Aerosol optical depth retrievals at the Izaña Atmospheric Observatory from 1941 to 2013 using artificial neural networks

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¿Por qué surgió este trabajo?

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Atmospheric Measurement Techniques
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Reconstruction of global solar radiation time series from 1933 to 2013 at the Izaña Atmospheric Observatory

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Abstract. This paper presents the reconstruction of the 80-year time series of daily global solar radiation (GSR) at the subtropical high-mountain Izaña Atmospheric Observatory (IZO) located in Tenerife (The Canary Islands, Spain). For this purpose, we combine GSR estimates from sunshine duration (SD) data using the Ångström–Prescott method over the 1933/1991 period, and GSR observations directly performed by pyranometers between 1992 and 2013. Since GSR measurements have been used as a reference, a strict quality control has been applied based on principles of physical limits and comparison with LibRadtran model. By comparing with high quality GSR measurements, the precision and consistency over time of GSR estimations from SD data have been successfully documented. We obtain an overall root mean square error (RMSE) of 9.2 % and an agreement between the variances of GSR estimations and GSR measurements within 92 %. Nonetheless, this agreement significantly increases when the GSR estimation is done considering different daily fractions of clear sky (FCS). In that case, RMSE is reduced by half, to about 4.5 %, when considering percentages of FCS > 40 % (∼ 90 % of days in the testing period). Furthermore, we prove that the GSR estimations can monitor the GSR anomalies in consistency with GSR measurements and, then, can be suitable for reconstructing solar radiation time series. The reconstructed IZO GSR time series between 1933 and 2013 confirms change points and periods of increases/decreases of solar radiation at Earth's surface observed at a global scale, such as the early brightening, dimming and brightening. This fact supports the consistency of the IZO GSR time series presented in this work, which may be a reference for solar radiation studies in the subtropical North Atlantic region.

1 Introduction

Solar radiation controls the energy radiative balance in the Earth and, thus, our weather and climate. For this reason, its study has been one of the main objectives of the research community during the last decades. Recently, the focus is on evaluating the long-term trends of solar radiation reaching the Earth's surface (global solar radiation, GSR) as well as on identifying the variability driven by climate change (Stanhill and Cohen, 2001; Sanroma et al., 2010; Wild, 2009). Observational evidences of changes on GSR trends have already been reported at a global scale. A decrease of the solar radiation at the surface has been observed between the 1960s and the 1990s, an effect known as *dimming*, with a general decline between 4 and 6 % over 30 years considering worldwide distributed stations (e.g. Ohmura and Lang, 1989; Gilgen et al., 1998; Stanhill and Cohen, 2001; Liepert, 2002; Pinker et al., 2005; Wild et al., 2005; Sanchez-Lorenzo et al., 2007; Wild, 2009). In contrast, since the 1980s a partial recovery has been documented, with an increase of the solar radiation known as *brightening* (Wild et al., 2005, 2007, 2008, 2012; Gilgen et al., 2009). Trends between +1.0 and +10.7 % $decade^{-1}$ have been reported from the 1980s onwards (Wild, 2009, and references herein).

The causes of the *dimming/brightening* phenomena are not well understood yet (IPCC, 2007; Wild et al., 2012),

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¿Por qué surgió este trabajo?

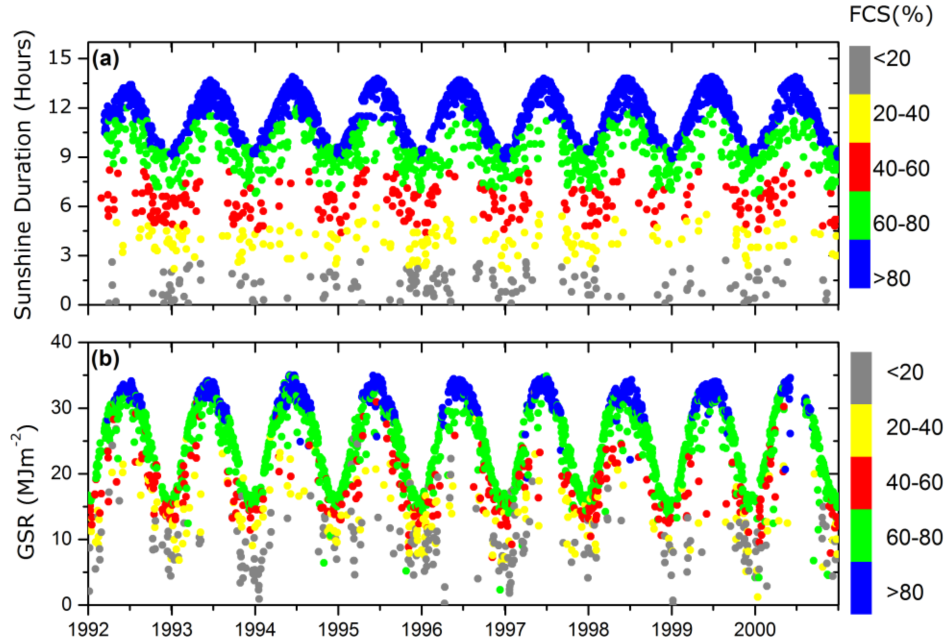
Ecuación de Ångström-Prescott

$$\boxed{\frac{H}{H_o} = a\frac{n}{N_d} + b}$$

FCS (%)	$a \pm$ SEM	$b \pm$ SEM	% days
≤ 20	0.304 ± 0.120	0.347 ± 0.012	9
20–40	0.449 ± 0.144	0.348 ± 0.050	5
40–60	0.516 ± 0.085	0.325 ± 0.048	8
60–80	0.402 ± 0.041	0.399 ± 0.033	23
≥ 80	0.475 ± 0.039	0.339 ± 0.038	55

Coeficientes a y b determinandos entre 1992 y 2000 en Izaña como una función de la fracción de cielo despejados (FCS). SEM es el error estándar de la media.

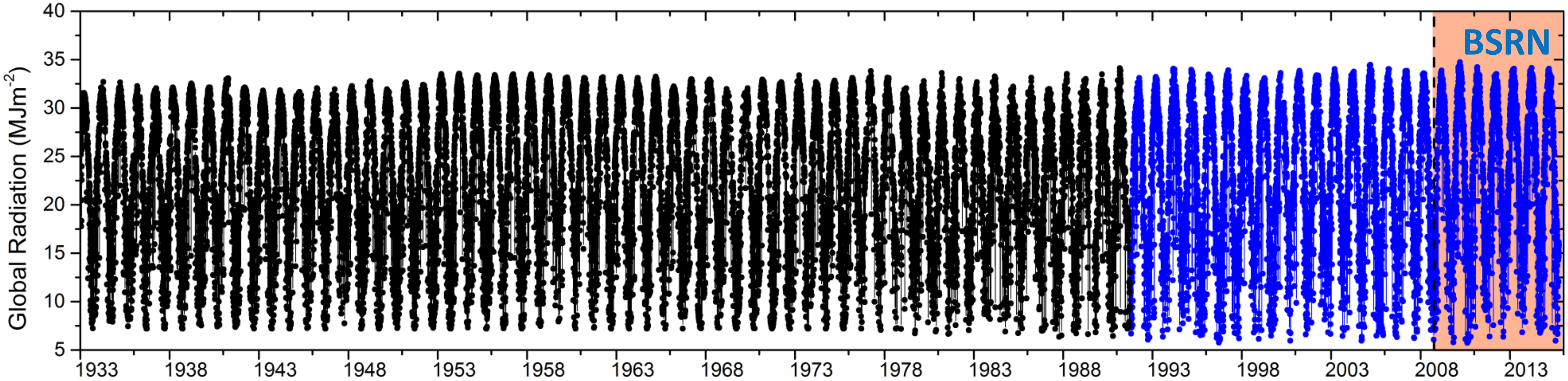
$$\boxed{\mathrm{FCS}(\%) = n/N_d \cdot 100}$$



Series temporales de la **(a)** insolación diaria (horas) y **(b)** la radiación global diaria entre 1992 y 2000 en Izaña. La escala de colores indican la fracción de cielo despejado (FCS, %).

¿Por qué surgió este trabajo?

GSR Estimada 1933-1991 — **GSR Observada 1992-2015**

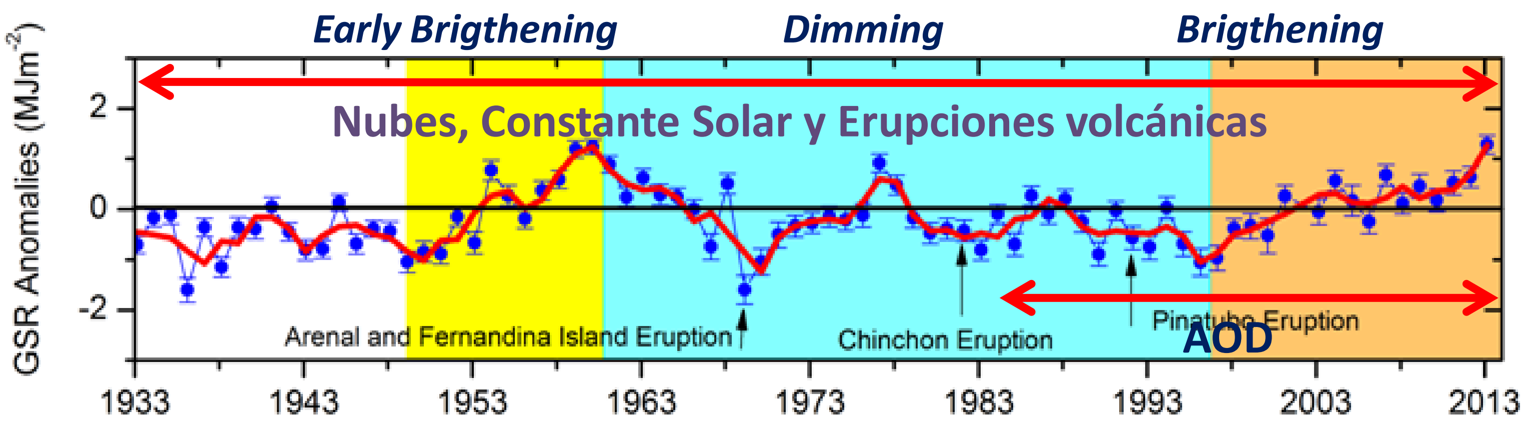


Campbell Stokes

CM-5, CM-11 and CM-21

Series radiación global en Europa:

Stockholm: 1923
Netherlands: 1928
Izaña: 1933 / 1917
Potsdam: 1937

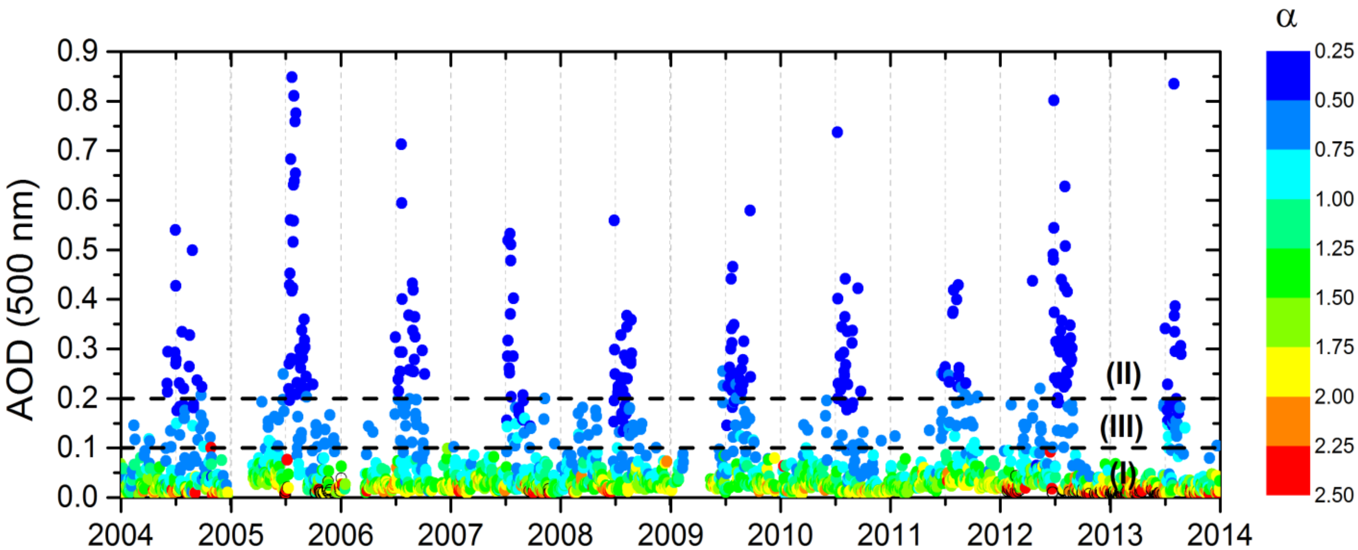


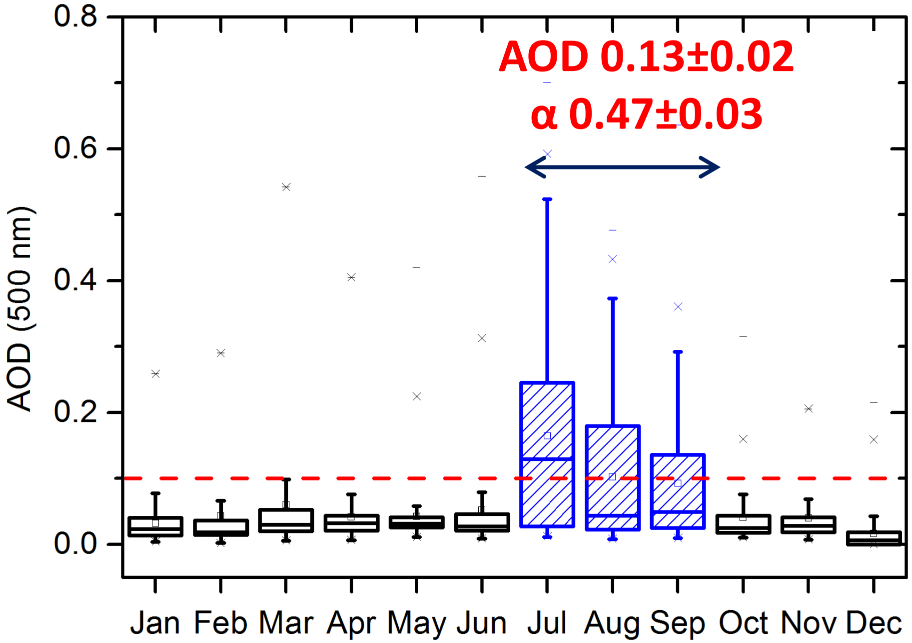
¿Qué factores modulan la radiación solar, a qué son debidos los fenómenos de global "*brigthtening*" y "*dimming*"?

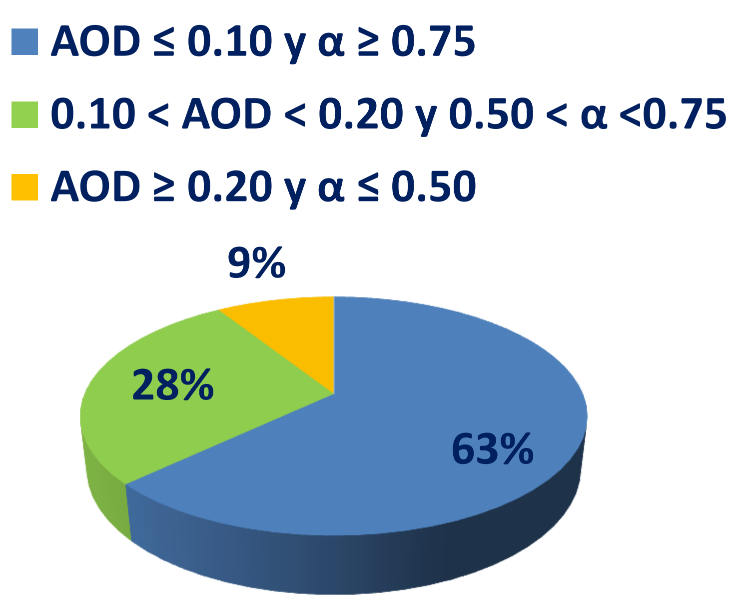
Las posibles causas podrían ser:

- **Nubes: FCS (fracción de cielo despejado) + Octas**
- **Constante Solar**
- **Erupciones Volcánicas**
- **AOD**
  - **Mark-I (769.9 nm): 1984-2013 (Barreto et al., 2014)**
  - **GAW/PFR: 2001-2013(Nivel 3.0)**
  - **CIMEL-AERONET: 2004-2014 (Nivel 2.0)**

Serie de AOD a 500 nm en IZAÑA: 2004-2013 Fuente: (AERONET; Nivel 2.0)







¿Qué herramientas podemos utilizar para obtener la serie de AOD desde 1933?

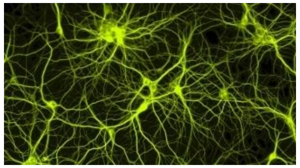
- **LUT: No disponemos de los inputs necesarios para discriminar el AOD entre 1933 y 1984. El AOD diario estimado es extremadamente sensible a incertidumbres en los inputs del modelo.**

- **TRANSMITANCIA APARENTE: No disponemos de medidas de radiación directa previas a 2005.**

- **MEDIDAS DE RADIACIÓN GLOBAL Y DIFUSA: No disponemos de medidas de radiación global previas a 1977 y difusa previas a 2005.**

- **REDES NEURONALES: Temperatura, insolación, visibilidad, presión, humedad relativa, octas.**

- <u>Red Neuronal Artificial (ANN)</u>: herramienta que imita el funcionamiento de las neuronas cerebrales para resolver un problema, por medio de interconexiones neuronales.



Esquema básico de una ANN

Capa de Entrada (INPUTS) → Capa Oculta (NEURONAS, PESOS, FUNCIÓN DE TRANSFERENCIA) → Capa de Salida (OUTPUTS)

<u>Diseño de la red</u>

Número de capas — Número de neuronas — Selección de inputs

Función de entrenamiento — Función transferencia

Entrenamiento de la red con Inputs para los que son conocidos los outputs (targets).

- Aplicamos la red a estos inputs de forma recursiva calculando los pesos hasta conseguir que los outputs se ajusten a los targets lo mejor posible

Validación de la red

Se utilizan inputs para los que sean conocidos los outputs, pero que no se utilizaran en el proceso de entrenamiento

¿Qué inputs disponemos en Izaña para reconstruir la serie de AOD?

INPUTS: Juliano (Nd) – Visibilidad (VIS) – FCS – HR – Temp

- Visibilidad: 1941-2009
- FCS: 1917-actualidad (Horas de insolación)
  - 1917-2000: Campbell-Stokes
  - 2000-actualidad: CS record Kipp & Zonen
- HR: 1916 - actualidad
- Temp: 1916– actualidad
- Octas: 1916-2009 (A partir de 2009, aplicamos el método de Long and Ackerman (2000) para detectar días despejados, García et al., 2014 y Cámara de todo cielo SONA)

AOD 1941-2009

ENTRENAMIENTO DE LA RED

- Para cada mes de estudio calculamos una red neuronal: J,A,S (octas = 0)
- Período de entrenamiento: 2003-2009 (PFR; Nivel 3.0), divido de forma aleatoria en 3 muestras:

70%: Muestra de entrenamiento 15%: Muestra de validación	Se crea la RED
15%: Muestra de test	Se verifica la RED

- Se repite el proceso iterativo de entrenamiento 1000 veces seleccionando la red que de mejores coeficiente de Pearson, pendiente e intercepción en la muestra de test

Redes Neuronales : Selección de inputs y resultado del entrenamiento

¿Qué inputs son realmente relevantes?

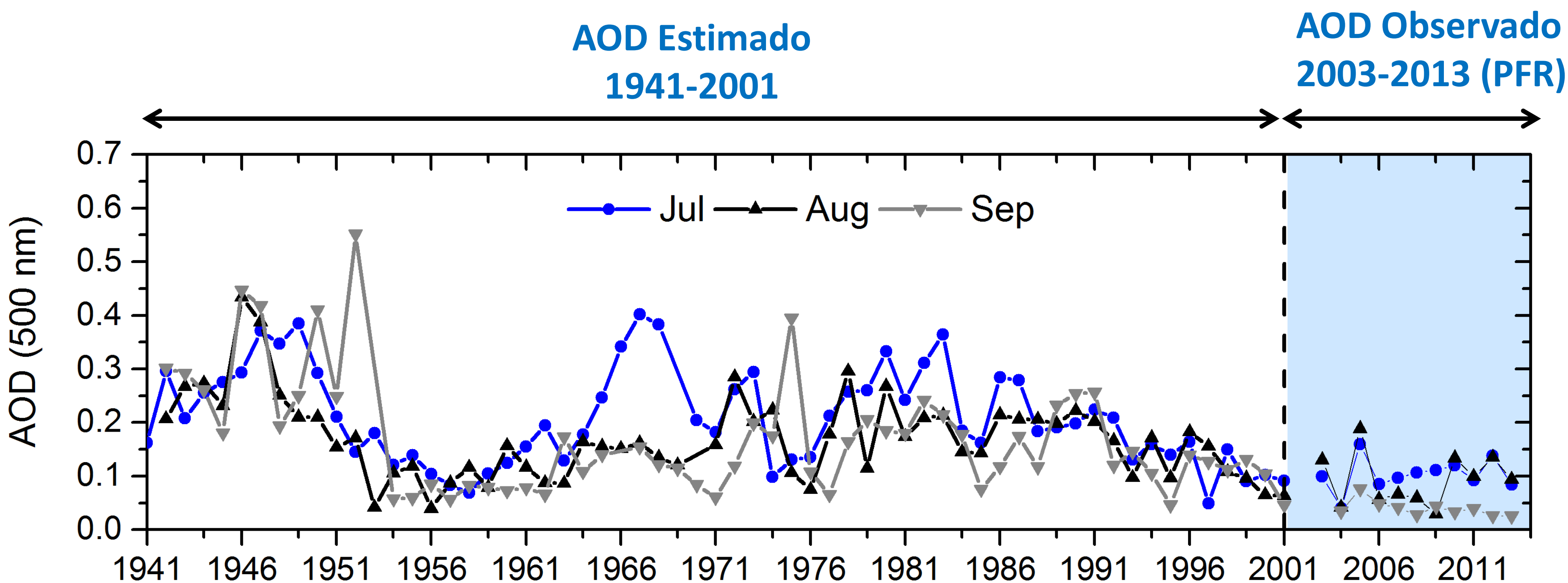
Inputs	*R*	*Pendiente*	*Intercepción*
Nd-VIS	***0.79***	***0.61***	***0.03***
Nd-VIS-FCS	***0.94***	***0.90***	***0.01***
Nd-VIS-FCS-HR	***0.99***	***0.99***	***-0.01***
Nd-VIS-FCS-HR-Temp	***0.97***	***0.92***	***0.01***

¿Qué diseño tienen las Redes?

Inputs:
Nd, VIS, FCS, HR

1 capa oculta
30 neuronas
Función hiperbólica

Outputs:
AOD



Validación cuantitativa:

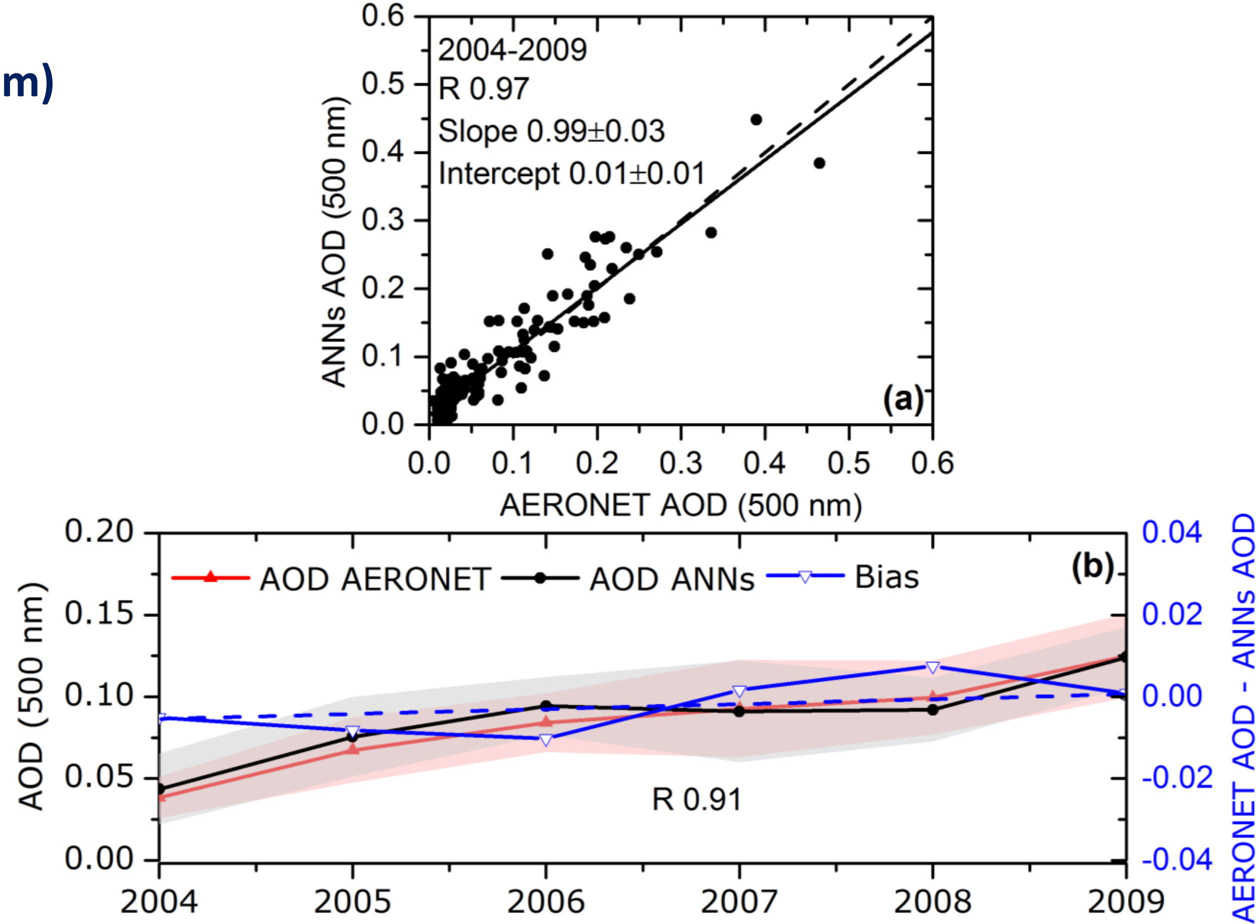
- **CIMEL-AERONET (500 nm): 2004-2009**
- **MARK-I (769.9 nm): 1984-2009**

Validación cualitativa:

- **Serie de número de días con código SYNOP 05-06**
- **Porcentaje de tiempo (horas) de procedencia del viento**

Validación del AOD estimado a partir de la red neuronal

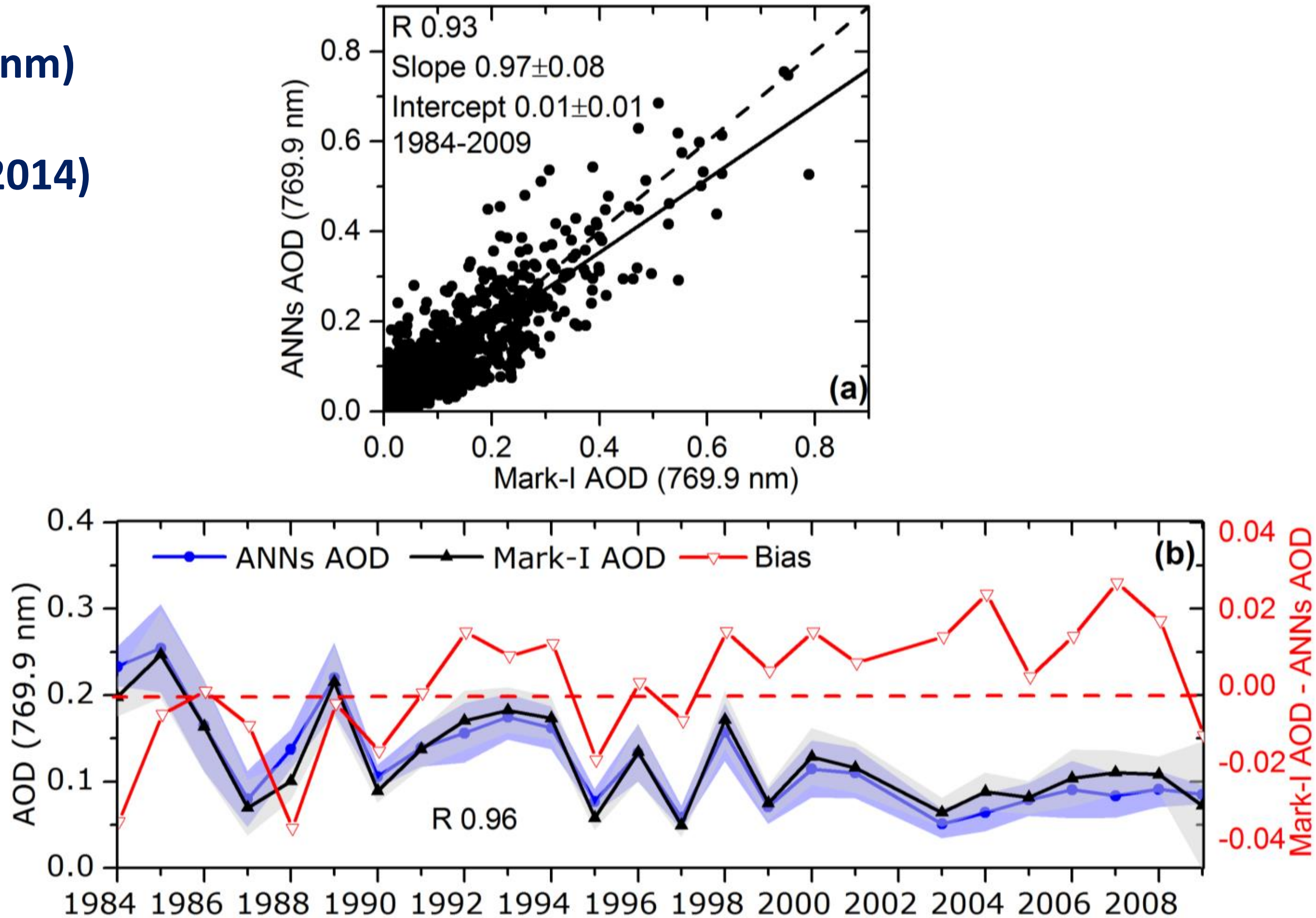
CIMEL-AERONET (500 nm)
2004-2009



(a) AOD estimado a partir de la red neuronal frente a los valores diarios de AOD-AERONET a 500 nm considerando días despejados (octas = 0) en el período 2004-2009. **(b)** Serie temporal de las medias mensuales de Julio de AOD-AERONET y el AOD estimado a partir de la red neuronal (eje de la izqda.) y serie temporal de las diferencias entre ambos valores de AOD (eje de la dcha.)

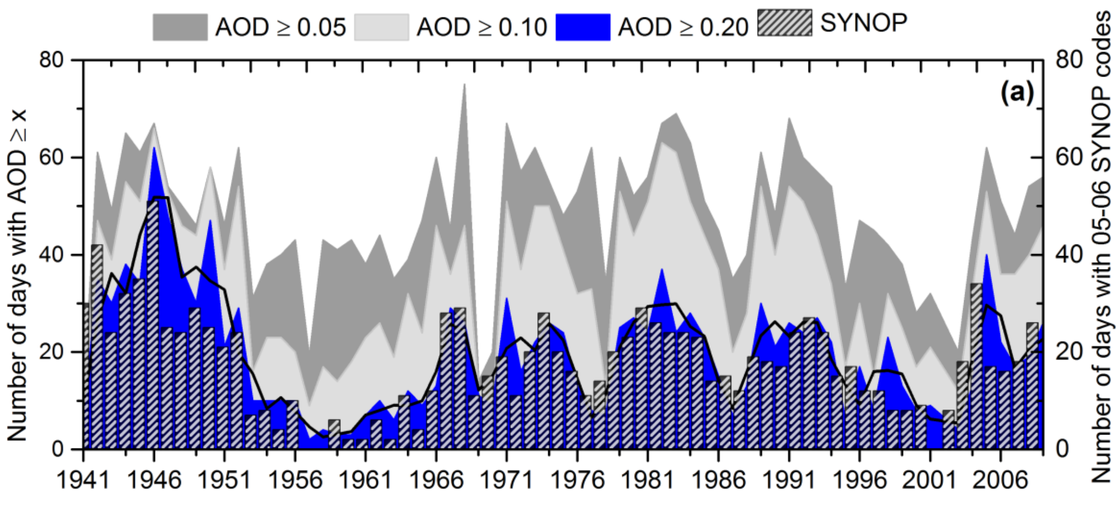
Validación del AOD estimado a partir de la red neuronal

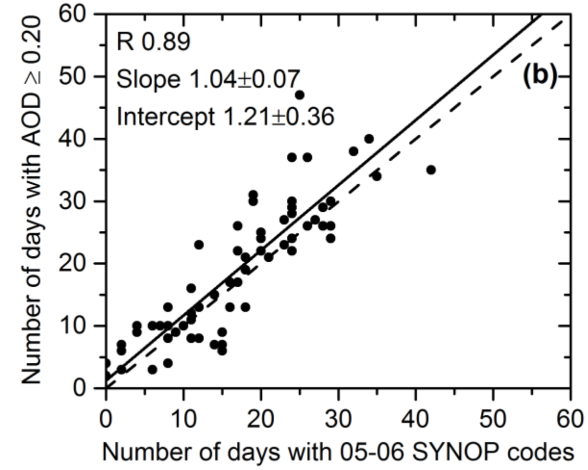
MARK-I (769.9 nm)
<u>1984-2009</u>
(Barreto et al., 2014)



(a) AOD estimado a partir de la red neuronal frente a los valores diarios de AOD-MARK-I a 769.9 nm considerando días despejados (octas = 0) en el período 1984-2009. **(b)** Serie temporal de las medias mensuales de Julio de AOD-MARK-I y el AOD estimado a partir de la red neuronal (eje de la izqda.) y serie temporal de las diferencias entre ambos valores de AOD (eje de la dcha.)

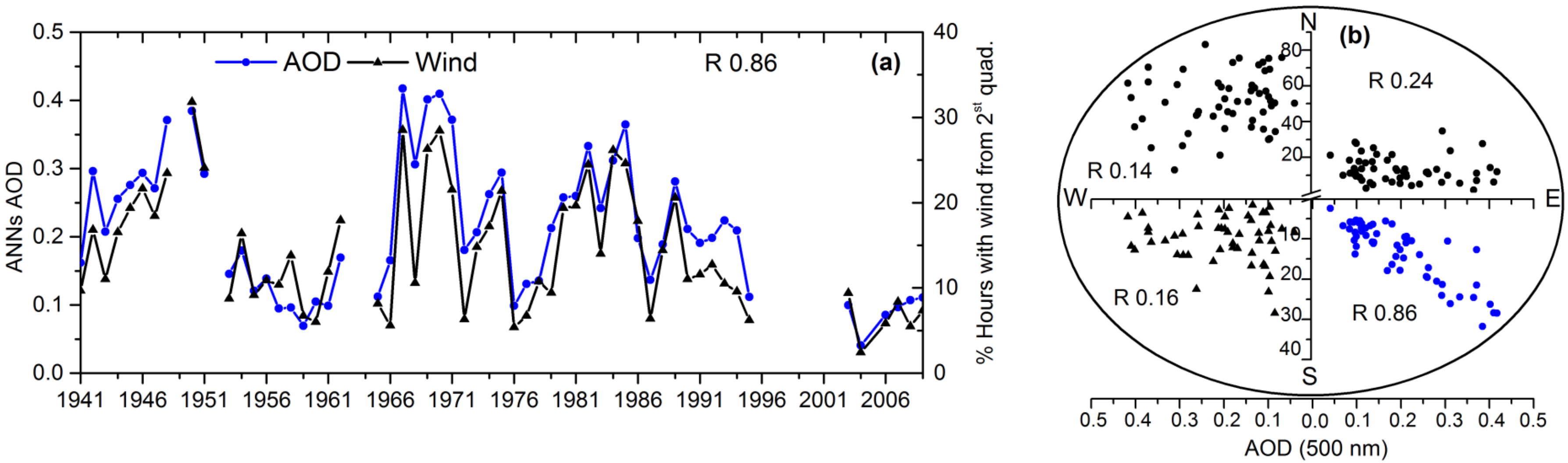
Validación del AOD estimado a partir de la red neuronal





(a) En el eje de la izqda. tenemos la serie temporal del número de días agrupados por intervalos de AOD (AOD≥0.05; AOD≥0.10; AOD≥0.20) para J-A-S, mientras que en el eje de la dcha. tenemos el número de días reportados por los observadores con código SYNOP 05-06 (calima o polvo en suspensión) para el período comprendido ente 1941 y 2009. **(b)** Número de días con AOD estimado a partir de la red con AOD≥0.20 frente al número de días con código sinópticos de 05-06.

Validación del AOD estimado a partir de la red neuronal



(a) Serie temporal de las medias mensuales para Julio del AOD estimado a partir de la red neuronal (linea azul) y el porcentaje mensual en número de horas en el que el viento procede del segundo cuadrante (SE) (linea negra) **(b)** Porcentaje de tiempo (horas) en los que el viento procede de cada uno de los cuadrantes en el período comprendido entre 1941 y 2009.

Conclusiones

- **Las redes neuronales han demostrado ser una herramienta muy útil para estimar el AOD a partir de variables meteorológicas.**

- **La serie de AOD obtenida capta las variaciones a corto y largo plazo comparado con medidas coincidentes de AOD y otras variables :**

Valores diarios:

- **MARK-I (1984-2009) a 769.9 nm: R 0.93**
- **AERONET (2004-2009) a 500 nm: R 0.97**

Valores mensuales (Julio):

- **MARK-I (1984-2009) a 769.9 nm: R 0.91**
- **AERONET (2004-2009) a 500 nm: R 0.96**

A larga escala (1941-2009):

- **Número de días con código SYNOP 05-06 y número de días con AOD≥0.20: R 0.89**
- **Porcentaje de tiempo (horas) en los que el viento procede del SE: R 0.86**

Estos resultados confirman la consistencia de la serie de AOD en el período 1941-2009 y la capacidad de la misma para hacer un seguimiento de las variaciones inter-anuales del "dust" procedente del Sahara.

MUCHAS GRACIAS!!!!

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[illegible] [illegible] 73-year [illegible] 500 nm [illegible] high-m[illegible] Izañ[illegible] Observ[illegible] Fo[illegible] this purpose, we have combined AOD estimates from artificial neural networks (ANNs) from 1941 to 2001 and AOD measurements directly obtained with a Precision Filter Radiometer (PFR) between 2003 and 2013. The analysis is limited to summer months (July–August–September), when the largest aerosol load is observed at IZO (Saharan mineral dust particles). The ANN AOD time series has been comprehensively validated against coincident AOD measurements performed with a solar spectrometer Mark-I (1984–2009) and AERONET (AErosol RObotic NETwork) CIMEL photometers (2004–2009) at IZO, obtaining a rather good agreement on a daily basis: Pearson coefficient, R, of 0.97 between AERONET and ANN AOD, and 0.93 between Mark-I and ANN AOD estimates. In addition, we have analysed the long-term consistency between ANN AOD time series and long-term meteorological records identifying Saharan mineral dust events at IZO (synoptical observations and local wind records). Both analyses provide consistent results, with correlations > 85 %. Therefore, we can conclude that the reconstructed AOD time series captures well the AOD variations and dust-laden Saharan air mass outbreaks on short-term and long-term timescales and, thus, it is suitable to be used in climate analysis.

1 In[illegible]tion

[illegible] role in our climate and environment. In the last decades, numerous analyses have demonstrated that SSR records have not been constant over time, but have undergone climatologically significant decadal variations (e.g. Pallé and Butler, 2001; Stanhill and Cohen, 2001; Sanchez-Lorenzo et al., 2007; Wild, 2009; García et al., 2014a). From the 1930s to the early 1950s the few data available suggest an increase of the SSR in the first part of the 20th century, known as early brightening. This period is followed by a widespread period of reduced solar radiation from the 1950s to the end of the 1990s. This effect, extensively reported by the literature at a global scale, is known as dimming, with a general decline between 4 and 6 % decade^{-1} considering worldwide distributed stations. Recently, a gradual increase of the SSR has been documented, known as brightening, with trends between +1 and +11 % decade^{-1} from the 1980s onwards (Ohmura and Lang, 1989; De Bruin et al., 1995; Gilgen et al., 1998; Stanhill and Cohen, 2001; Ohmura, 2006; Wild et al., 2005; Sanchez-Lorenzo et al., 2007; Wild et al., 2008; Wild, 2009; Lachat and Wehrli , 2013; García et al., 2014a).

The causes of these phenomena are not fully understood currently, but it has been pointed out that changes in the transmissivity of the Earth's atmosphere play a significant role. These changes might be due to changes on global cloud cover and atmospheric aerosol concentrations. Wild et al. (2005) found that the changes are observed under all cloud-

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