ESA Climate Change Initiative Phase-II Sea Surface Temperature

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Stratospheric Aerosol and Impacts on Infrared SST Retrievals

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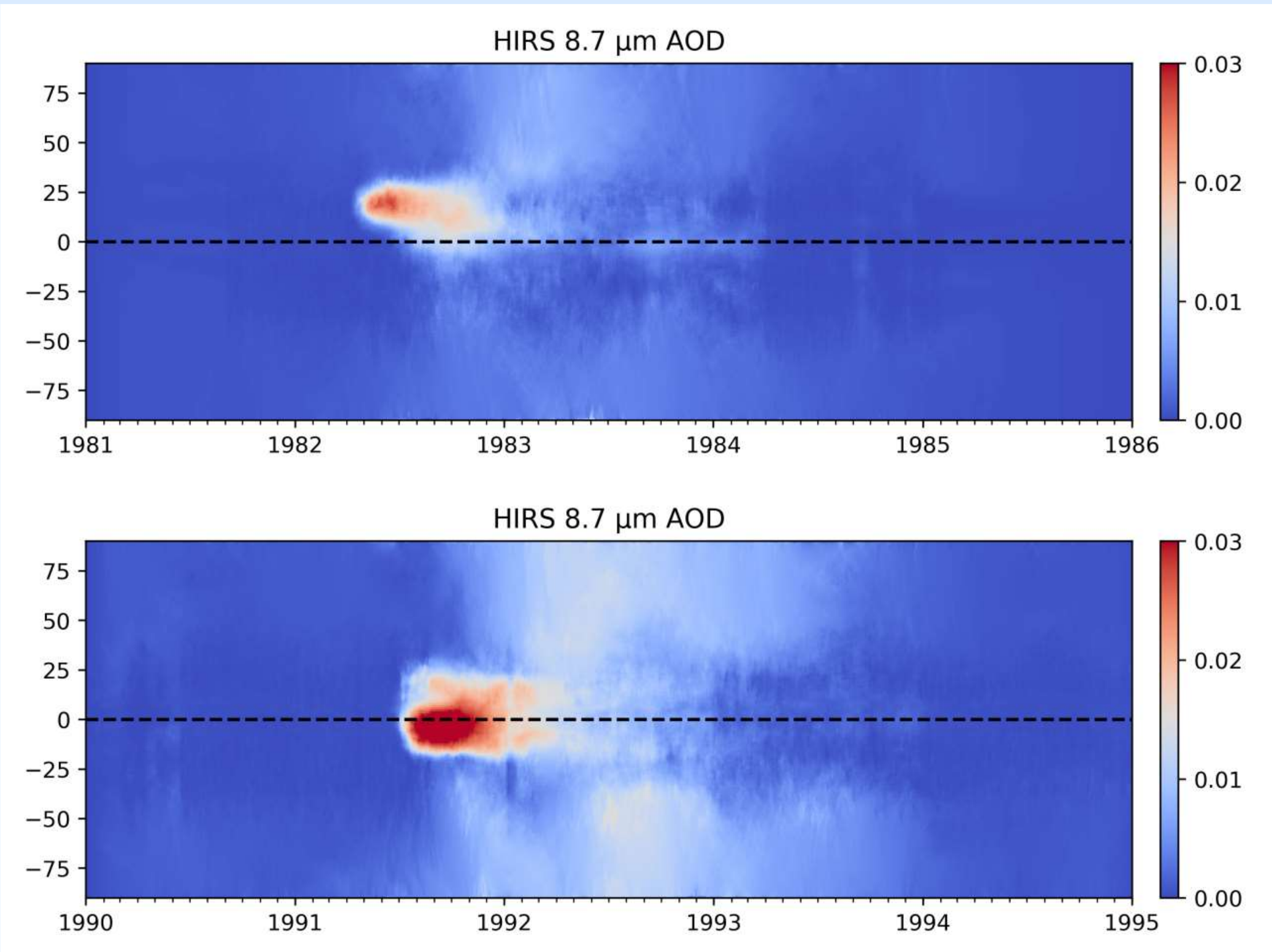
Introduction

Large explosive volcanic eruptions, such as Mount Pinatubo (1991) and El Chichón (1982), can inject megatons of sulphur dioxide into the stratosphere. The gas quickly forms a sulphuric acid aerosol which remains in the stratosphere for a couple of years. In addition to its direct impact on the planets climate, stratospheric aerosol can cause cold biases over 1 K in infrared SST retrievals from space.

We present here a climatology of infrared aerosol index retrieved from the High-resolution Infrared Radiation Sounder (HIRS) which has been carried on board NOAA polar orbiters since 1978. This aerosol index provides the information necessary to adapt the AVHRR SST retrievals for the present of volcanic sulphate aerosol. We show how this approach reduces the significant biases otherwise present in the AVHRR climate data record.

HIRS Aerosol Optical Depth



Stratospheric aerosol optical depth retrieved using HIRS. Top: El Chichón using NOAA-7. Bottom: Mount Pinatubo using NOAA-10 and NOAA-12

SST Retrieval

For the AVHRR instruments we use an Optimal Estimation (OE) retrieval of the form:

$$\hat{x} = x_a + S_a K^T (K S_a K^T + S_\varepsilon)^{-1}(y - F(x_a))$$

Where $\hat{x}$ is the retrieved state, x_a is the *a priori* state, y the vector of brightness temperature (BT) observations, K the tangent linear matrix, S are the covariance matrices, and F is the forward model.

In order to account for aerosol in the SST retrieval we must include aerosol in the state vector, i.e. we need to have:

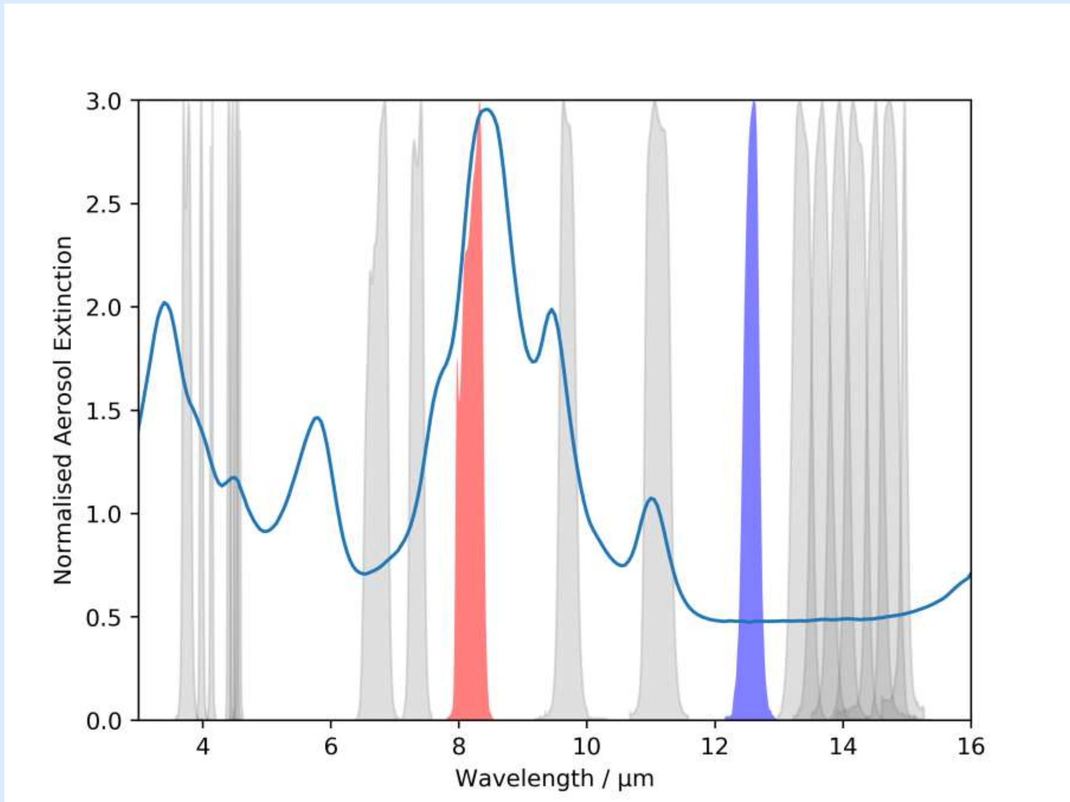
- Estimate of a priori aerosol amount
- Estimate of uncertainty in aerosol amount
- Include aerosol in the forward model

The ATSR instruments have dual-view design which allows an aerosol-robust retrieval following Merchant et al. (1999). As such, the aerosol prior is not required for the ATSR SST retrieval. However, the prior will be used by the Bayesian cloud detection scheme which makes use of the same forward modelled outputs and prior information as the AVHRR SST retrieval.

We use the RTTOV11.3 forward model for both cloud detection and SST retrieval.

Aerosol Retrieval

We measure stratospheric aerosol loading with the High-resolution Infrared Radiation Sounder (HIRS) using a retrieval method based on Baran and Foot (1994). They used the temperature difference between the 8.3 µm channel on NOAA-10 and NOAA-12 compared to the 12.5 µm channel on NOAA-11. Both channels correspond to atmospheric windows, but the 8.3 µm is highly sensitive to sulphate aerosol while the 12.5 µm is close to a minimum. Baran and Foot (1994) used this method to estimate aerosol mass loadings from the Mount Pinatubo eruption.



Normalised aerosol extinction of sulphate aerosol and HIRS spectral response functions. HIRS channel 10 may be located at either 8.3 or 12.5 µm depending on the instrument.

Unfortunately the two channels are not present on the same instruments. HIRS channel 10 was located at 8.3 µm on early HIRS instruments, but moved to 12.5 µm for later instruments (NOAA-11, and NOAA-14 onwards). Hence Baran and Foot (1994) had to use collocated observations between NOAA-11 and NOAA-10/12.

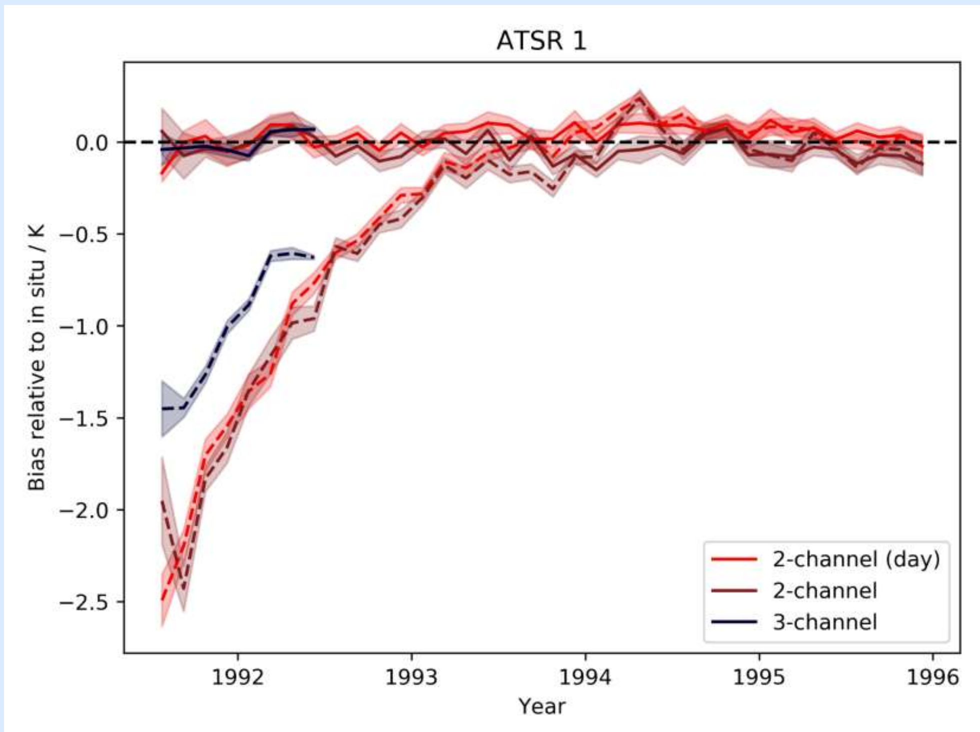
In order to retrieve aerosol loadings from El Chichón in the 1980s we cannot use the 12.5 µm channel. Instead we use the 11.1 µm channel combined with the 7 longer wavelength channels to estimate an "aerosol-free" 8.3 µm BT.

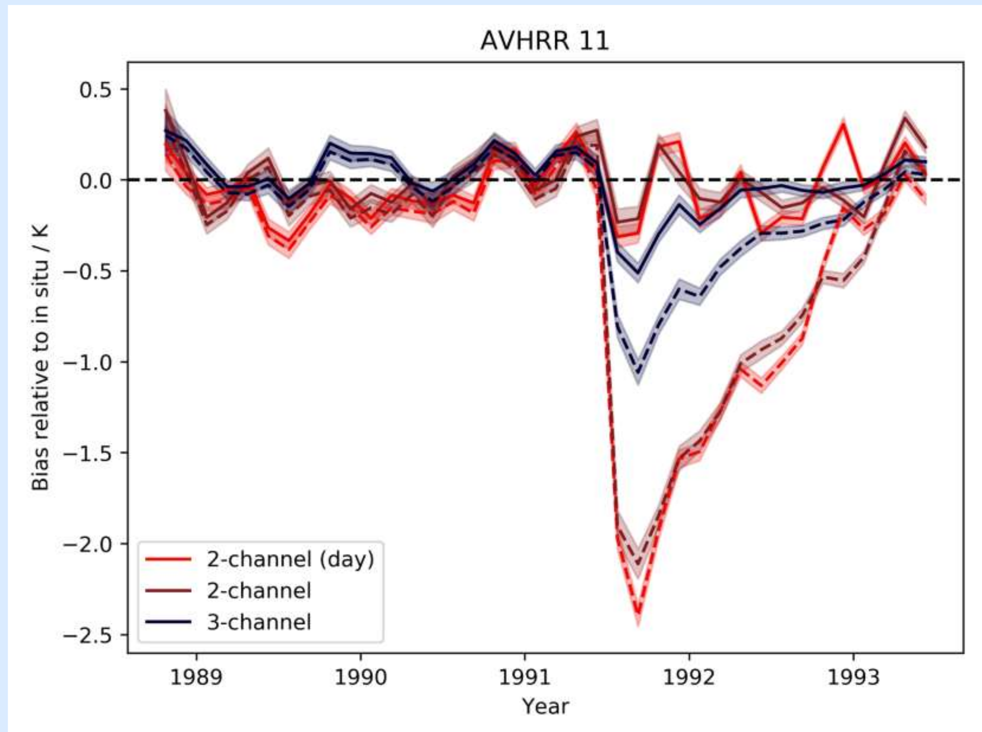
We use clear-sky HIRS observations from outside the two major volcanic eruptions to train our "aerosol-free retrieval" using a simple linear regression of the form:

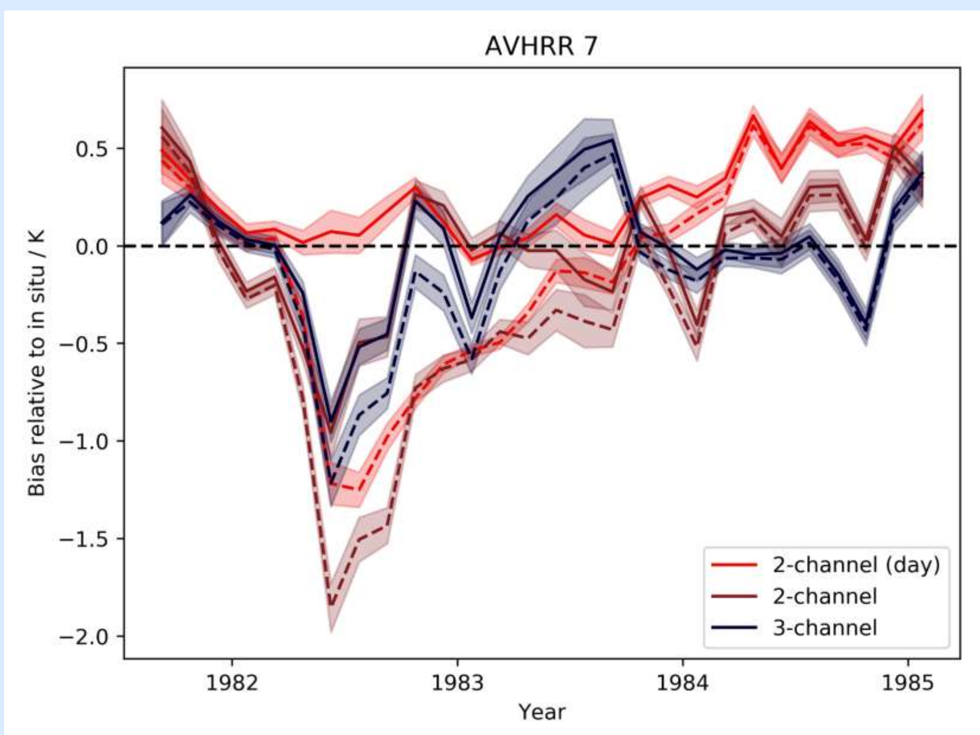
$\hat{T}_{8.3} = a_0 + a_1 s + \sum b_i T_i$ where *a*, *b* are coefficients and *s* is the path length

We then use radiative transfer simulations to relate the retrieved aerosol optical depth to the aerosol concentration (particle density) required by the forward model used in our SST retrieval.

Stratospheric Aerosol







Satellite – in situ SST around latitude of eruption (ATSR / AVHRR11: 10°S - 10°N; AVHRR 7: 5°N - 25°N). In situ includes drifters, tropical moorings and ships. Dashed lines show bias when aerosol is neglected (for ATSR this is a single-view retrieval). Solid lines show bias with aerosol-aware retrieval. Shaded area shows ±one standard error.

We test the retrieval by applying it to data from AVHRRs 7 and 11 and comparing the satellite SSTs to *in situ* measurements from drifters, tropical moorings, and ships.

Without accounting for the aerosol effects (dashed lines) we see retrieval biases up to ~2 K for a two-channel retrieval and ~1 K for a three-channel retrieval.

With the aerosol-aware OE retrieval the agreement with in situ is substantially improved. The greatest improvement is seen for the two-channel retrieval where aerosol signal has disappeared. The three-channel retrieval is still showing some aerosol related biases – although reduced in magnitude from ~1 K to ≲0.5 K.

References

Baran A. J. and J. S. Foot (1994) New application of the operational sounder HIRS in determining a climatology of sulphuric acid aerosol from the Pinatubo eruption. *J. Geophys. Res.*, 99(D12), 25673-25679. doi:10.1029/94JD02044

Merchant, C. J., A. R. Harris, M. J. Murray, and A. M. Závody (1999), Toward the elimination of bias in satellite retrievals of sea surface temperature: 1. Theory, modeling and interalgorithm comparison, *J. Geophys. Res.*, 104(C10), 23565-23578, doi:10.1029/1999JC900105

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