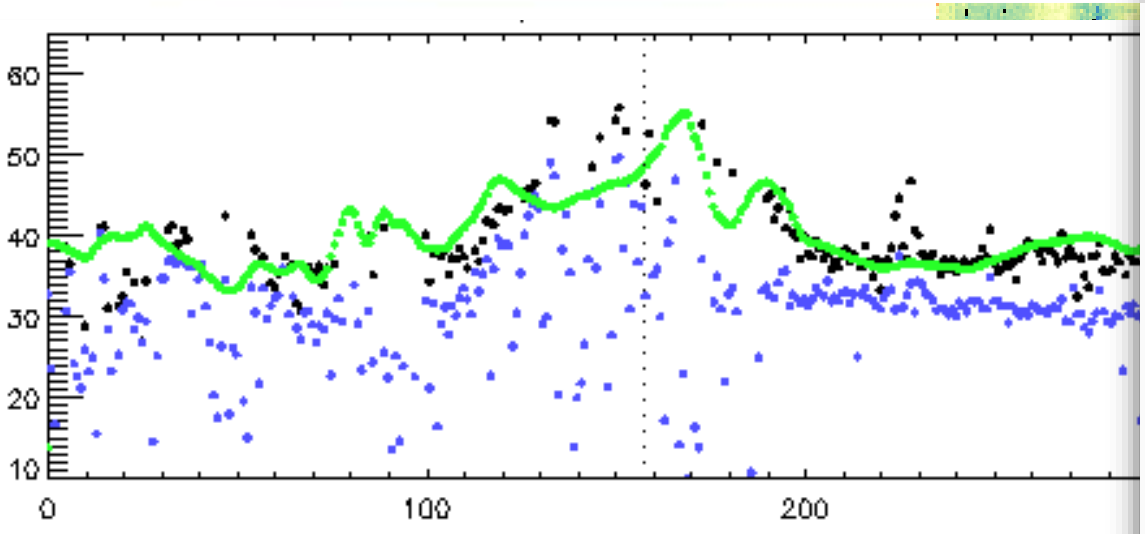






2021 June 21 12:05 MODIS AQUA

Effect of BRDF assm.



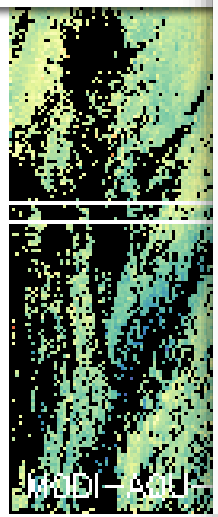
BRDF0.9 = BRDF0.8 x 1.04

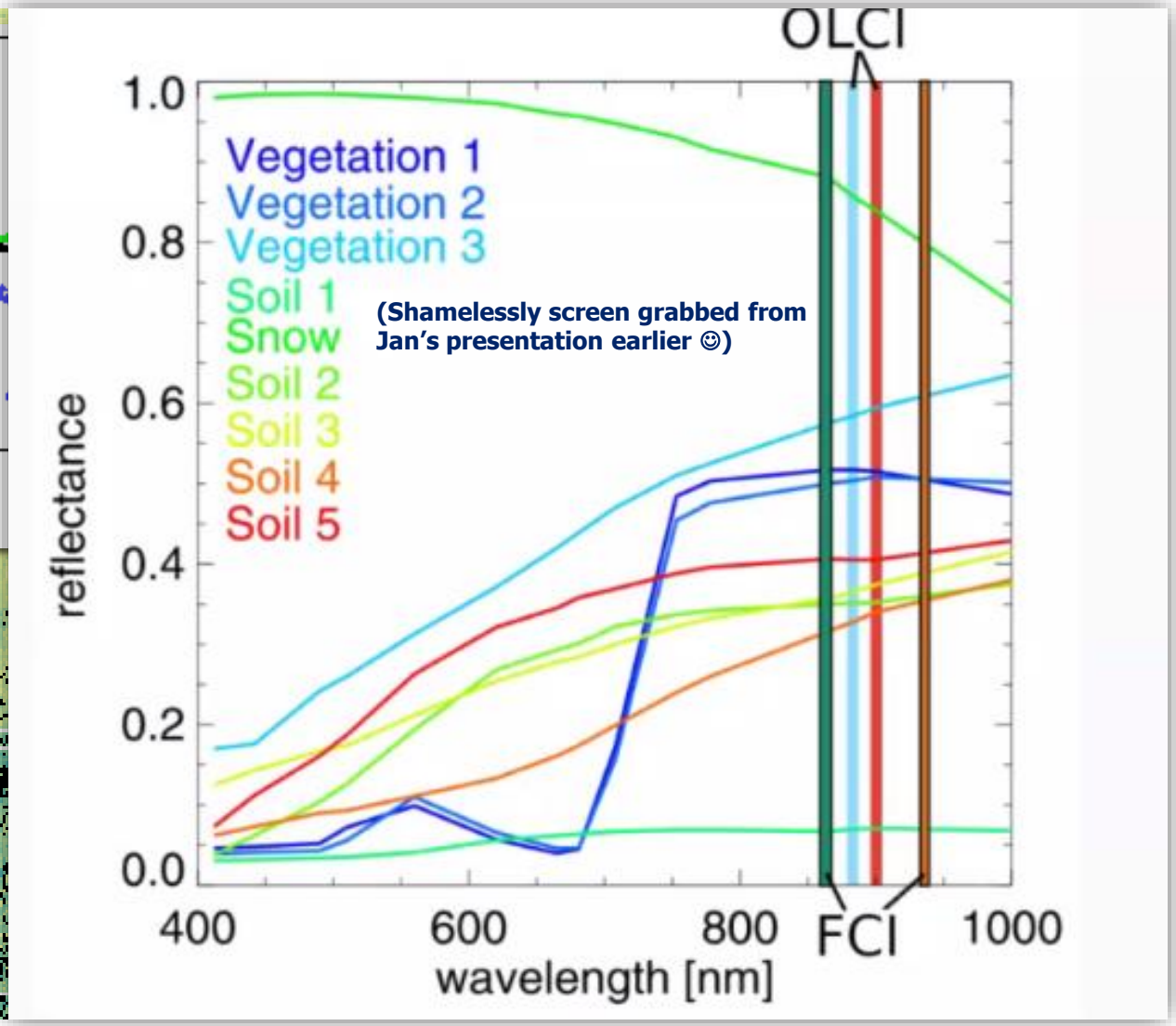
!! Typically 1% Error in Measurement OR RTM -> 5% error in TCWV !!

Calibration

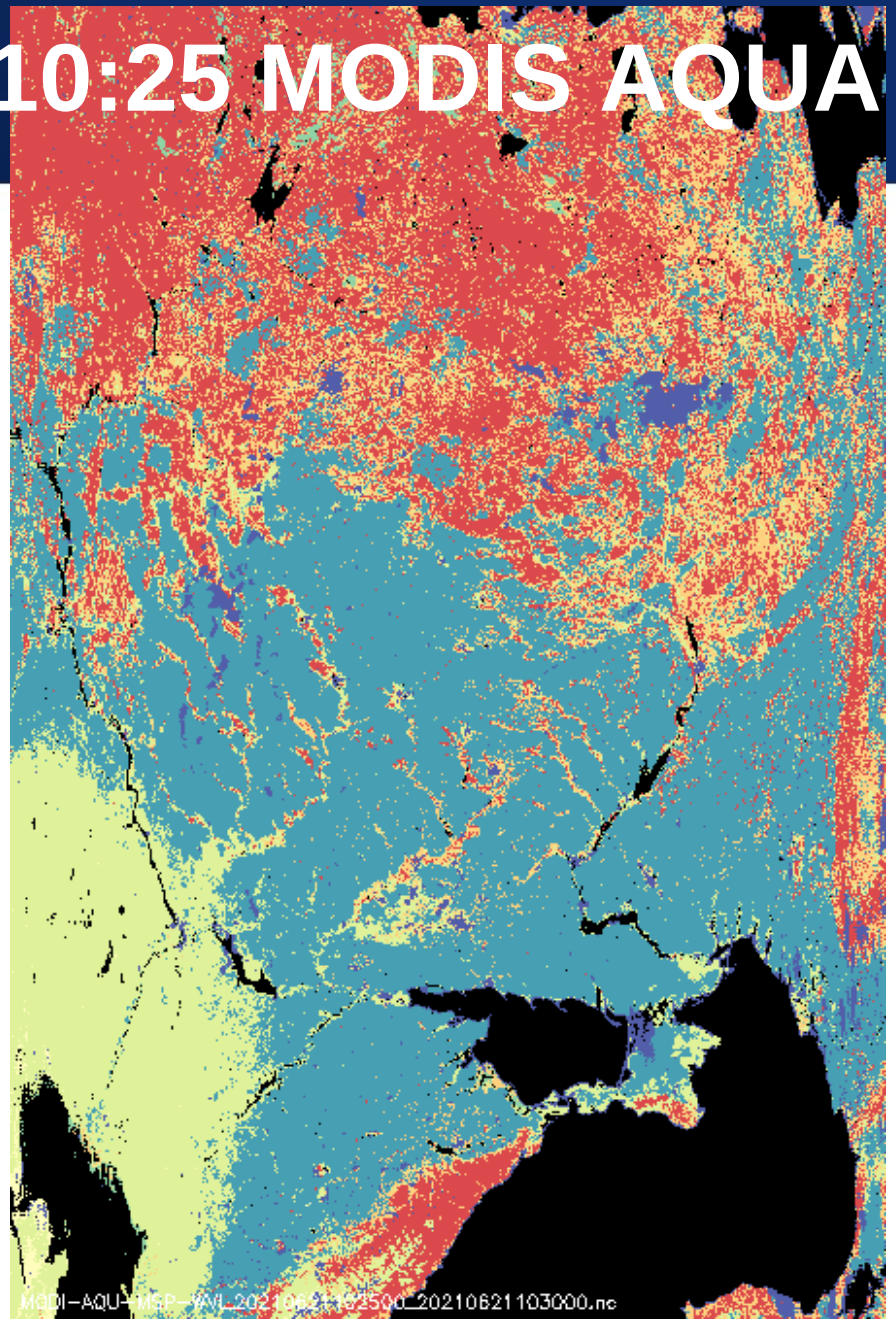
BRDF transfer 0.8-0.9

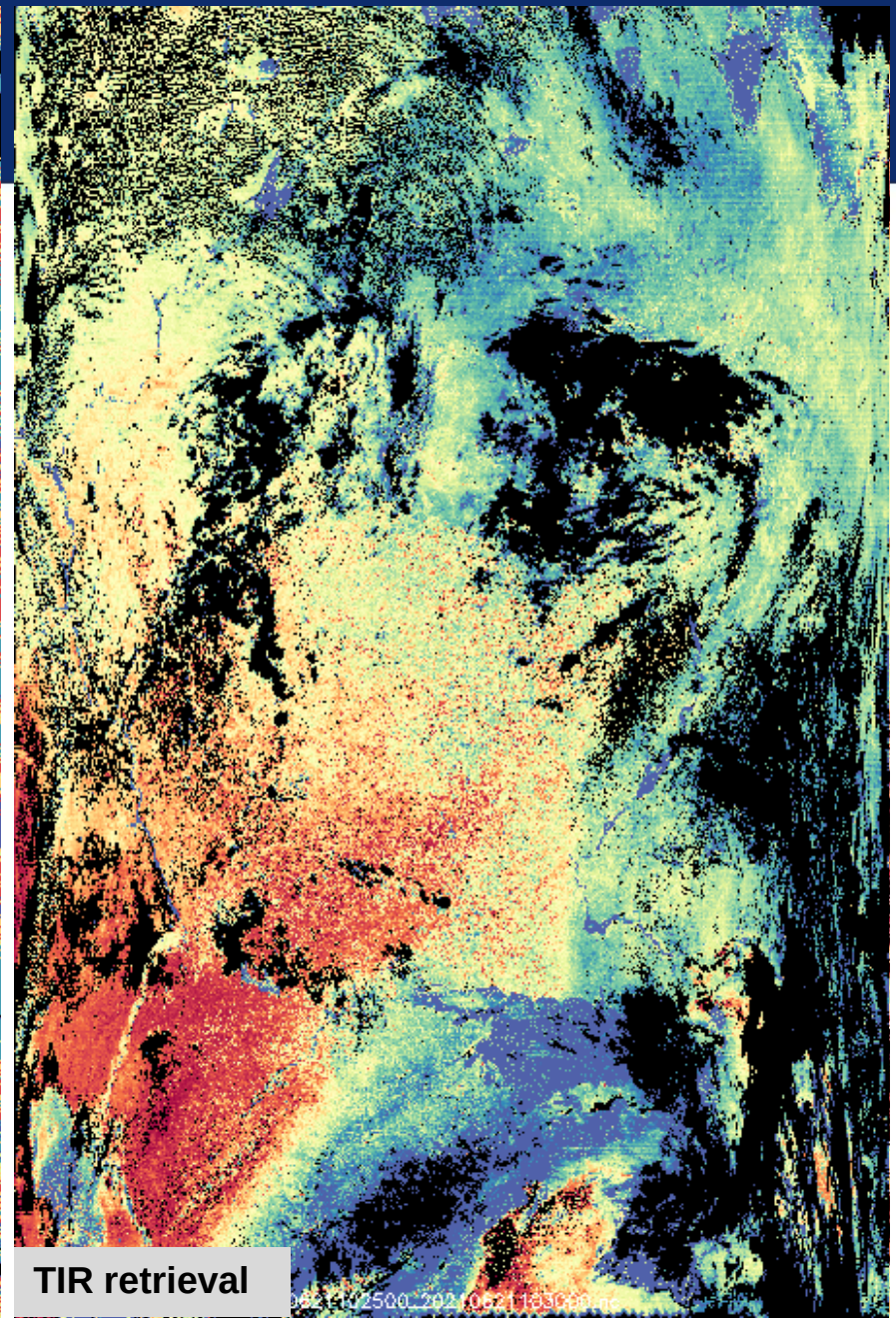
RTTOV fast model error



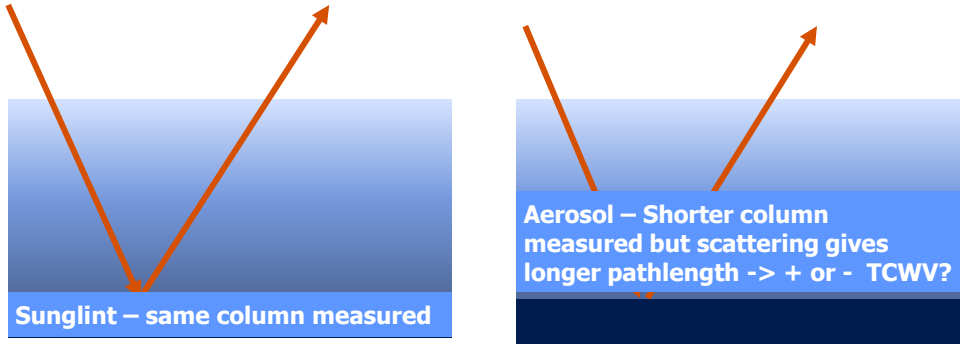


2021 June 21 10:25 MODIS AQUA

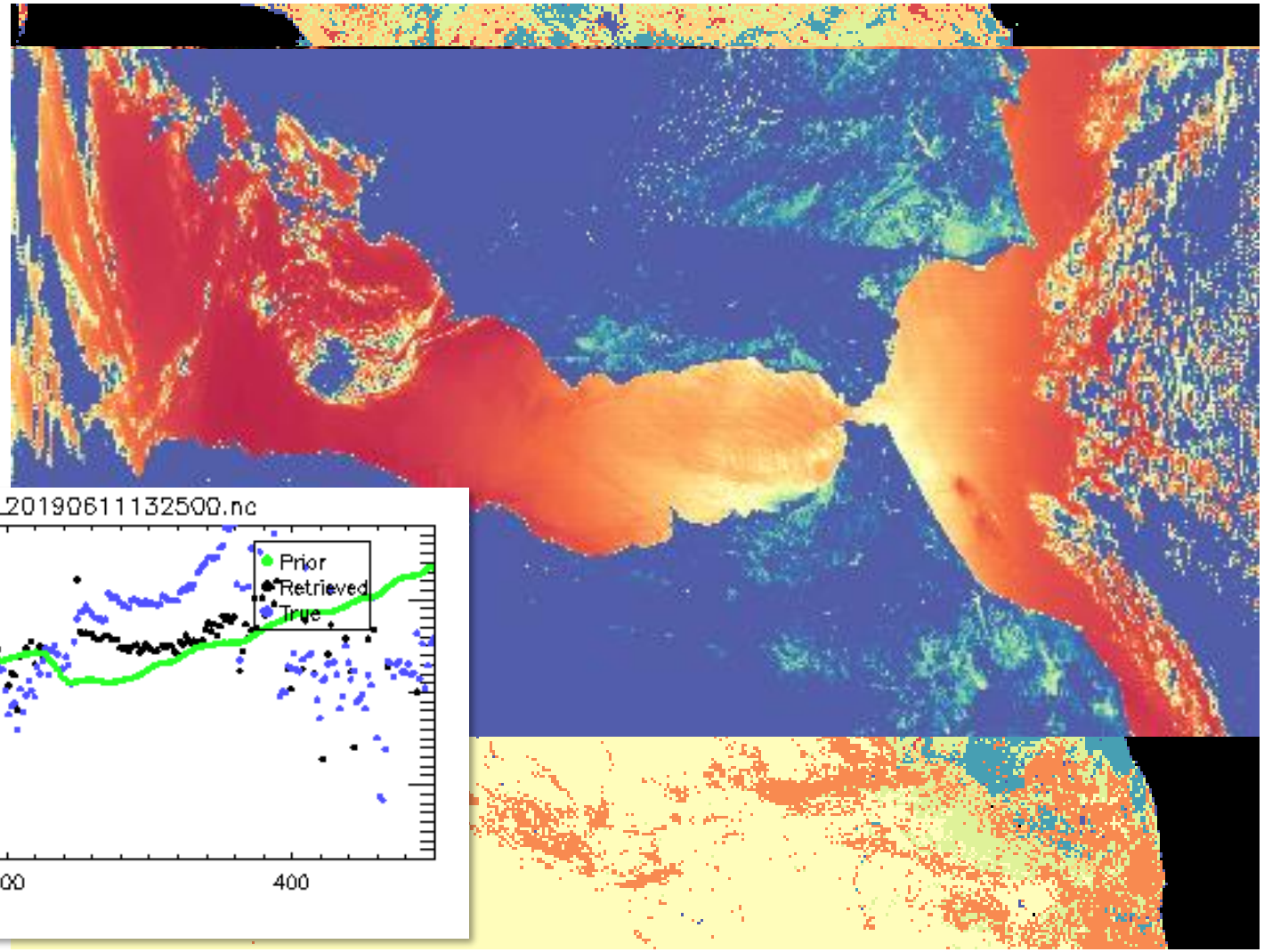


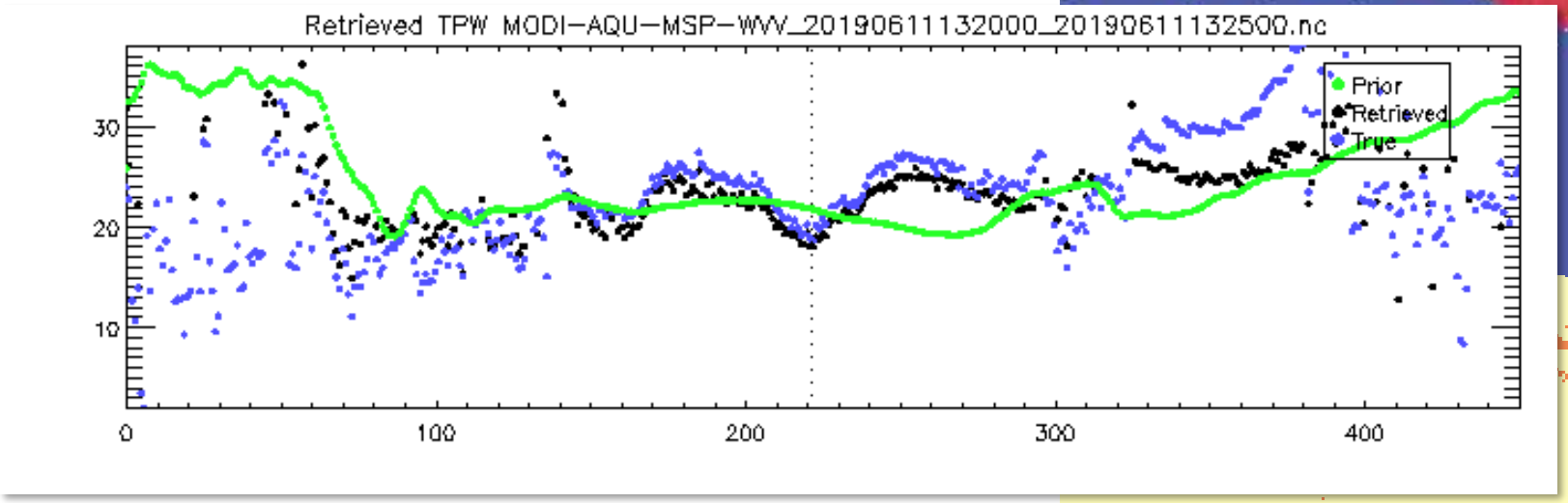


2019 June 11 13:25 MODIS AQUA: Sunglint region



Brighter targets better – but may have different effects





Averaging kernel for TPW to quantify the dependency from forecast

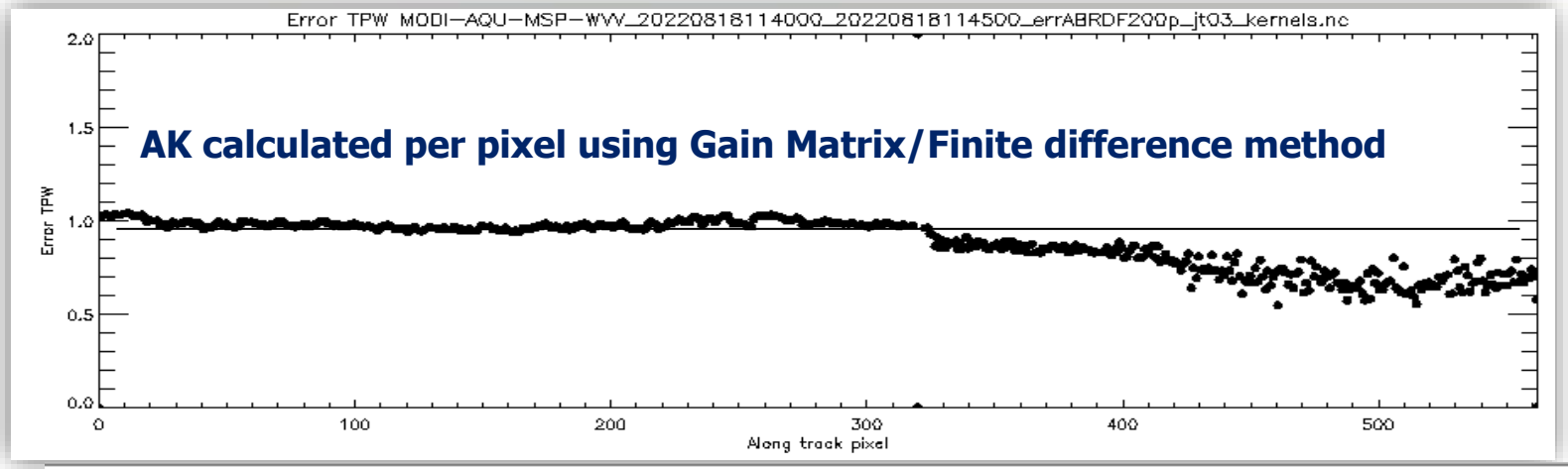
AK_TPW [0:1]
0 = fully dependent
1 = independent

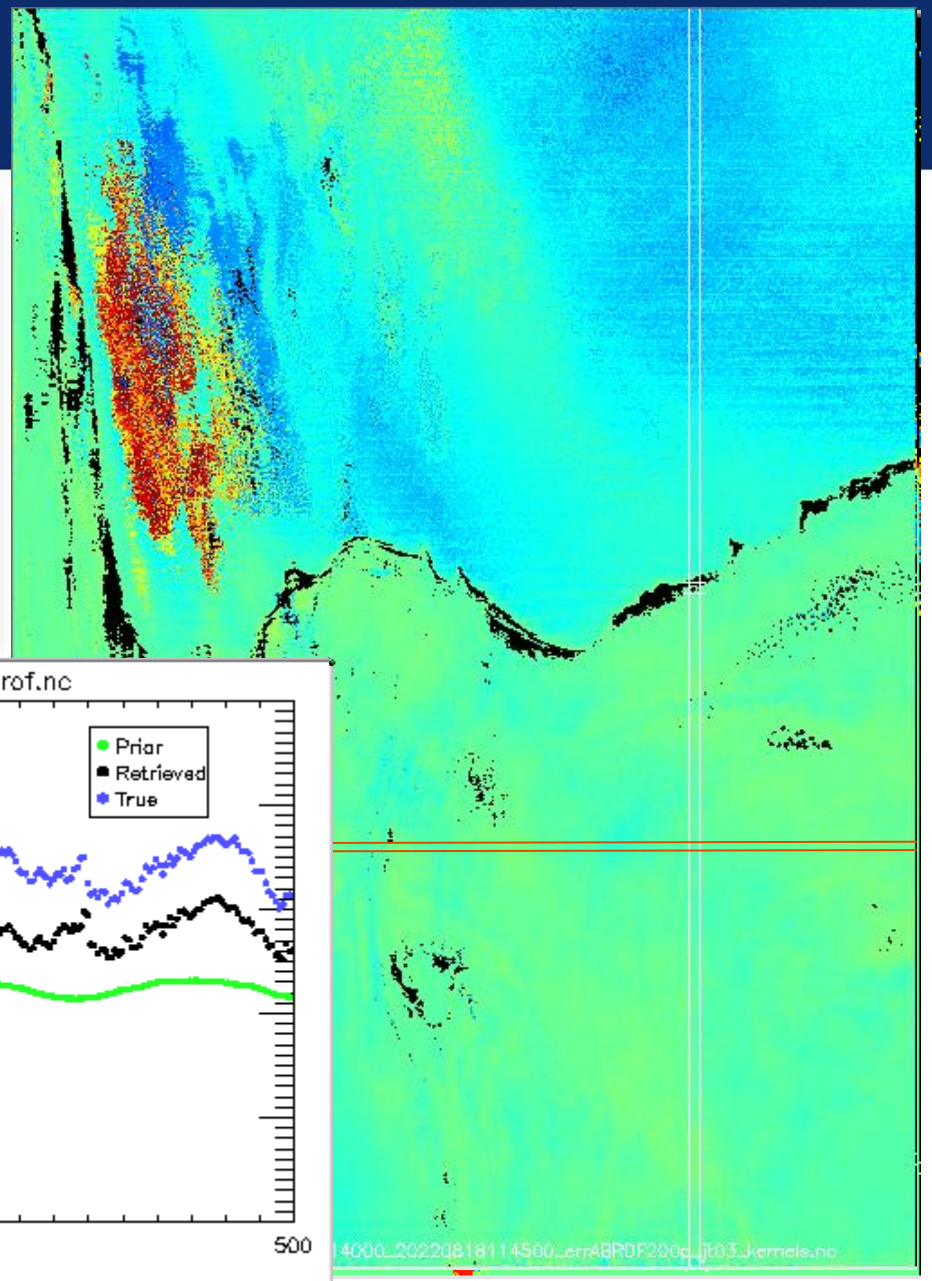
A=dx/dx ☺

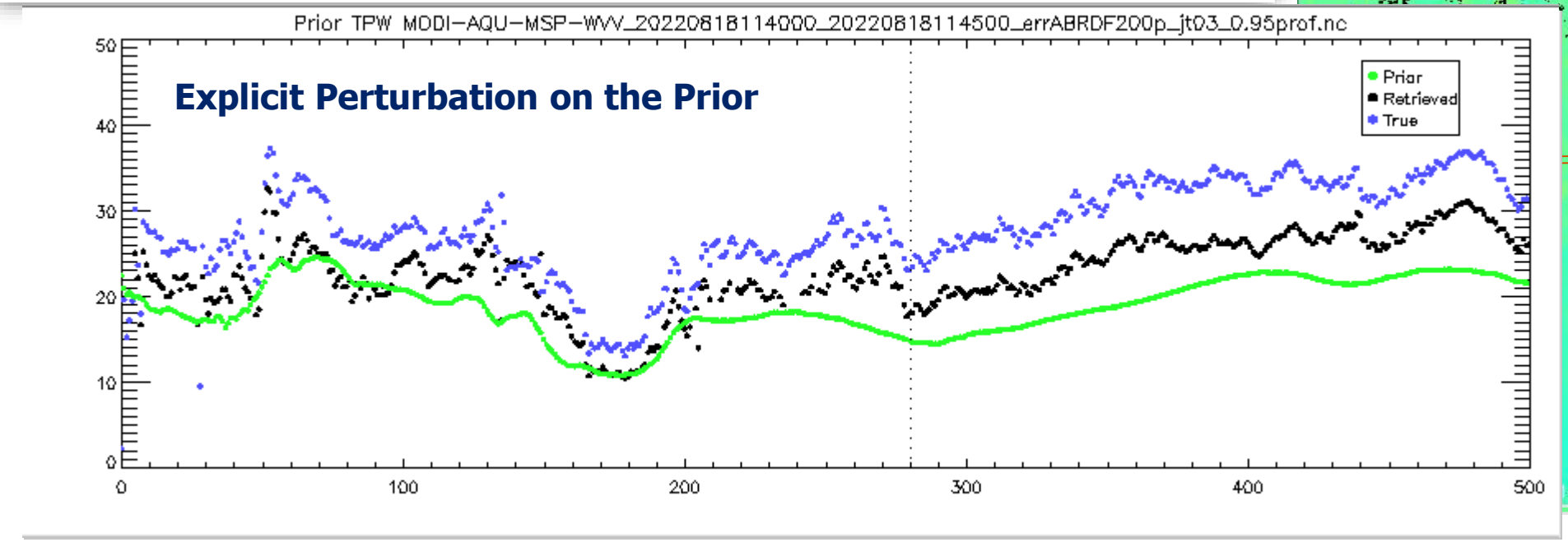
A=dTCWV(x)/dx ☺

A_c=dTCWV(x)/dTCWV(x) ?
A_c=Gain.dx (linear F.D.)

AK_TPW for retrieval from MODIS



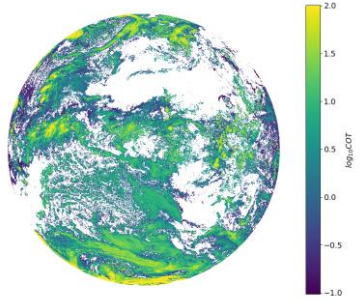




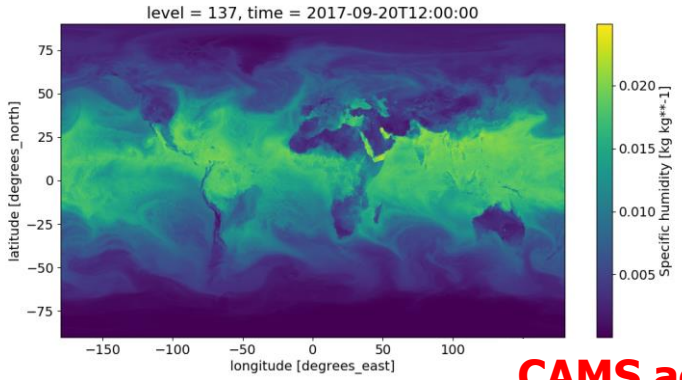
First TPW experiments from FCI 0.9µm channel Using Publically available Synthetic 24 hour data set

FCI synthetic dataset Atmosphere modelling: ancillary data

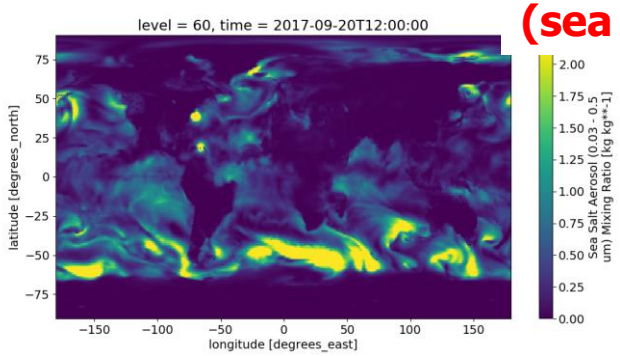
OCA log_{10}(COT)



IFS humidity



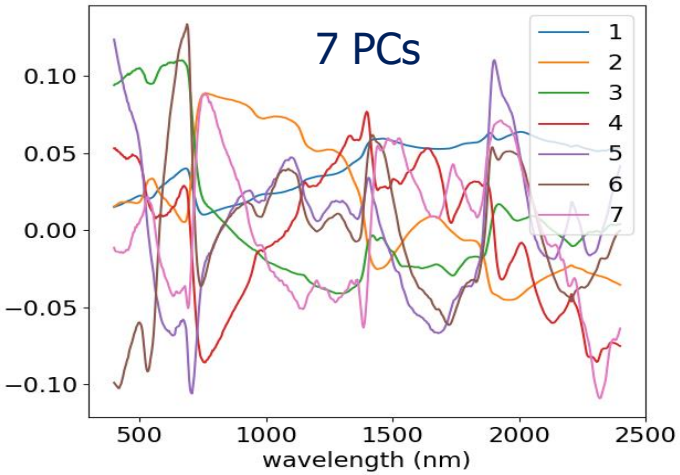
CAMS aerosol (sea salt)

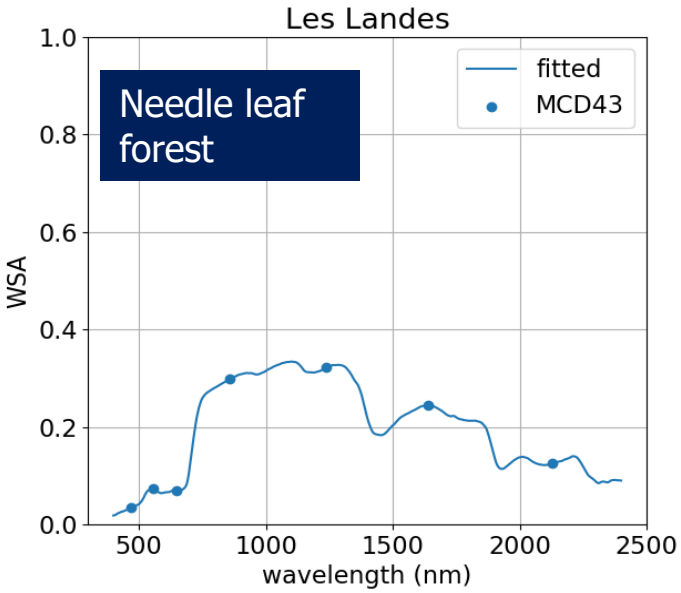


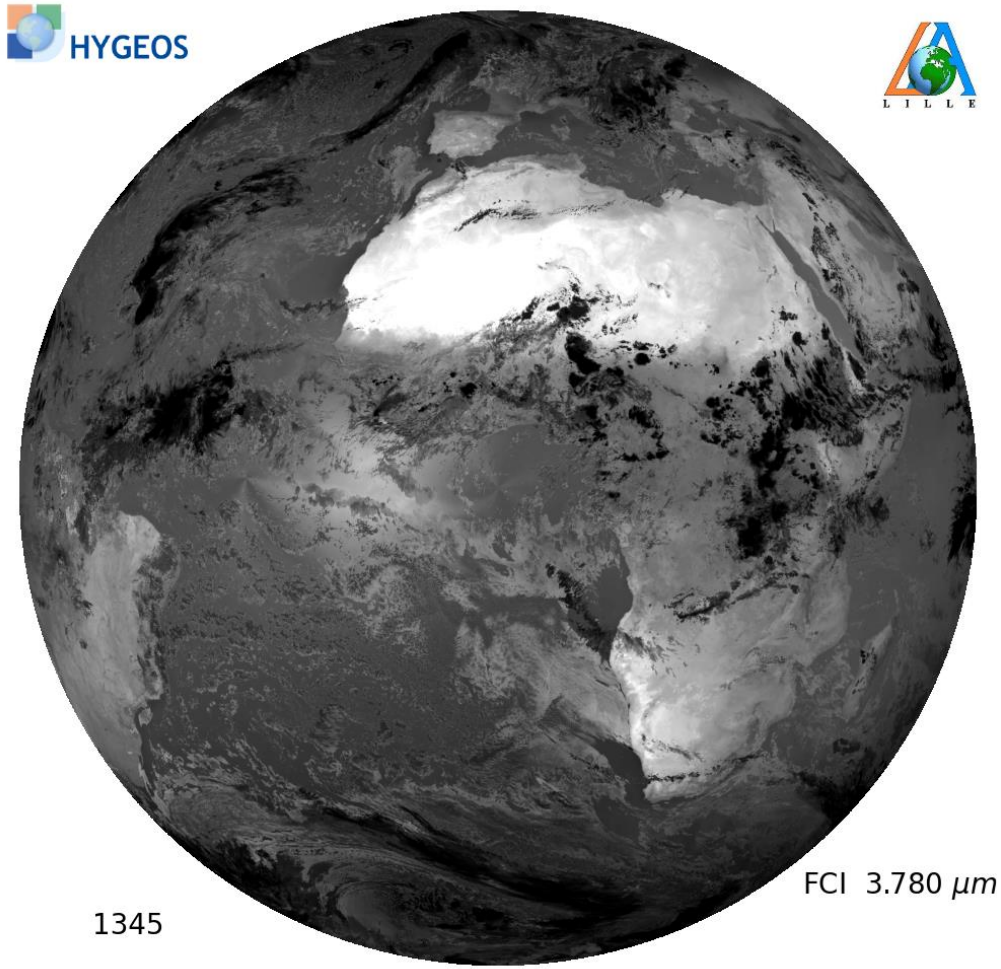
- Gas
  - P, T ,Q , O_3 profiles from ECMWF (137 levels)
- Clouds
  - IWC and LWC profiles from ECMWF (137 levels) scaled to match OCA product (phase, COT and CTH)
  - Cloud effective radius profiles parametrisation using OCA r_{eff}
- Aerosols
  - 11 CAMS aerosol load profiles (60 levels)

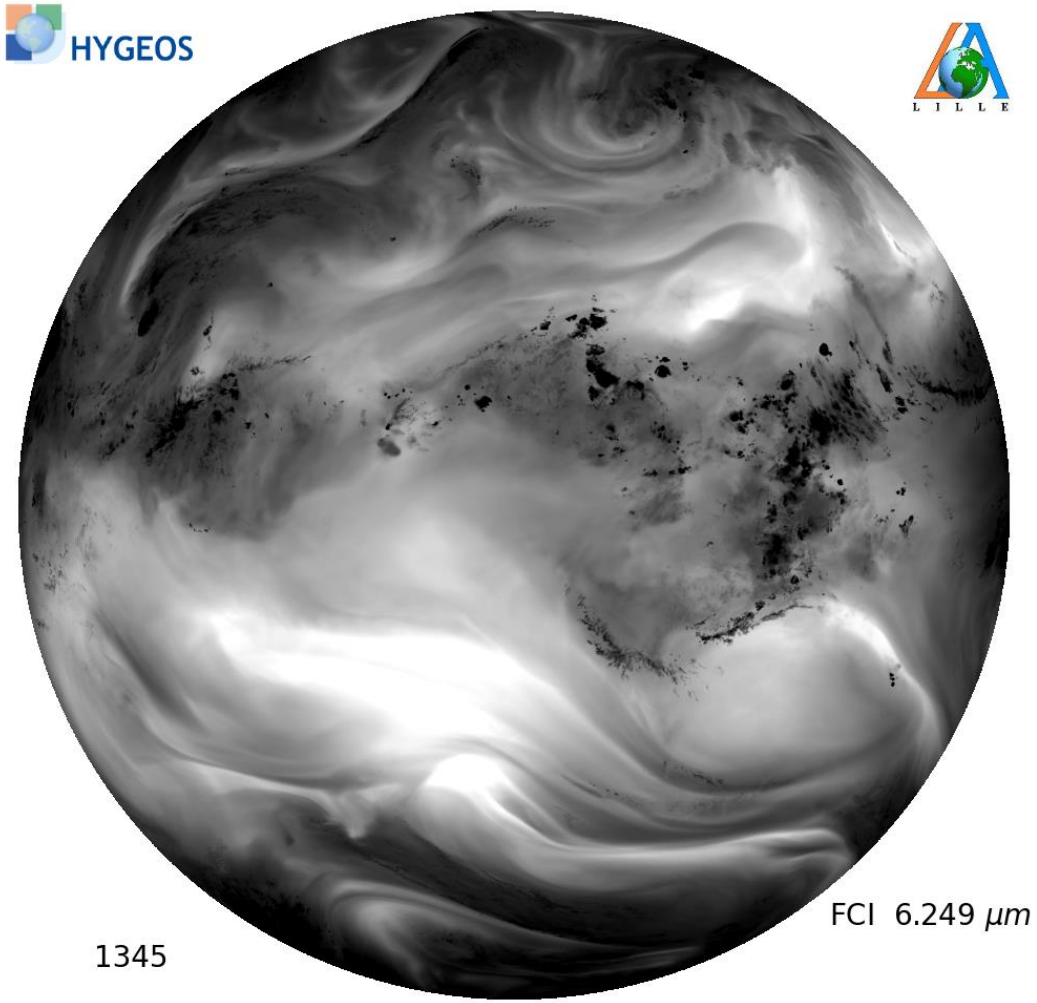
- Spectral k_0, k_1, k_2 land BRDF parameters
- Principal component analysis using ECOSTRESS library (https://ecostress.jpl.nasa.gov/)
  - Around 2000 spectra of rock, manmade, mineral, soil, water, vegetation, non photo-synthetic vegetation
  - PCA --> 7 components obtained

- Spectral k_0,k_1 and k_2 obtained from MODIS MCD43 product by fitting the corresponding white sky albedo with the 7 components






HYGEOS
LILLE
1345
FCI 3.780 μm

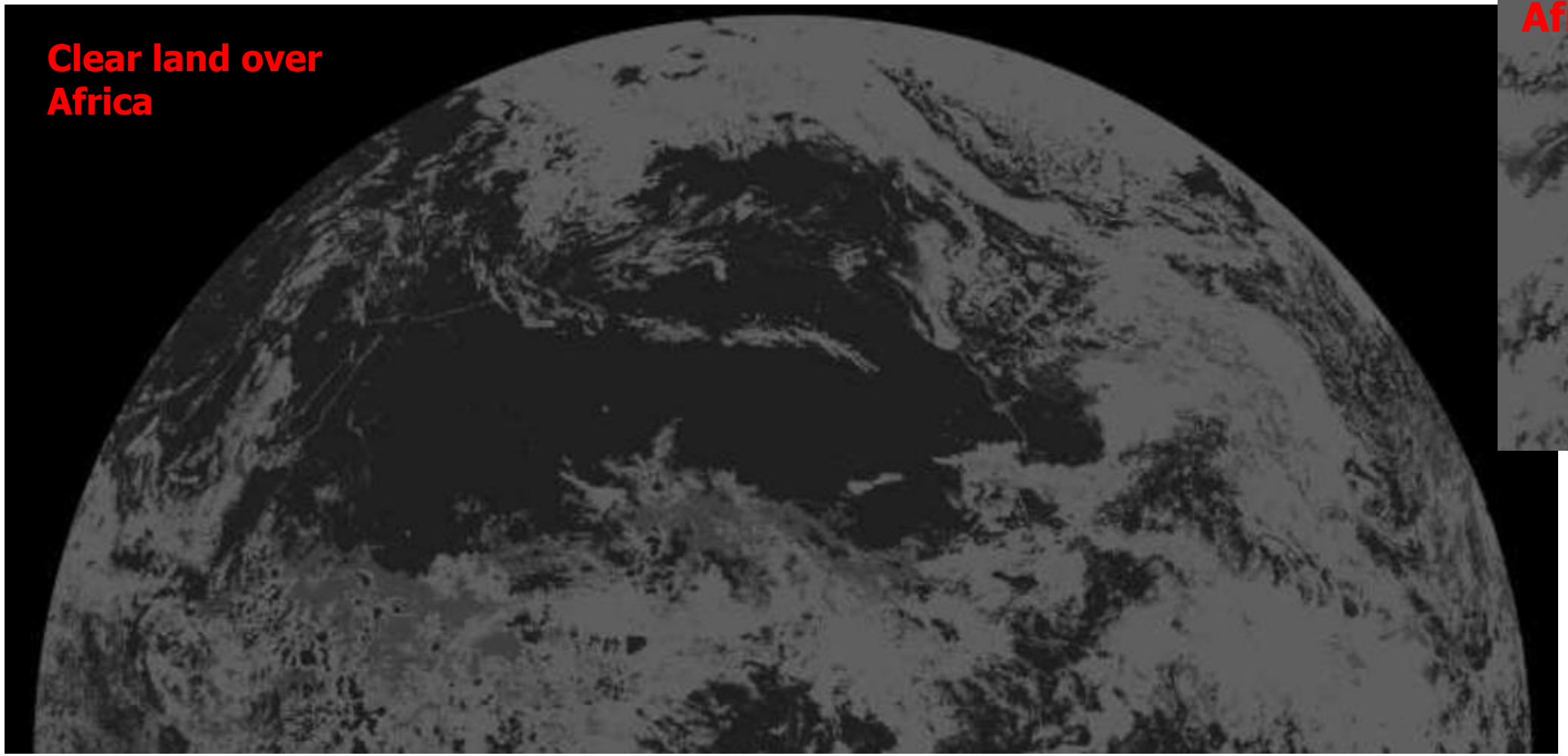

HYGEOS
LILLE
1345
FCI 6.249 μm

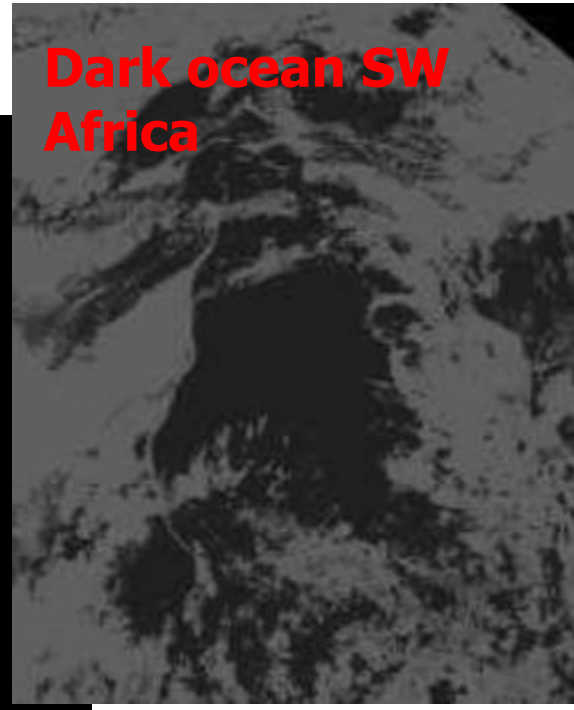
Difference between METimage and FCI TPW-VIS

METimage TPW-VIS algorithm baseline	FCI attempt
0.865μm	0.865μm
0.914μm	0.914μm
1.240μm	1.610μm
Forecast	Forecast
Surface BRDF from MODIS	Clear-sky reflectance product from SEVIRI/FCI

FCI simulated L1c data, 20 Sept 2017, 16:00-16:10

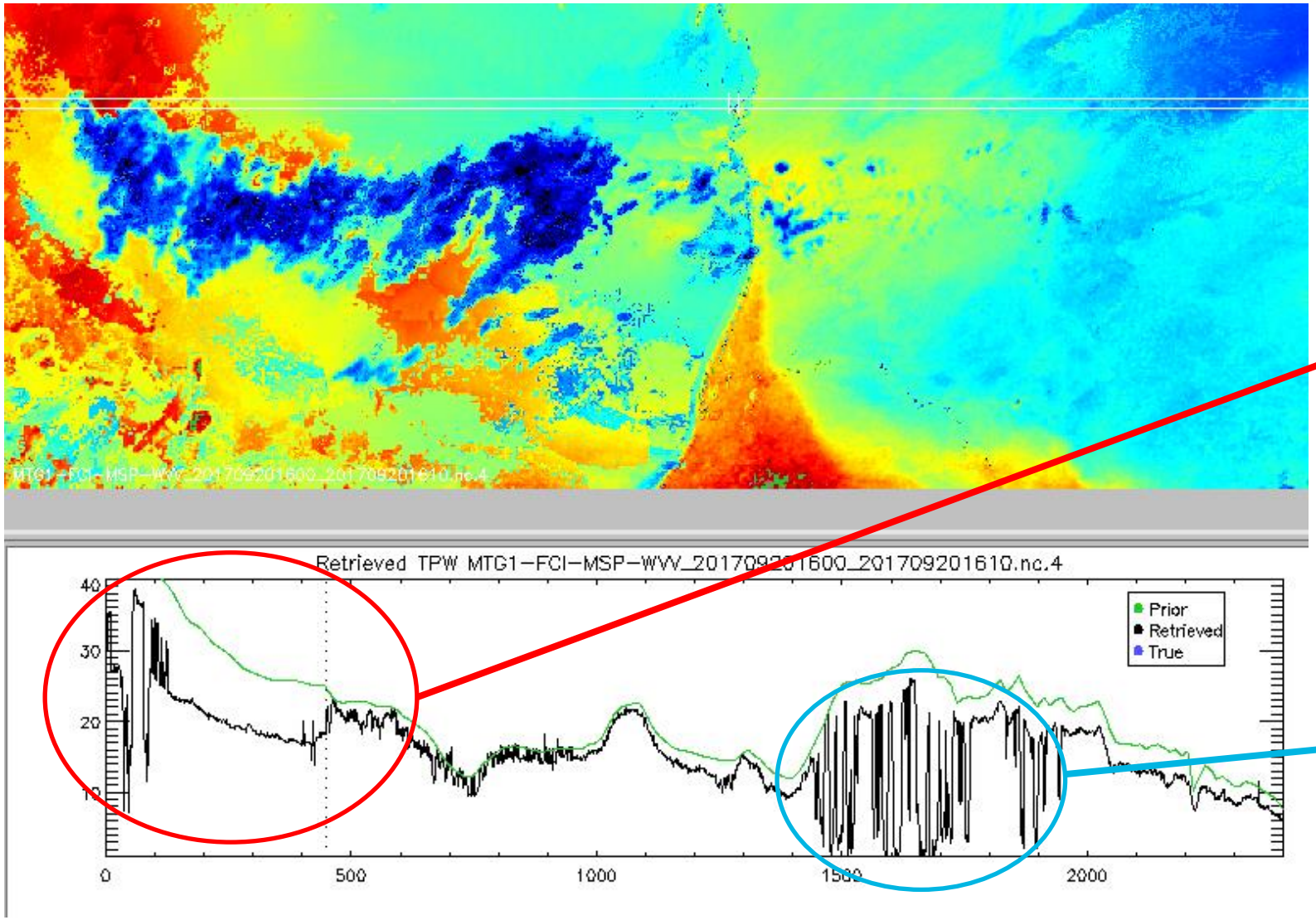
https://www.eumetsat.int/new-fci-l1c-24h-spectrally-representative-test-dataset





EUMETSAT

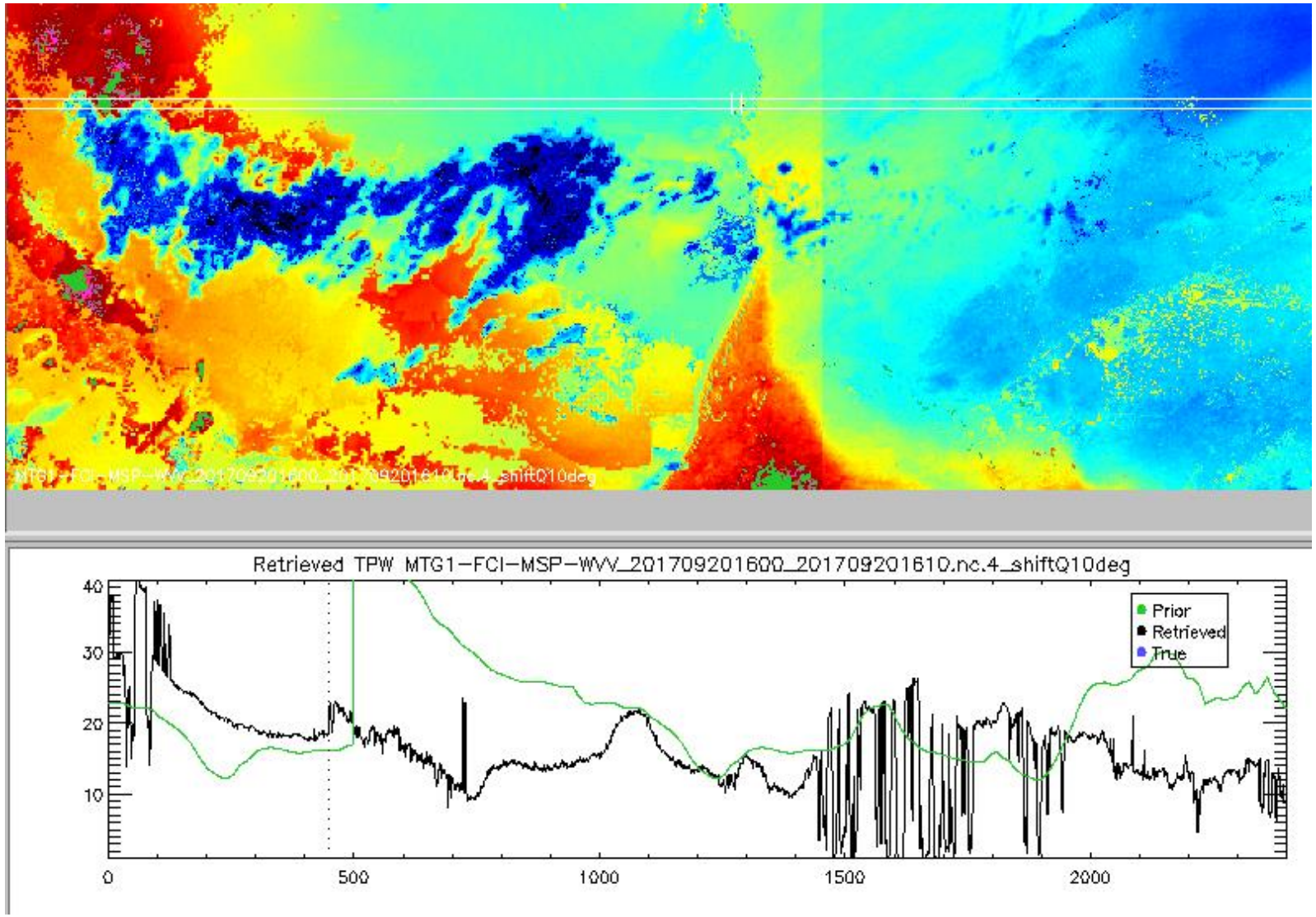
Land



Effect of dust/aerosols

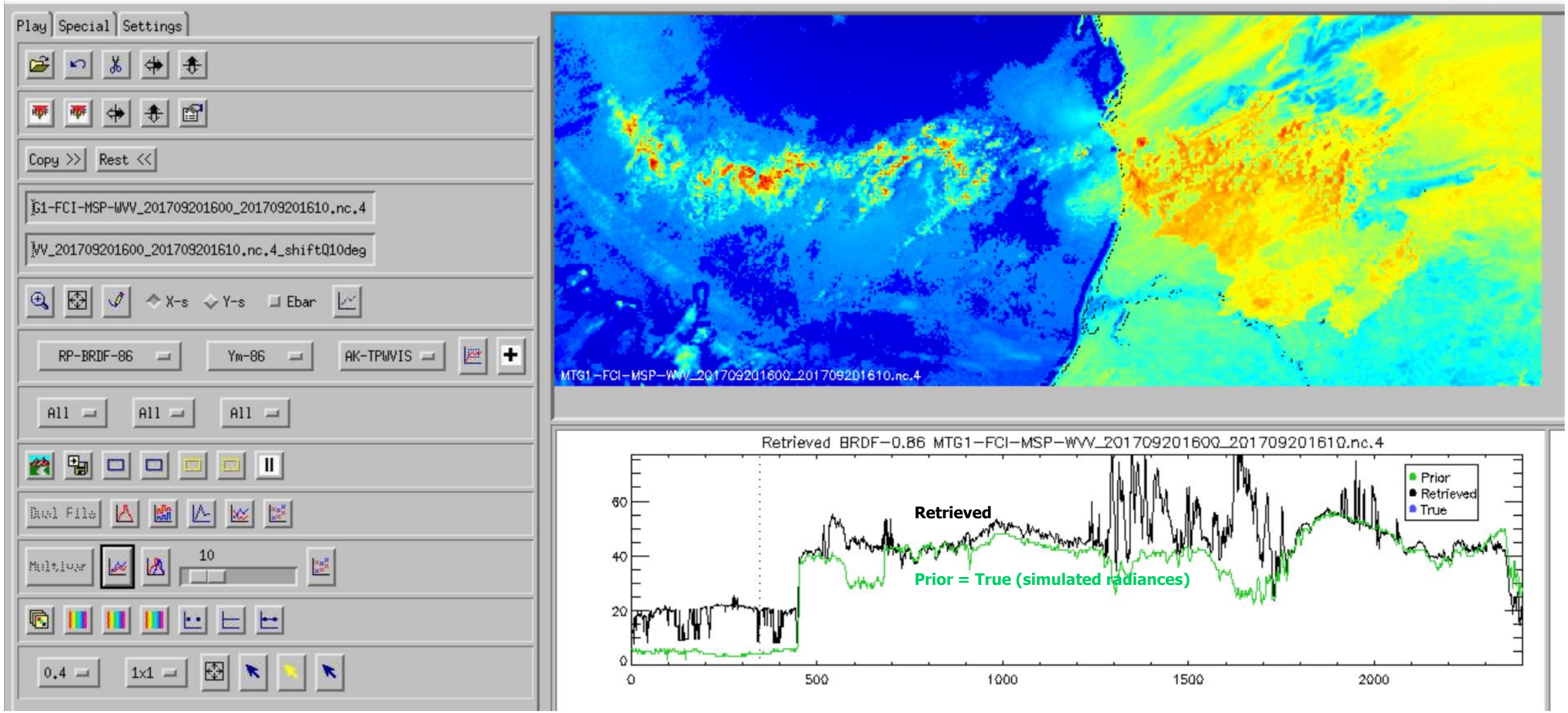
Clouds

Land with 10deg shift in prior forecast



Confirms Forecast Independence Of TCWV

Retrieved BRDF – comparison to truth



Outlook

- Implementing spectral BRDF constraint 0.8-0.9µm via PCs and more channel input
- Introduction of aerosol optical depth in state vector
  - Characterise accuracy and averaging kernel
- Start comprehensive validation exercises based on MODIS, SEVIRI – dry run for VII, FCI
- Further study of FCI retrieval using synthetic data
  - Testing BRDF approach
  - Combined NIR/TIR

More general activities (EUM/RSP)

- MTG-FCI
  - METimage algorithm(s) applied to FCI (initially offline)
  - Clone (to NIR) or Extension (NIR+TIR) of operational GII
  - Testing algorithms on 24 simulated dataset
- RSP new coordinated effort on TCWV from optical imagers
  - Algorithm development & Maintenance
  - EPS-SG, MTG, S3
  - Cal/Val activities
  - Outreach (e.g. to ESSL)
- Activities on with Hyperspectral / synergies – through studies

Thanks!