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Clear-Sky Estimation of Earth Outgoing Longwave Radiation and Atmospheric Heating Rate with IASI

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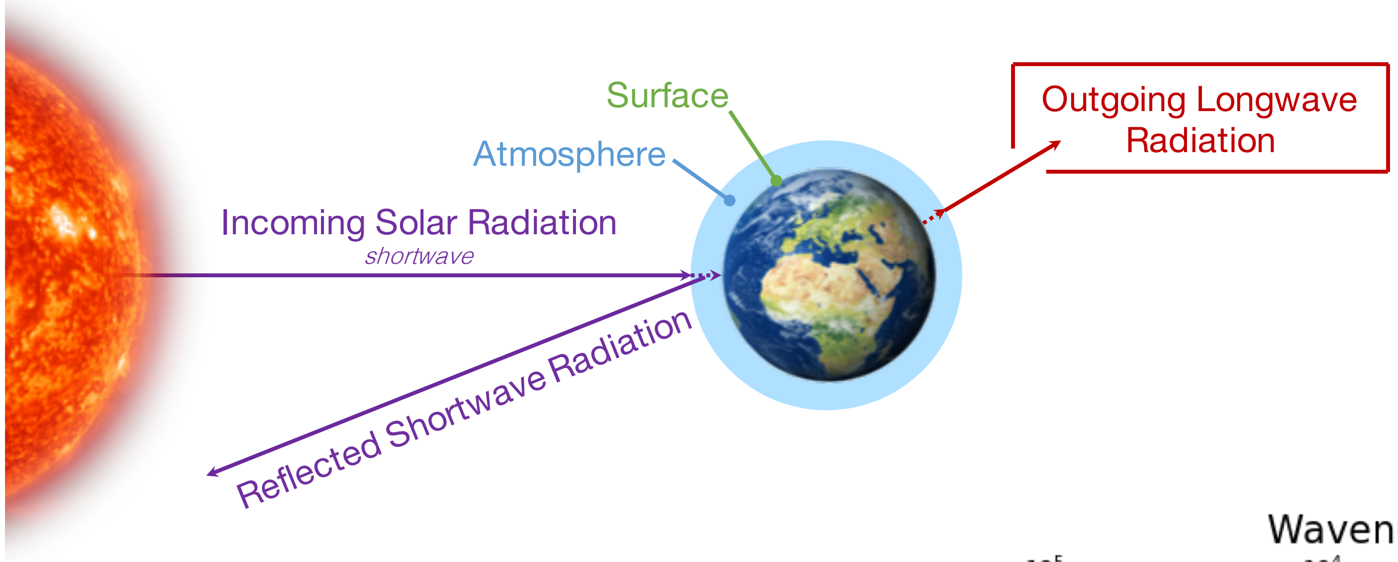
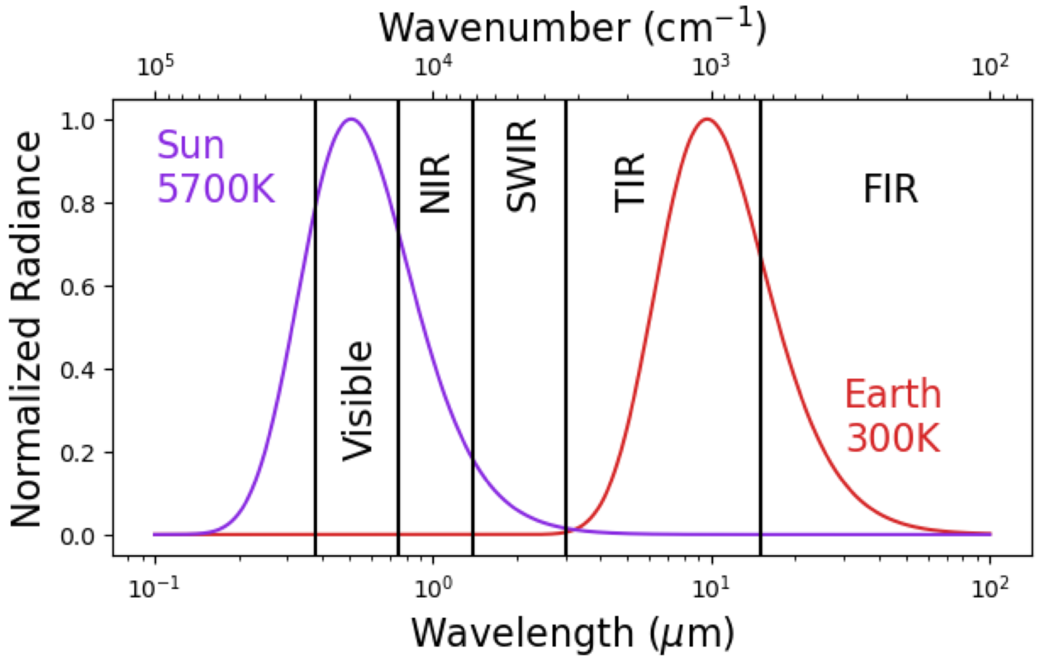
The Earth Radiation Budget (ERB)



- The Earth Radiation Budget is defined by
  - Incoming solar radiation (ISR)
  - Outgoing reflected shortwave (RSW)
  - Outgoing longwave radiation (OLR)
- This equilibrium is the main driver of the climate system
- The ERB is an Essential Climate Variable that can only be measured from space (GCOS)

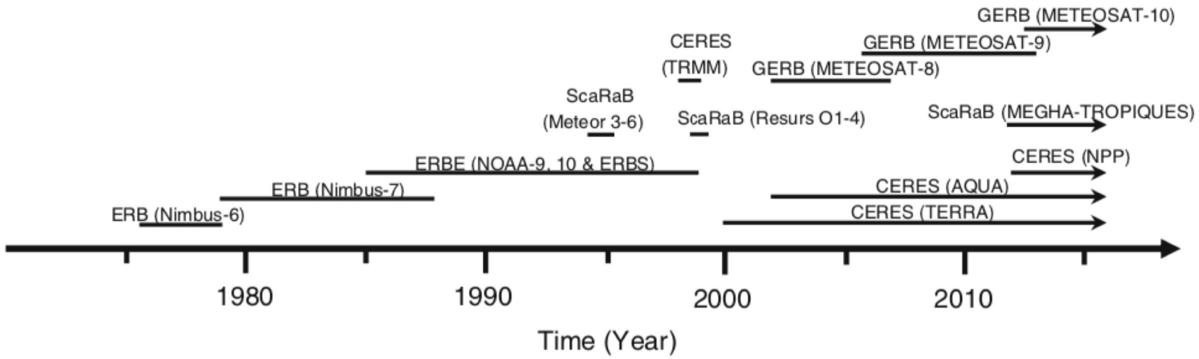


This work focuses on the longwave radiation

Two kinds of spaceborne measurement of the OLR

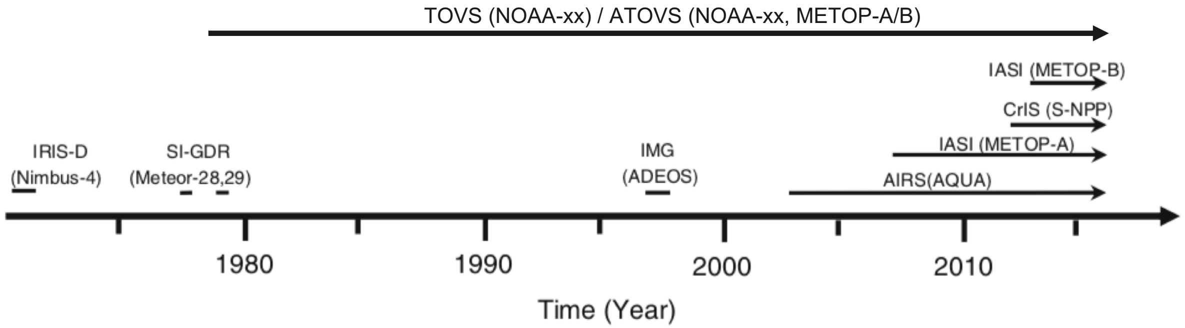
Source : Brindley et Bantges (2013)

Broadband radiometers



- e.g. ERB, CERES, ScaRaB (1975-…)

IR sounders

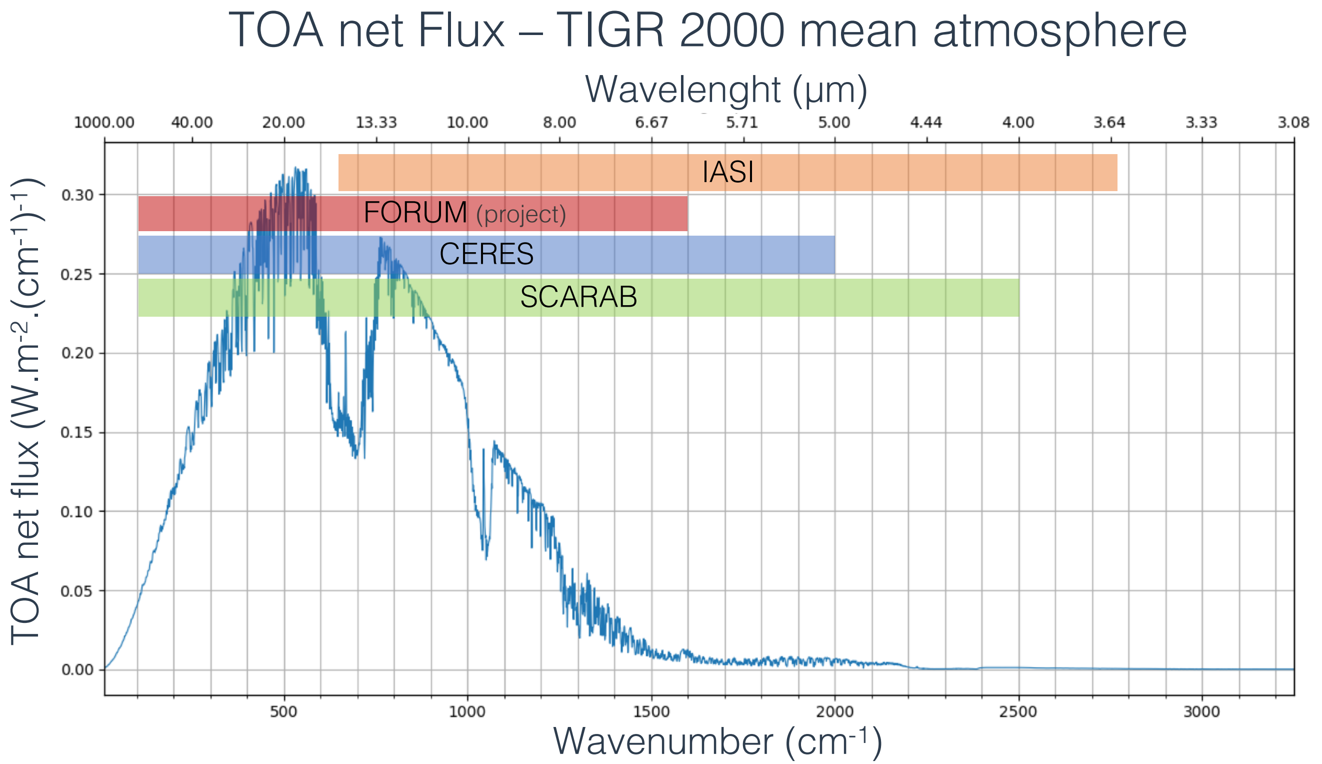


- Low resolution: e.g. TOVS/ATOVS (1978-…)
- High resolution: e.g. AIRS, IASI, CrIS (2002-…)

Broadband Radiometers	Accessible Variables	IR sounders
✓	TOA Net flux (OLR)	✓
x	Radiative Flux and cooling rate spectra	✓
x	Radiative Flux and cooling rate profiles	✓

- IASI combines a high spectral and radiometric stability and long term coverage (20 years)
- IASI offers a continuous coverage of the TIR spectrum from 645 to 2760 cm^{-1} (3,63 – 15,5 μm)
- IR Radiative flux estimation → One of the original objectives of IASI

How to determine radiative flux from IASI measurements?



	Spectral band (cm^{-1})		TOA net flux ($W.m^{-2}$)	% of all
	All	10 – 3250	222.22	100.0
IR Sounders	IASI	645 – 2760	112.68	50.7
IR Sounders	FORUM	100 – 1600	217.42	97.8
	FORUM+IASI	100 – 2760	220.67	99.3
Broadband radiometers	CERES	100 – 2000	219.55	98.8
Broadband radiometers	SCARAB	100 – 2500	220.50	99.2

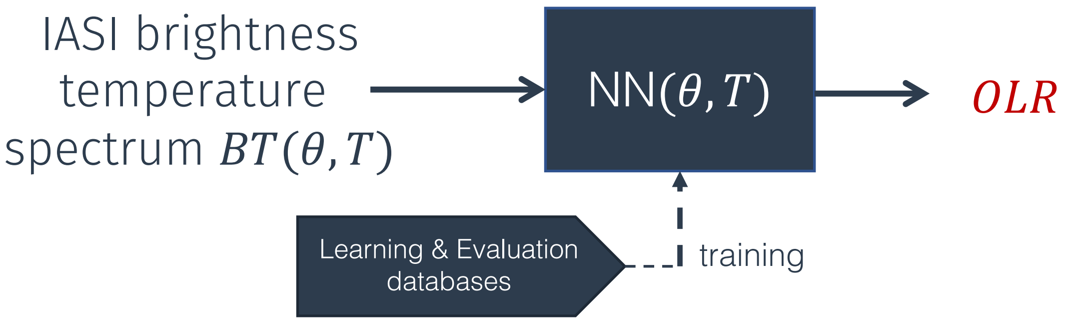
Challenges using IASI measurement to retrieve OLR and heating rate

- The LW spectrum is not entirely covered by IASI
  - Only around 50% of the OLR is included into IASI spectral coverage $[645 - 2760]\ \mathrm{cm}^{-1}$ range
- Radiances depend on the viewing angle
  - IASI measures radiances with angles ranging from 0° to 57° whereas the OLR is integrated over all angles
- No instrument have the same spectral coverage
  - IASI, CERES and Scarab spectral coverage are different implying difficulties in inter-comparisons

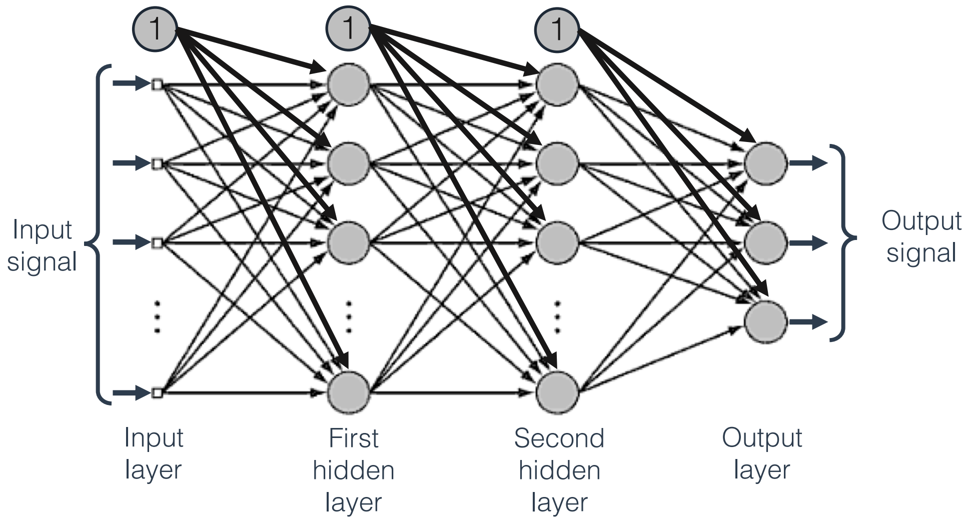
A neural network approach to retrieve OLR from IASI

Suite of 30 Neural networks (NN)

- 15 measurement angles ($\theta \in [0{,}58]°$)
- 2 types of atmospheres ($T \in \{\text{tropical}, \text{mid–latitude}\}$)



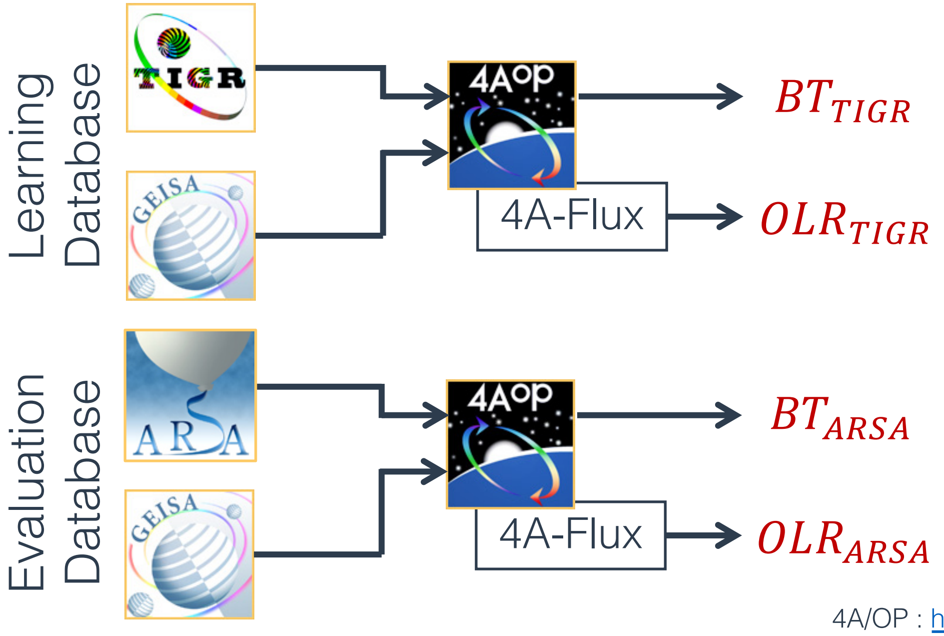
NN(θ, T) : Multilayer perceptron with 2 hidden layers



This work focuses on the estimation of OLR over the tropics

Databases:

- 4A/OP line-by-line radiative transfer code with 4A-Flux: a new module dedicated to radiative fluxes and vertical heating rate calculations (*Tellier et al. in prep.*)
- GEISA 2015 spectroscopic database
- Learning database: TIGR 2000 representative atmospheric database
- Evaluation database: ARSA radiosounding database



References :
4A/OP : https://4aop.aeris-data.fr/
GEISA : https://geisa.aeris-data.fr/
TIGR : https://ara.lmd.polytechnique.fr/index.php?page=tigr
ARSA : https://ara.lmd.polytechnique.fr/index.php?page=arsa

Performance of the NN approach – Methodology

Approach 1:

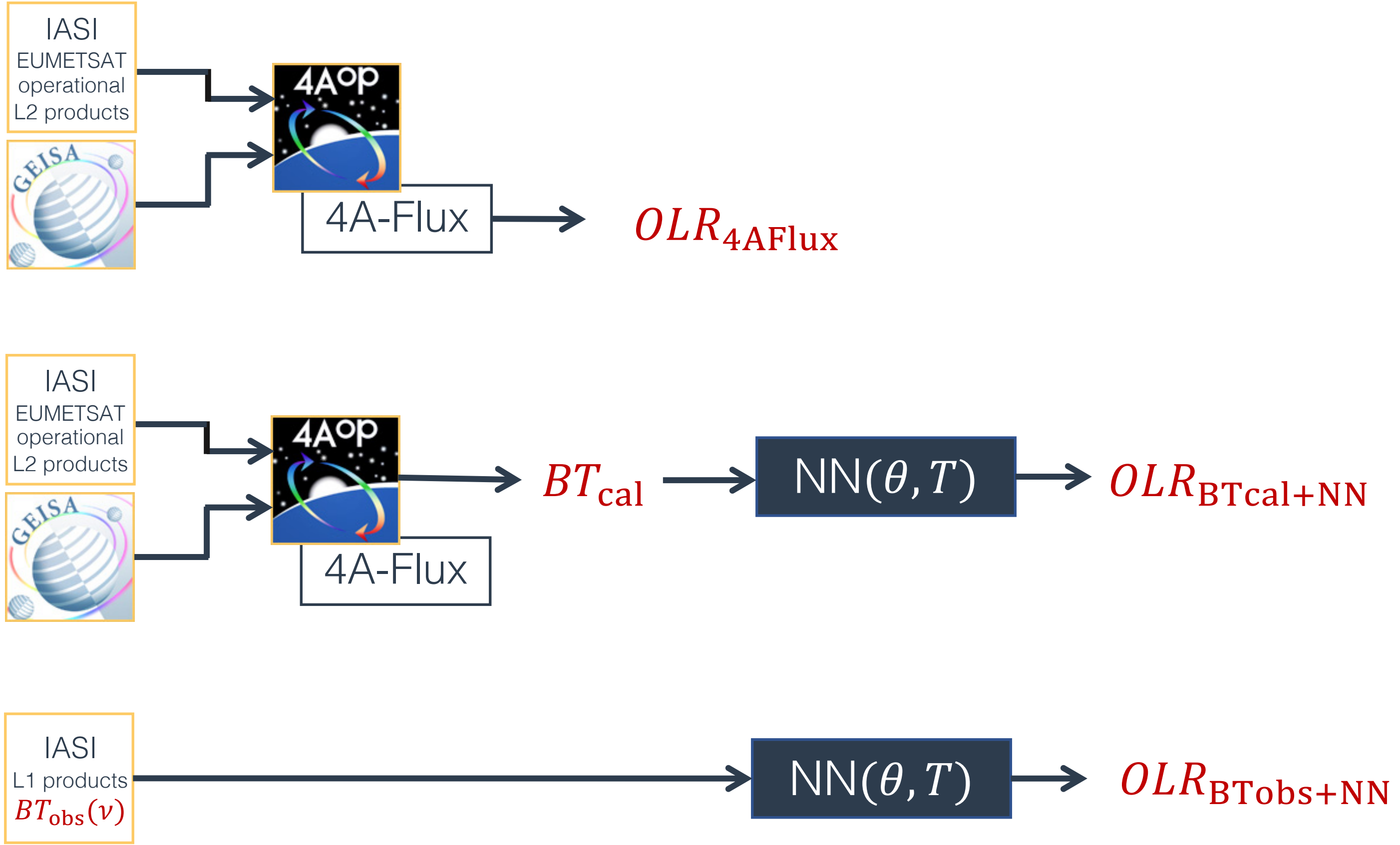
- A direct computation of OLR with 4A-Flux from IASI-L2

Approach 2:

- An indirect retrieval of OLR with the NN applied to calculated BT

Approach 3:

- Retrieval of OLR from IASI L1



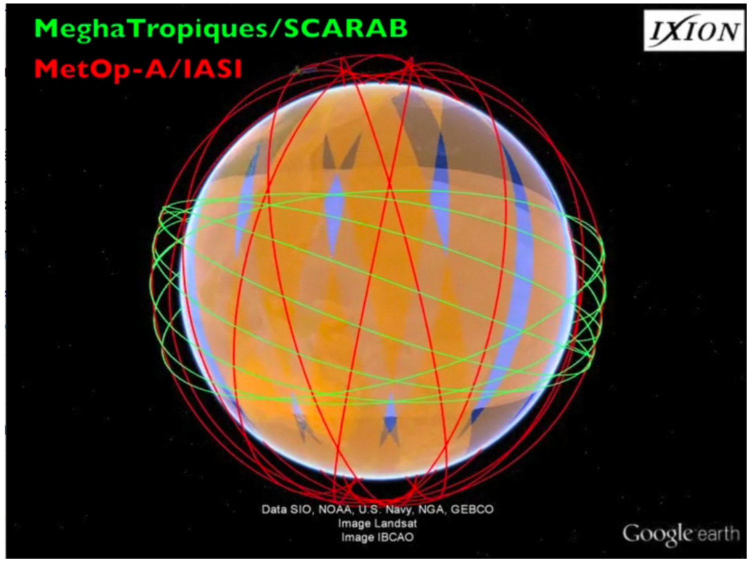
The objective is to compare each approach together and with independent sets of observations

Computation time of each approach (100 levels atmospheres)

	Approach 1	Approach 2	Approach 3
For 1 situation	390 sec	72 sec	**5 ms**
For 1 month of IASI	~ 26 years	~ 5 years	**~ 2 h 14 min**

* Computation times does not include input/output file access times.
One month of IASI data contains approximately 2 millions situations that fits our conditions (clear-sky, night, ocean, tropical or temperate)

Performance of the NN approach – Results



Difference	Approach 2–1 $OLR_{\mathrm{BTcal+NN}} - OLR_{\mathrm{4AFlux}}$	Approach 3–1 $OLR_{\mathrm{BTobs+NN}} - OLR_{\mathrm{4AFlux}}$	Approach 3 – Scarab $OLR_{\mathrm{BTobs+NN}} - OLR_{Scarab}$
Bias $\pm$ stdev $(W.m^{-2})$	$-0.22 \pm 0.15\ W.m^{-2}$	$-0.22 \pm 0.68\ W.m^{-2}$	$-1.21 \pm 2.58\ W.m^{-2}$
Bias $\pm$ stdev (%)	-0.08 ± 0.05 %	-0.08 ± 0.25 %	-0.45 ± 0.95 %

Dataset: 124988 collocated points IASI/Scarab for 2016 observations

Collocation criteria:
- Nearest neighbors
- Maximum distance: 25 km
- Maximum time shift: ± 3 h
- Close nadir observations only
- Tropical atmospheric type
- Ocean surface
- Clear-sky only
- Night only
- Instrument PSF not taken into account

Results: Approach 2–1
- OLR retrieved with the NN approach applied to calculated BT produces OLR values very close to 4A-Flux simulations
- Bias and standard deviation are lower than typical errors between line-by-line radiative transfer models

Results: Approach 3–1
- Applied to IASI L1, the NN bias remains identical but the standard deviation increases due to random discrepancies between observed and measures BT spectra

Results: Approach 3–Scarab
- Compared to collocated Scarab OLR, both bias and standard deviation of the NN approach increases

Comparative results

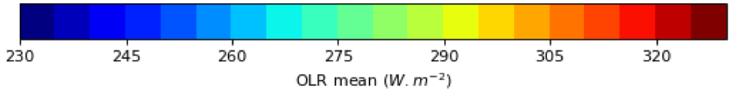
OLR standard deviation between the 6 RFMIP benchmark radiative transfer model	$0.61\ \mathrm{W.m^{-2}}$
OLR Bias and stdev. [Scarab–CERES] (*Roca et al., 2015*)	$-0.74 \pm 6.60\ \mathrm{W.m^{-2}}$
OLR Stdev. [AIRS–CERES] for all scenes (*Sun et al., 2010*)	less than $3\ \mathrm{W.m^{-2}}$

IASI-A clear-sky nighttime OLR time series on tropical oceans

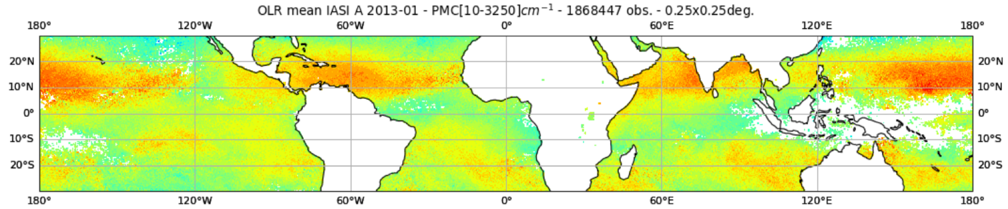
Complete IASI-A daily mean clear-sky OLR estimated with the NN suite applied on IASI L1 with a 3 month moving average

<u>Conditions</u>:

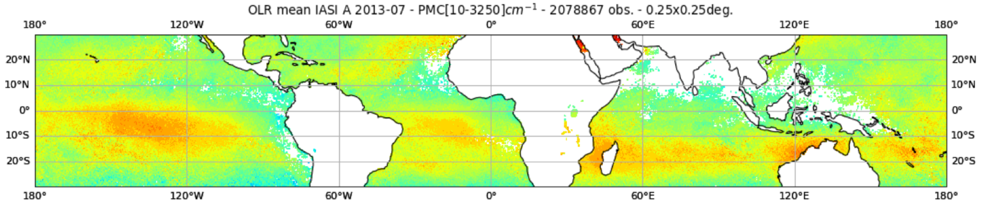
- Nighttime
- Tropical
- Oceans



IASI A – January 2013



IASI A – July 2013

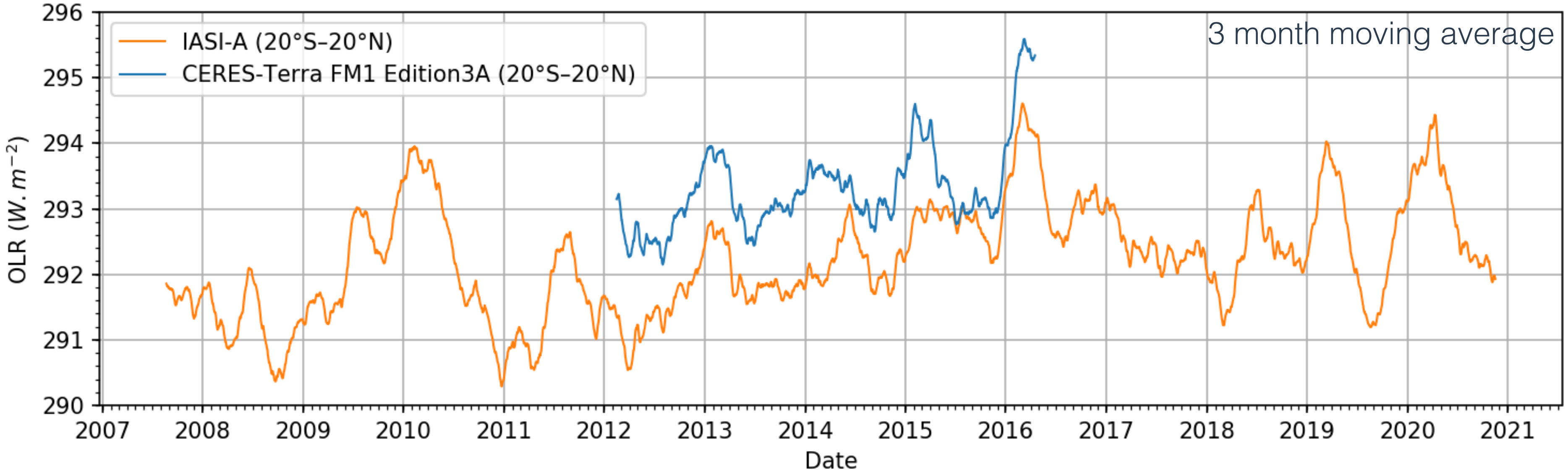


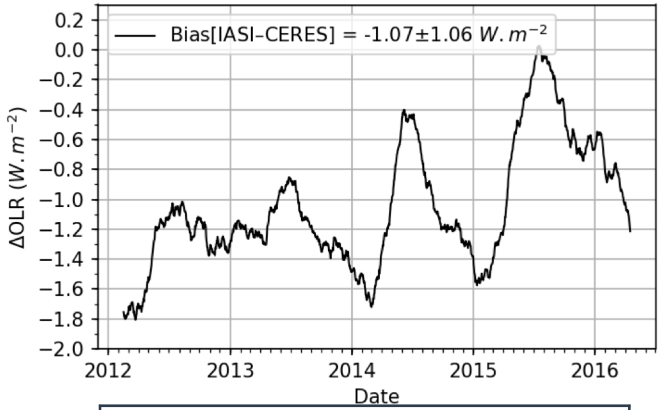
Examples of monthly mean OLR maps (0.25°x0.25° spatial resolution)

Remarks:

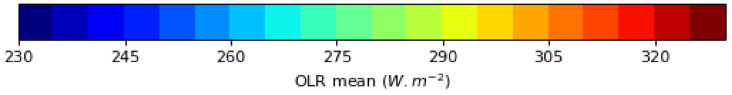
- The high OLR during 2009–2010 and 2016 periods is partly caused by strong El Niño events
- Higher OLR in the Northern (resp. Southern) tropical seas in January (resp. July) 2013
- Clouds over the Northern Indian Ocean in July 2013 has prevented measurement to be made in some areas
- Very high OLR over the Red Sea and the Persian Gulf (hot & dry)

IASI-A and CERES-Terra Clear-sky tropical oceans OLR time series

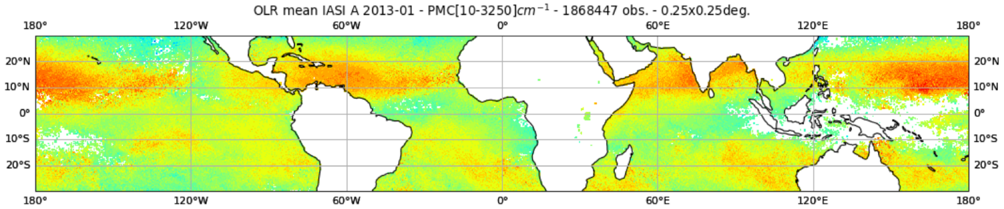




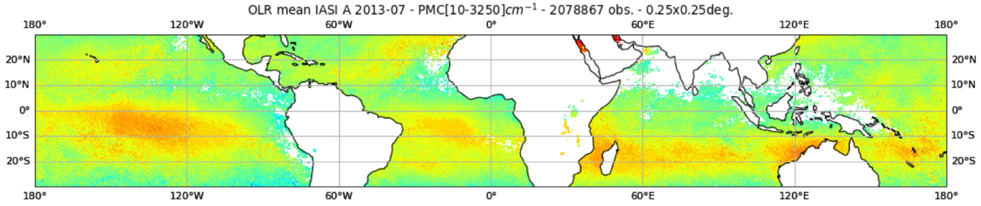
Bias ± stdev [IASI − CERES]
$-1.07 \pm 1.06\ W.m^{-2}$ $-0.40 \pm 0.39\ \%$



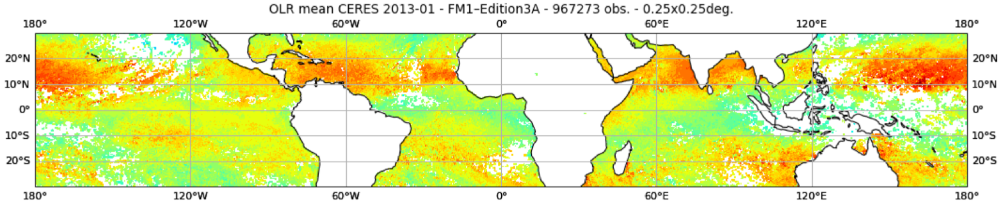
IASI A – January 2013



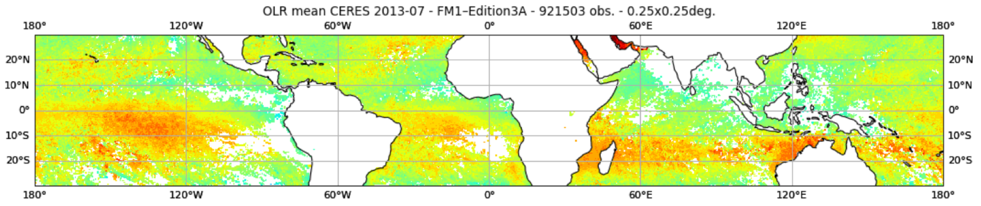
IASI A – July 2013



CERES Terra FM1 – January 2013

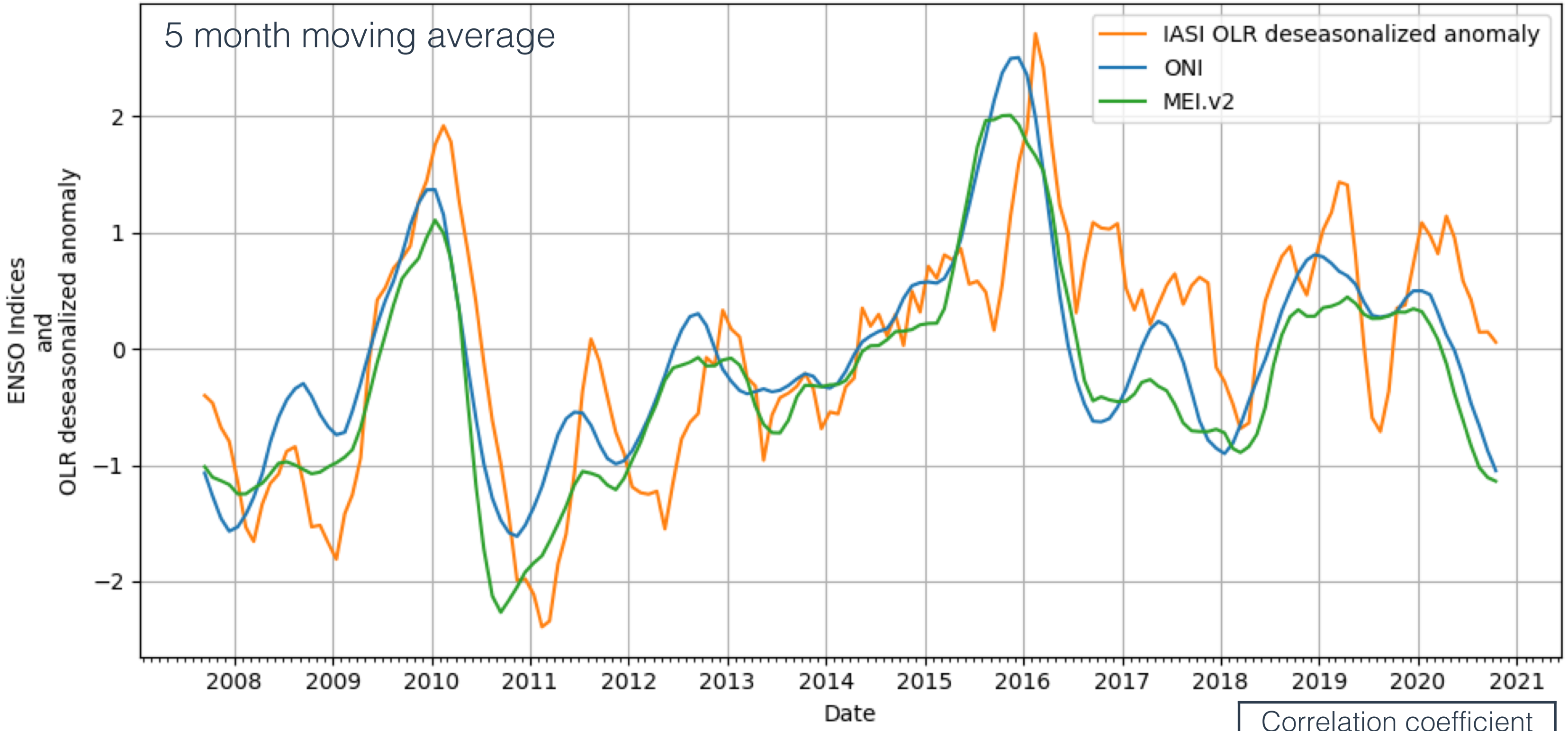


CERES Terra FM1 – July 2013



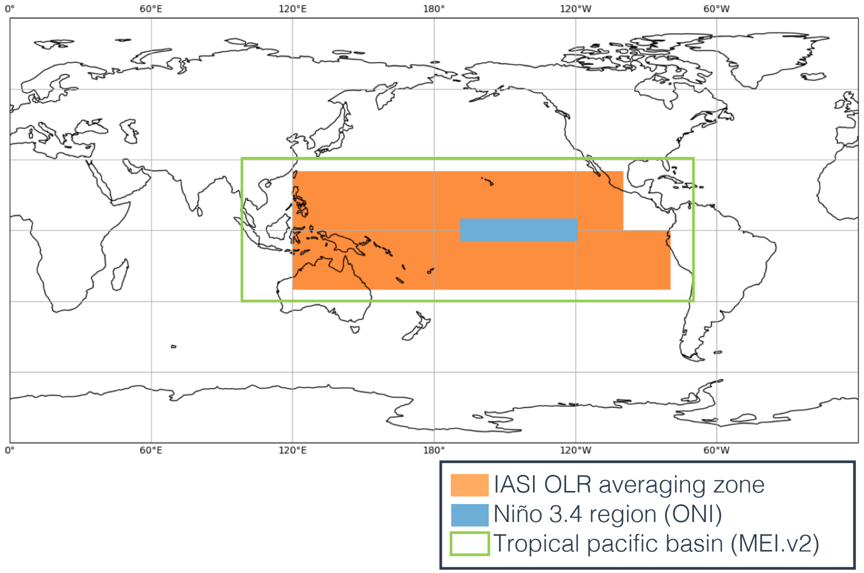
- The same patterns appear on the OLR maps for IASI and CERES
- The bias [IASI–CERES] is close to the bias [IASI–Scarab]
- The standard deviation is lower as we consider the daily mean OLR and not single observations
- Caveat 1: Terra and Metop-A don't have the same orbit and diurnal variations of SST can lead to 0.5 $W.m^{-2}$ OLR discrepancies and cause a systematic errors
- Caveat 2 : The LW domains are not exactly the same for the two instruments (CERES 100–2000 cm^{-1} and IASI 10–3250 cm^{-1})

IASI-A OLR compared to ENSO indices



Reference ENSO indices

- ONI: Oceanic Niño Index SST in Niño 3.4 region
- MEI.v2: Multivariate ENSO Index Version 2
- IASI OLR: 5 month moving average of the deseasonalized OLR anomalies over regions: 25°S – 0°S ; 120°E – 80°W and 0°S – 25°N ; 120°E–100°W



	Correlation coefficient	
	No shift	2 months shift
ONI & MEI.v2	0.95	0.95
ONI & OLR anom.	0.71	0.81
MEI.v2 & OLR anom.	0.74	0.80

Preliminary results:

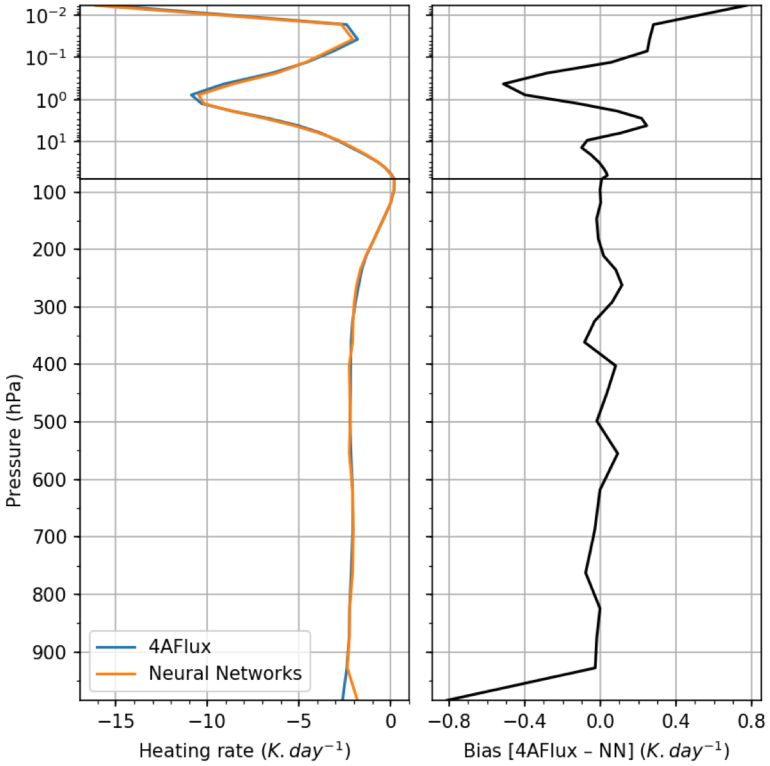
- Medium to high correlations between the OLR anomaly and ENSO indices
- The OLR anomaly depends on other factors than ENSO (cloud coverage, temperature and water vapor profiles…)
- El Niño phase of 2009-2010 and the neutral phase of 2013-2014 show a good intercorrelations
- A time shift is noticeable on the OLR anomaly compared to ENSO indices – Correlation coefficients are higher when the OLR anomaly time series is shifted by two months.

Conclusions and perspectives

Conclusions:

- A suite of Neural Networks has been developed to retrieve the clear-sky OLR from IASI measured radiance spectra
- This approach is both the fast and accurate compared to line-by-line simulations
- IASI OLR time series can be used to detect climate phenomena such as ENSO

Neural Network bias on LW vertical heating rate retrieval (ARSA database 1762 situations)



Perspectives:

- Inter-comparisons (IASI/CERES) are performed to evaluate the Neural networks on temperate oceans
- An extension of the Neural Networks on land and during daytime will enrich the possibilities of studies
- The Neural network approach applied to the determination of the LW vertical heating rate is under study
- Beyond IASI, future satellite missions are being prepared such as IASI-NG, FORUM. Benefiting form advanced methods such as neural network approaches, these missions will improve our understanding of essential radiative climate variables.

LMD

Thank you for your attention

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