Implementation of the Bessel's method for solar eclipses prediction within the WRF-ARW model

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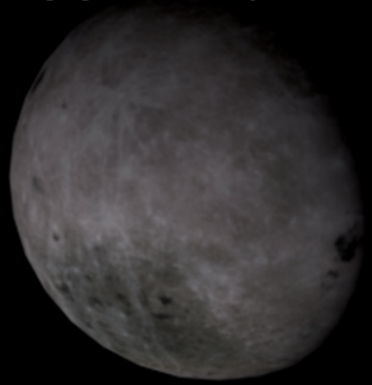

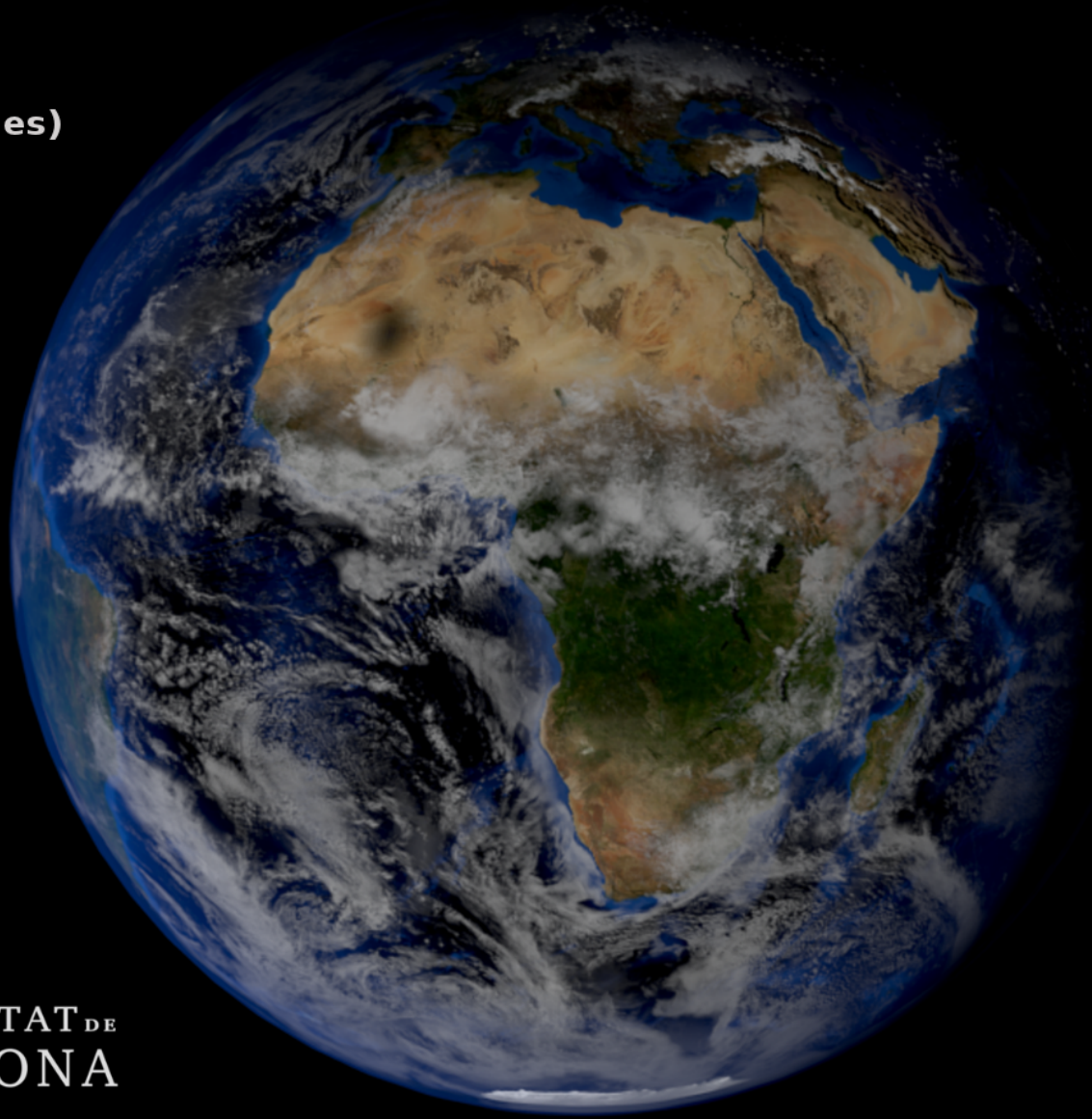

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Contribution

- We propose a new module for computing the solar eclipses based on the Bessel's method.
- The algorithm uses a look-up file where the besselian elements are stored from 1950 to 2050 (for any partial, annular, total and hybrid eclipse). This file can be easily modified in the future.
- The algorithm computes the degree of obscuration of the solar disk at each grid-point. Based on these variables the incoming solar radiation is modified for each solar scheme.
- The compatible schemes are: Dudhia, Goddard, New Goddard, RRTMG, RRTMG fast, CAM and FLG.
- New variables in the history file for diagnosis: degree of obscuration, mask and coordinates of the path of the eclipse.
- Solar eclipse prediction can be enabled/disabled in the namelist.input

Contribution

Fundamentals:

- Montornès A., Codina B., Zack J., Sola Y.:Implementation of the Bessel's method for solar eclipses prediction in the WRF-ARW model. 2015 (submitted to ACPD, attached).
- Oral contribution to the 15th EMS Annual Meeting & 12th European Conference on Applications of Meteorology (ECAM), attached.

Code review

The modifications in the code are related with the following files

- Registry/Registry.EM_COMMON (modified)
- phys/module_ra_eclipse.F (new)
- phys/Makefile (modified)
- phys/module_ra_sw.F (modified)
- phys/module_ra_gsfcsw.F (modified)
- phys/module_ra_goddard.F (modified)
- phys/module_ra_rrtmg_sw.F (modified)
- phys/module_ra_rrtmg_swf.F (modified)
- phys/module_ra_cam.F (modified)
- phys/module_ra_flg.F (modified)
- phys/module_radiation_driver.F (modified)
- run/eclipse_besselian_elements.dat (new)

Code review: Registry/Registry.EM_COMMON (modified)

Changes:

- ra_sw_eclipse: namelist (physics) variable for enabling (1) and disabling (0, default) solar eclipses. No domain dependent.
- ECOBSC: history 2D variable representing the degree of obscuration at each grid-point
- ECMASK: history 2D variable representing the status of the solar eclipse at each grid-point (0- No eclipse, 1- Partial/Penumbra region, 2- Total, 3- Annular)
- elon_track, elat_track: coordinates of the path of the eclipse.

Code review: phys/module_ra_eclipse.F (new)

What is it?

- This module is called by the phys/module_radiation_driver.F and it evaluates the solar eclipse conditions for all the domains comparing the simulation date with respect to the set of dates available in run/eclipse_besselian_elements.dat
- This module is composed of a set of 3 routines:
  - solar_eclipse (main)
  - load_besselian_elements: search the besselian elements in run/eclipse_besselian_elements.dat
  - compute_besselian_t: compute the besselian elements for a given time

Code review: phys/module_ra_*.F (modified)

Changes:

- Modules: phys/module_ra_sw.F (Dudhia), phys/module_ra_gsfcsw.F (Goddard), phys/module_ra_goddard.F (New Goddard), phys/module_ra_rrtmg_sw.F (RRTMG), phys/module_ra_rrtmg_swf.F (RRTMG fast), phys/module_ra_cam.F (CAM), phys/module_ra_flg.F (FLG).
- Add the degree of obscuration (obscur) as an input variable
- Modification of the incoming radiation S_{in} from

$$S_{in} = S_0 \mu_0 \tag{1}$$

to

$$S_{in} = S_0 \mu_0 (1 - D_{ij}) \tag{2}$$

where S_0 is the solar constant, μ_0 is the solar zenith angle and D_{ij} is the degree of obscuration at the grid-point (i, j).

Code review: phys/module_ra_*.F (modified)

Changes:

- When D_{ij} is 0 (i.e. non-eclipse episode or disabled in the namelist.input file), we recover the original computation.

Code review: phys/module_radiation_driver.F (modified)

Changes:

- We call the routine solar_eclipse
- We modify each scheme for considering the obscuration as an input variable.

Code review: run/eclipse_besselian_elements.dat (new)

What is it?:

- This file (ASCII) contains all solar eclipses (partial, annular, total and hybrid) since 1950 to 2050
- We modify each scheme for considering the obscuration as an input variable.
- The required variables for the history file are returned to the main code stream.

Code review: run/eclipse_besselian_elements.dat (new)

Table: File description (i)

Column	Description
1	Year of the episode
2	Day of the year of the episode
3	Central time in which the Besselian elements are valid
4	The first time in which the Besselian elements are valid
5	The last time in which the Besselian elements are valid
6,7,8,9	Polynomial coefficients for X
10,11,12,13	Polynomial coefficients for Y

Code review: run/eclipse_besselian_elements.dat (new)

Table: File description (ii)

Column	Description
14,15,16,17	Polynomial coefficients for l_1
18,19,20,21	Polynomial coefficients for l_2
22,23,24,25	Polynomial coefficients for μ
26	Value for tan f_1
27	Value for tan f_2
28	Value for Δt

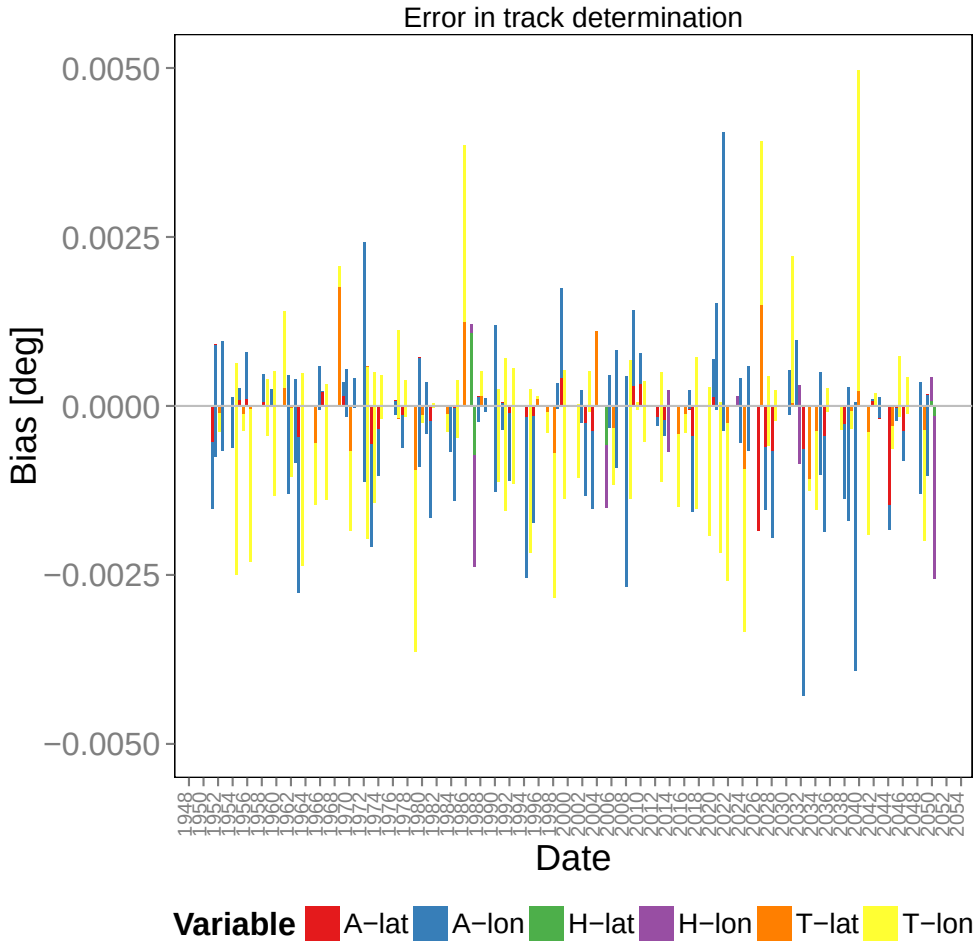
Each row is one episode. Episode between different days, are treated as two different events.

More info in the manuscript: Implementation of the Bessel's method for solar eclipses prediction in the WRF-ARW model (attached with this file).

Code testing

- Solar eclipse conditions: 4 cases of study (v 3.6.1)
  - Validation of the eclipse path from 1950-2050. Comparison with NASA values
  - Application for Dudhia in 4 study cases: 1994-11-03 (South America), 1999-08-11 (Europe), 2006-03-29 (North Africa) and 2009-07-22 (Eastern Asia).
  - More info in the manuscript: Implementation of the Bessel's method for solar eclipses prediction in the WRF-ARW model (submitted to ACPD, attached with this file).
- Solar schemes (v. 3.7.1)
  - Validation of Dudhia, Goddard, New Goddard, RRTMG, RRTMG fast, CAM and FLG in 1999-08-11 (Europe)

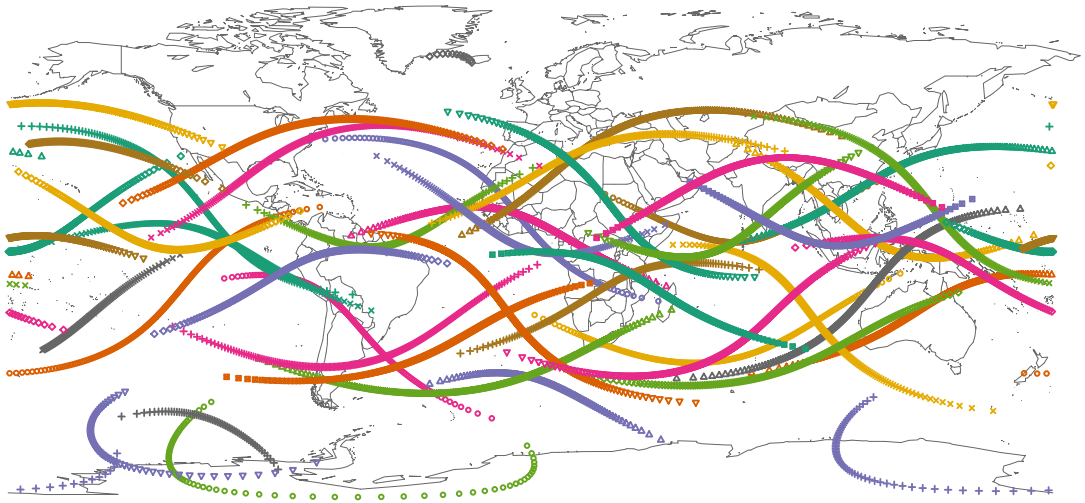
Code testing: Solar eclipse conditions



- All eclipse's path from 1950 to 2050 are evaluted using our algorithm and compared with respect to NASA's values.
- Bias $\leq \pm 5{\cdot}10^{-3}$ degrees (i.e. $\sim$550 m)
- Enough for mesoscale applications
- Note: Partial eclipses are not validated because the path is not defined.

Code testing: Solar eclipse conditions

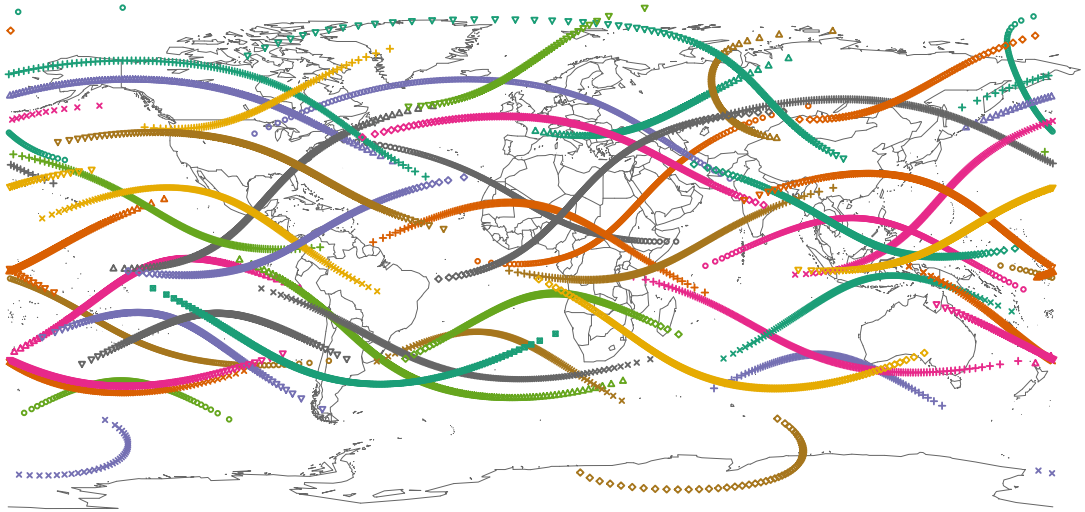
Annular eclipses from 1950 to 2050



1950−03−18	1962−07−31	1977−04−18	1994−05−10	2010−01−15	2026−02−17	2041−10−25
1951−03−07	1963−01−25	1979−08−22	1995−04−29	2012−05−20	2027−02−06	2042−10−14
1951−09−01	1965−11−23	1980−08−10	1998−08−22	2013−05−10	2028−01−26	2043−10−03
1952−08−20	1966−05−20	1981−02−04	1999−02−16	2014−04−29	2030−06−01	2044−02−28
1954−01−05	1969−03−18	1983−12−04	2001−12−14	2016−09−01	2031−05−21	2045−02−16
1954−12−25	1969−09−11	1984−05−30	2002−06−10	2017−02−26	2032−05−09	2046−02−05
1955−12−14	1970−08−31	1987−09−23	2003−05−31	2019−12−26	2034−09−12	2048−06−11
1957−04−30	1972−01−16	1988−09−11	2005−10−03	2020−06−21	2035−03−09	2049−05−31
1958−04−19	1973−01−04	1990−01−26	2006−09−22	2021−06−10	2038−01−05	
1959−04−08	1973−12−24	1991−01−15	2008−02−07	2023−10−14	2038−07−02	
1961−08−11	1976−04−29	1992−01−04	2009−01−26	2024−10−02	2039−06−21	

Code testing: Solar eclipse conditions

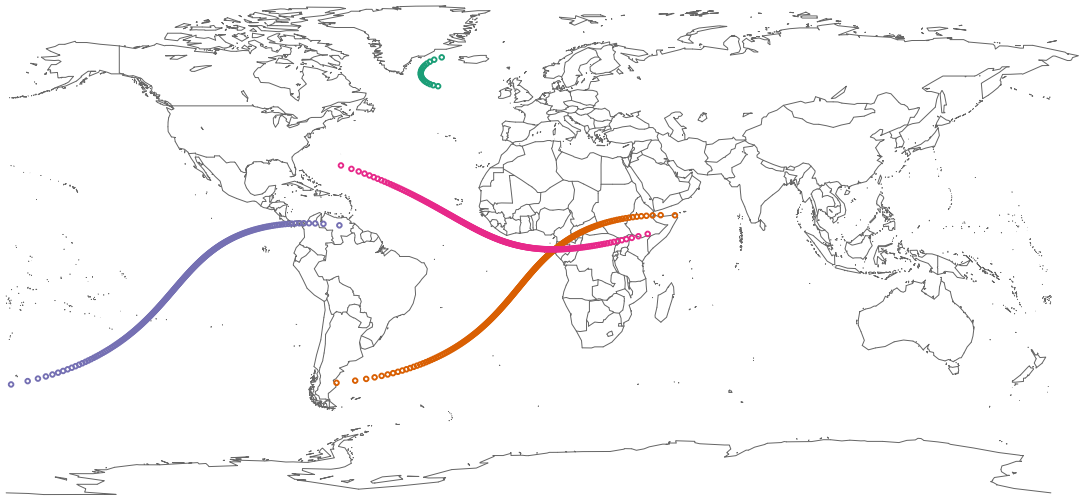
Total eclipses from 1950 to 2050



1950−09−12 1952−02−25 1954−06−30 1955−06−20 1956−06−08 1957−10−23 1958−10−12 1959−10−02 1961−02−15 1962−02−05
1963−07−20 1965−05−30 1966−11−12 1967−11−02 1968−09−22 1970−03−07 1972−07−10 1973−06−30 1974−06−20 1976−10−23
1977−10−12 1979−02−26 1980−02−16 1981−07−31 1983−06−11 1984−11−22 1985−11−12 1988−03−18 1990−07−22 1991−07−11
1992−06−30 1994−11−03 1995−10−24 1997−03−09 1998−02−26 1999−08−11 2001−06−21 2002−12−04 2003−11−23 2006−03−29
2008−08−01 2009−07−22 2010−07−11 2012−11−13 2015−03−20 2016−03−09 2017−08−21 2019−07−02 2020−12−14 2021−12−04
2024−04−08 2026−08−12 2027−08−02 2028−07−22 2030−11−25 2033−03−30 2034−03−20 2035−09−02 2037−07−13 2038−12−26
2039−12−15 2041−04−30 2042−04−20 2043−04−09 2044−08−23 2045−08−12 2046−08−02 2048−12−05

Code testing: Solar eclipse conditions

Hybrid eclipses from 1950 to 2050



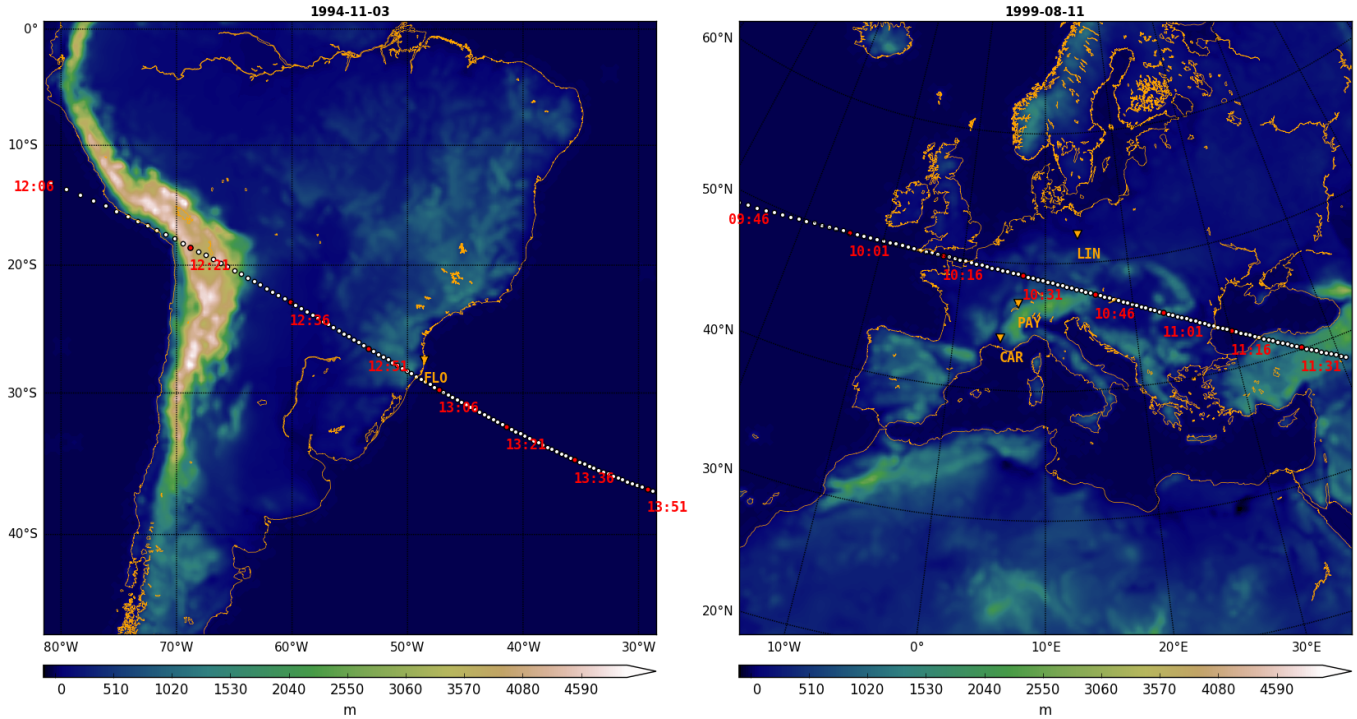
1986−10−03 2005−04−08 2023−04−20 2049−11−25
1987−03−29 2013−11−03 2031−11−14 2050−05−20

Code testing: Solar eclipse conditions

- The eclipse computation is validated in four study cases using Dudhia: 1994-11-03 (South America), 1999-08-11 (Europe), 2006-03-29 (North Africa) and 2009-07-22 (Eastern Asia).
- We compare the model outcomes with on-site data from BSRN stations.
- Simulations are initialized using ERA-Interim with a spin-up of 6 hours.
- The option icloud is disabled for a better comparison of the irradiance values between the baseline case (v 3.6.1) and the modified.
- More info in the manuscript: Implementation of the Bessel's method for solar eclipses prediction in the WRF-ARW model (submitted to ACPD, attached with this file).

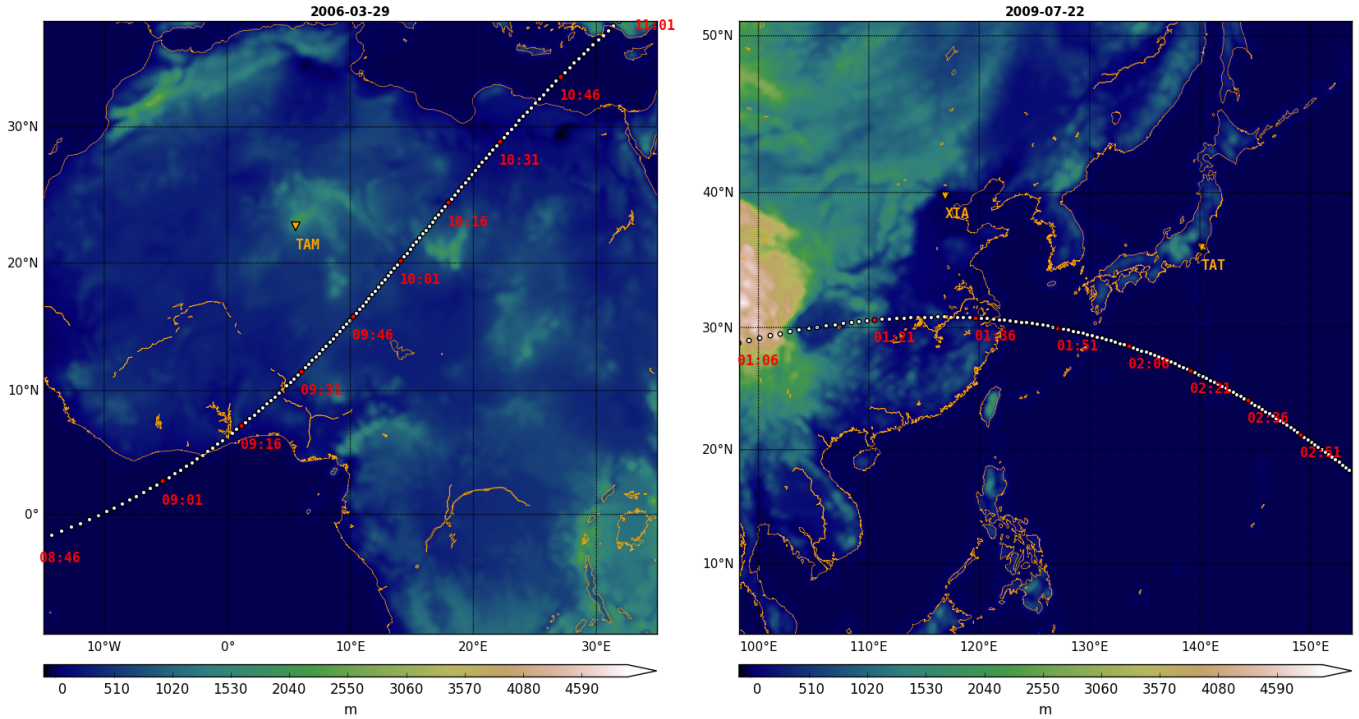
Code testing: Solar eclipse conditions

Grids: 1994-11-03 (South America) and 1999-08-11 (Europe)

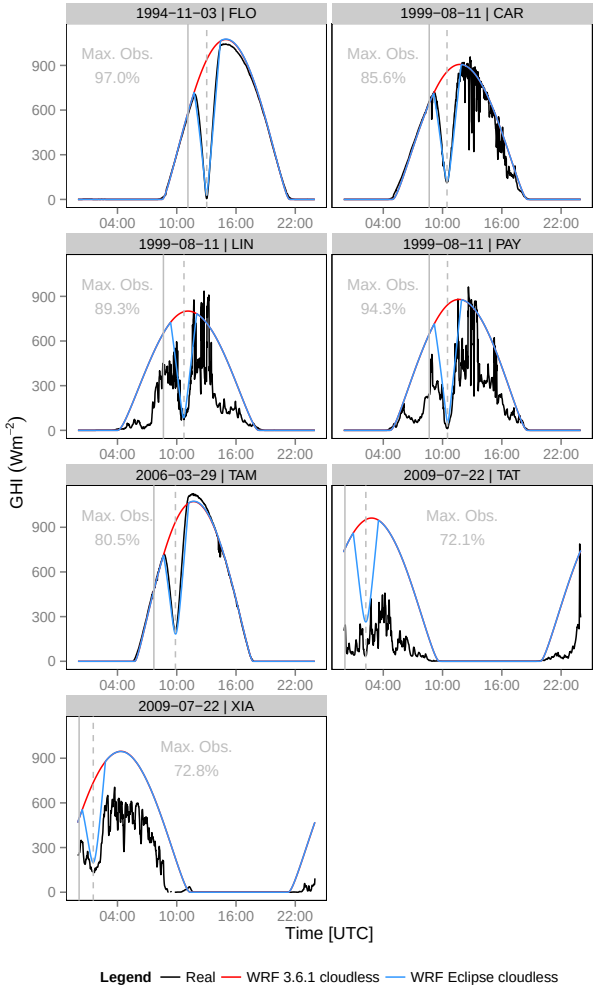


Code testing: Solar eclipse conditions

Grids: 2006-03-29 (North Africa) and 2009-07-22 (Eastern Asia)



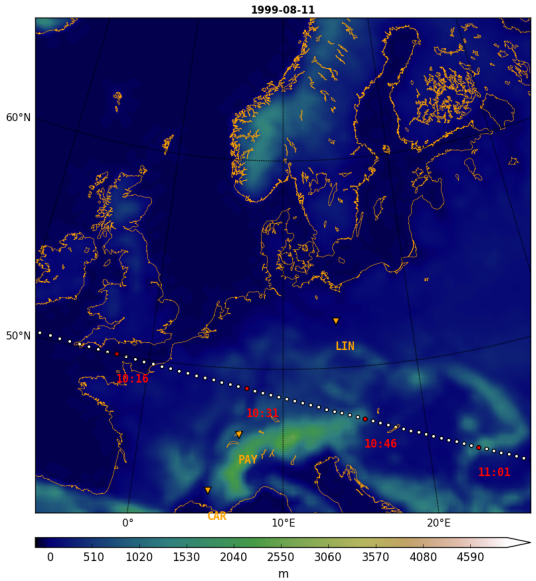
Code testing: Solar eclipse conditions



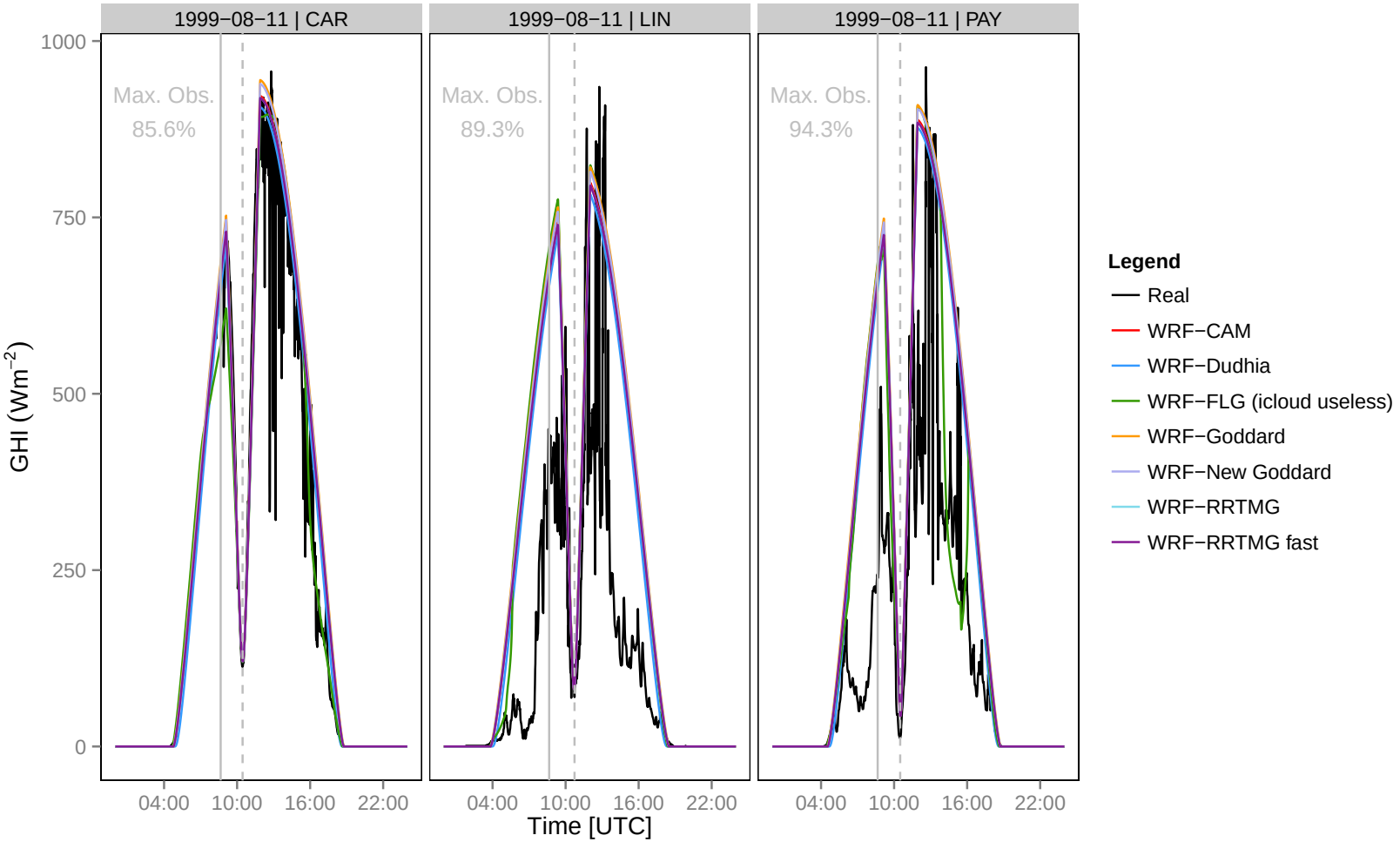
- Gray dashed line: time when the maximum obscuration is achieved
- Gray solid line: first time when a grid-point is perturbed by the eclipse
- The modeled eclipse is well synchronized with the real measurements
- The degree of obscuration is well simulated. TAT and XIA are highly affected by clouds.

Code testing: Solar schemes (v. 3.7.1)

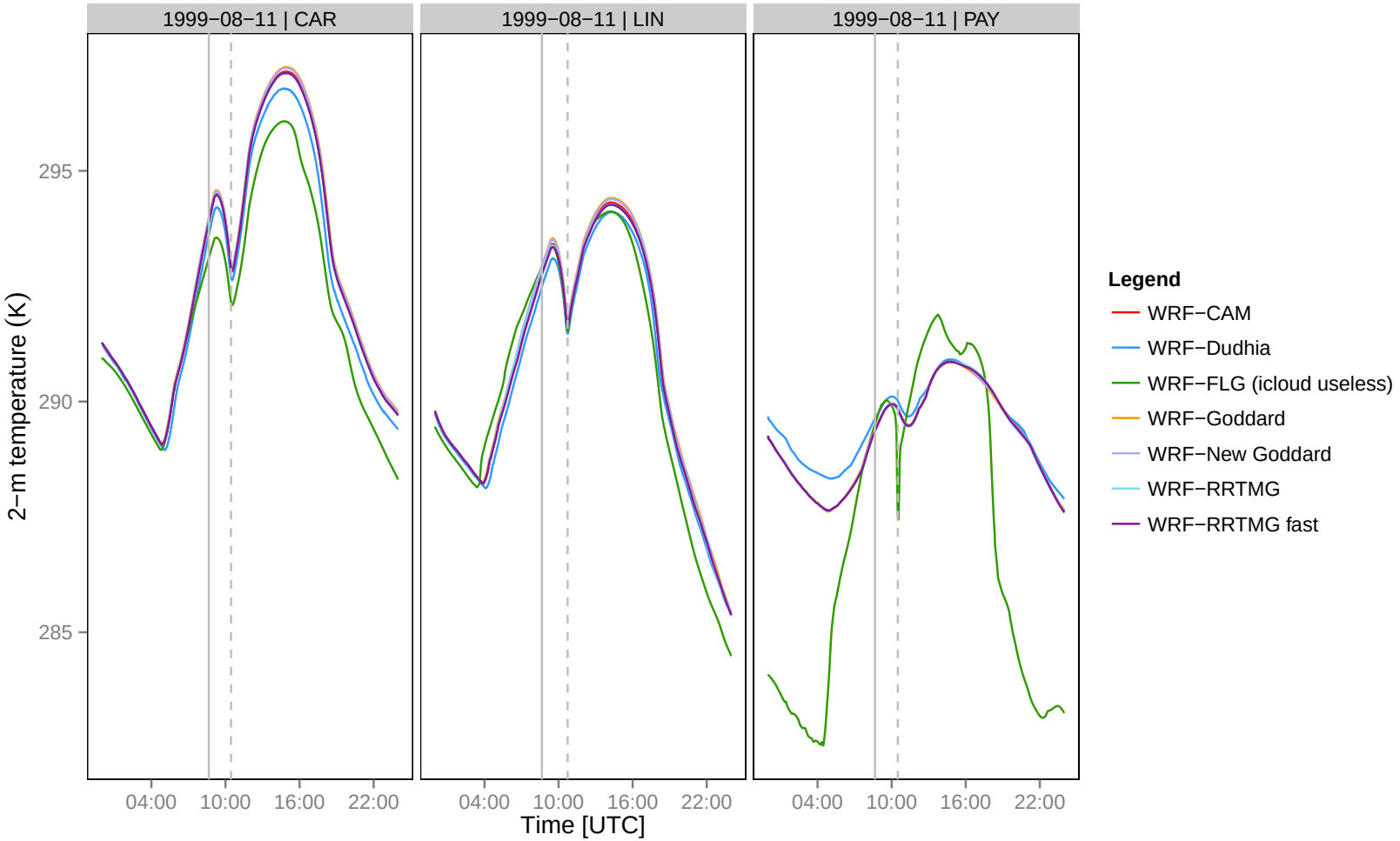
- We focus on the episode of 1999-08-11 for testing the different schemes
- For Dudhia, New Goddard, Goddard, CAM, RRTMG and RRTMG fast, we use the same domain described before.
- For FLG, we need to reduce the domain due to problems with the LW package over the Sahara. These problems have been observed with the unmodified version (both 3.6.1 and 3.7.1).



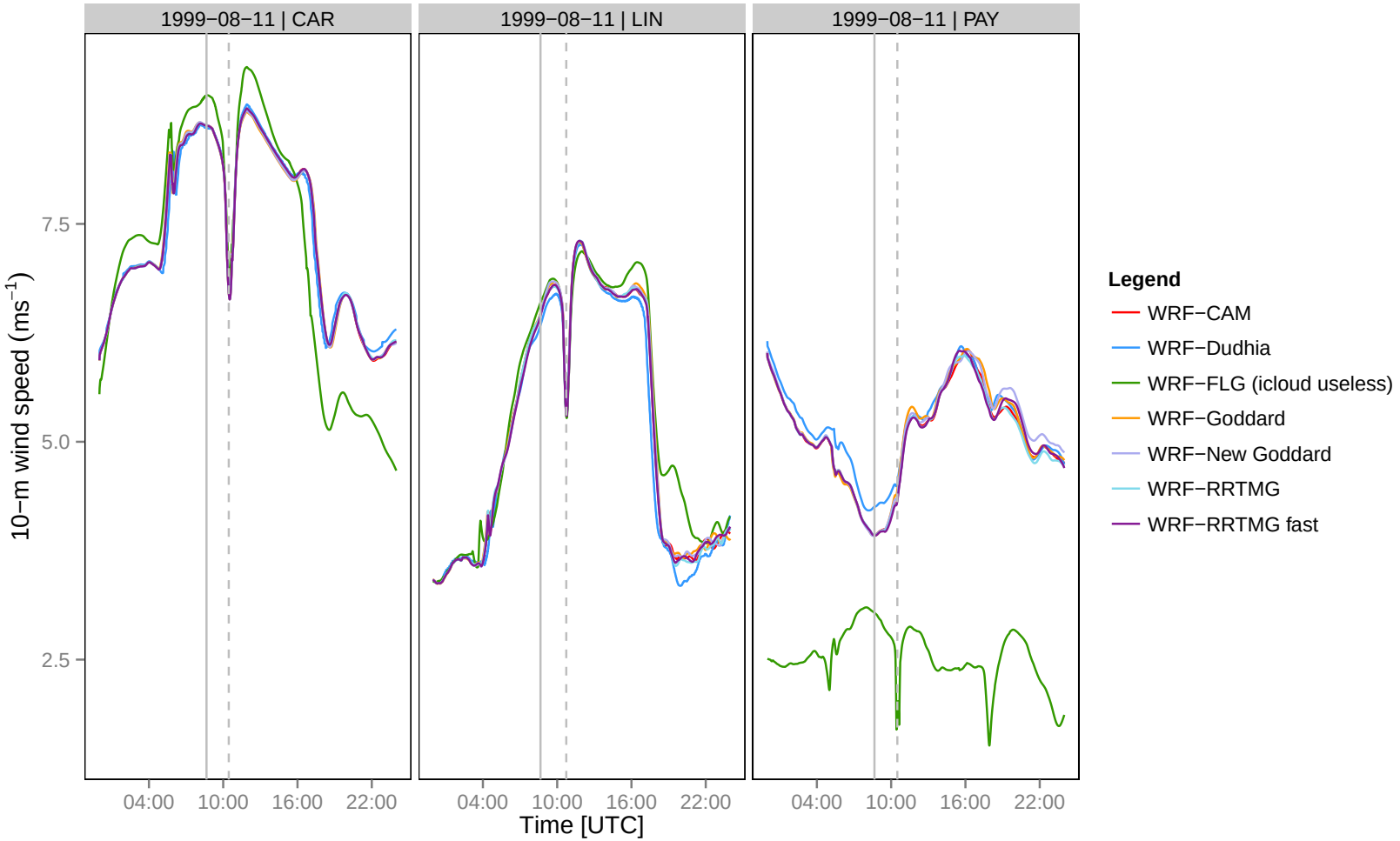
Code testing: Solar eclipse conditions



Code testing: Solar eclipse conditions



Code testing: Solar eclipse conditions



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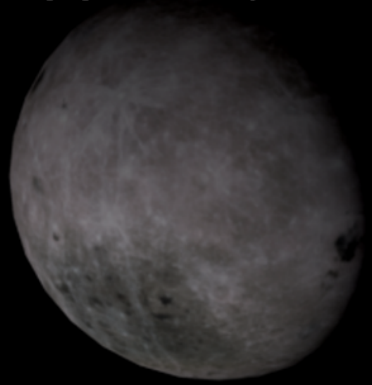

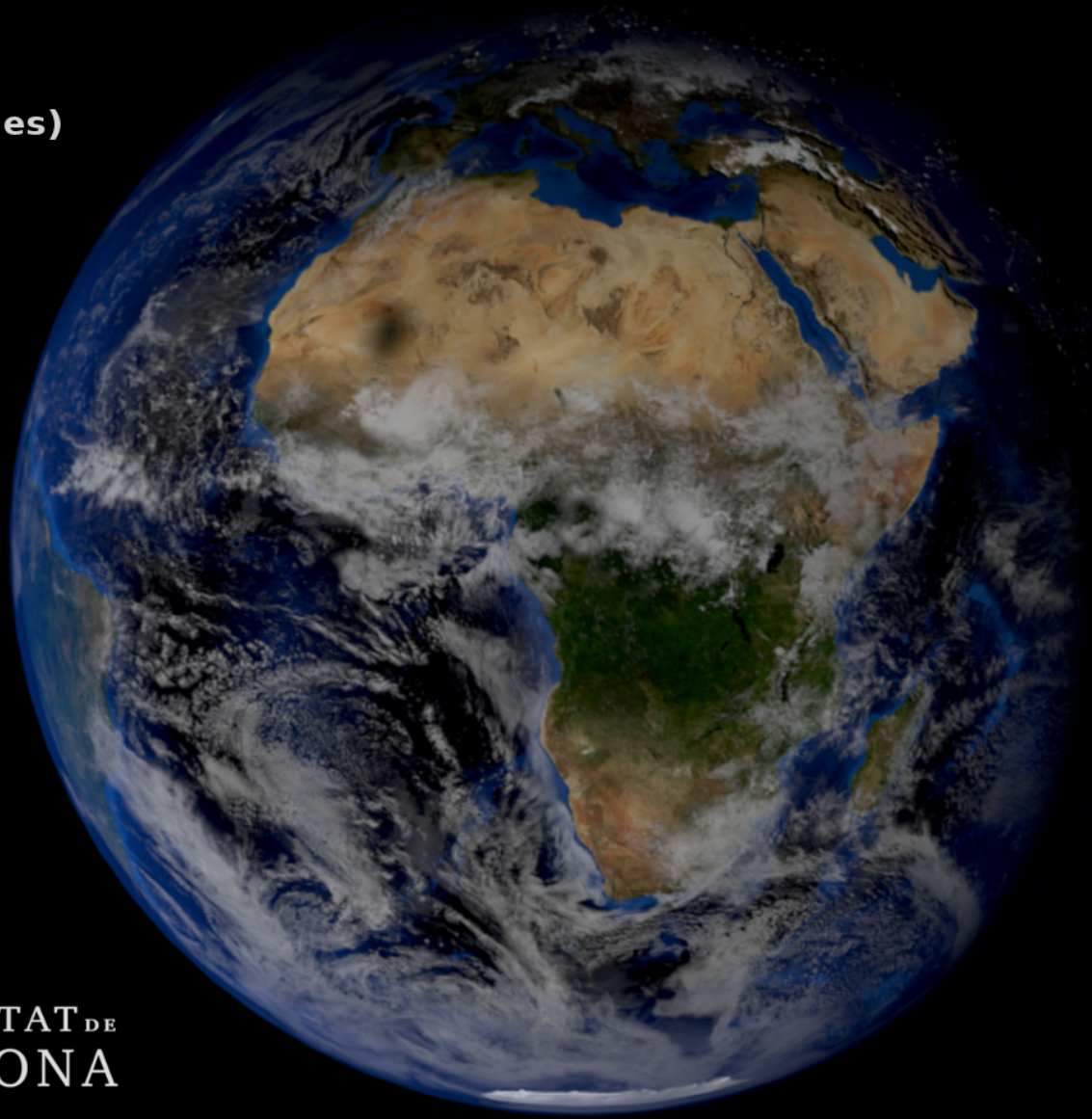

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