Temporal Variability of Observed and Simulated Hyperspectral Earth Reflectance

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CLARREO

Climate **A**bsolute **R**adiance and **Re**fractivity **O**bservatory

Objectives

1. Detect changes in climate
2. Attribute climate changes to physical processes
3. Test and improve climate model predictions

Measurement Requirements needed to address CLARREO Objectives

- High accuracy and ability to monitor that accuracy on orbit
- Sufficient information content
- Sensitivity to detect long-term trends

Science Questions

1. How do reflected solar radiation measurements change over space, time, and wavelength in response to changes in Earth's climate?
2. How well do climate models reproduce the variability observed in the Earth's climate system?

Observed and Simulated Reflectance

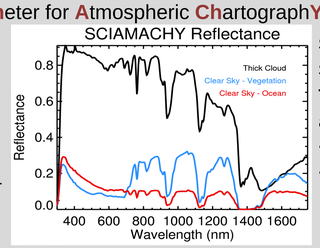
Scanning **I**maging **A**bsorption Spectro**m**eter for **A**tmospheric **Ch**artograph**Y**

SCIAMACHY hyperspectral reflectances are the best operational example of CLARREO-like reflectance spectra

Native Spectral Resolution: 0.24 - 1.5 nm

Nadir Spatial Resolution: 30 km (along-track) x 60 km (cross-track)

Radiometric Accuracy: Sun-normalized: 2-3%



Observing **S**ystem **S**imulation **E**xperiments

OSSE reflectances are simulated 21st century CLARREO-like reflectances

OSSE Inputs: IPCC AR4 climate model simulations

Climate Model: CCSM3 21st century simulations

Radiative Transfer Model: MODTRAN v5.3

Scene Types Output: All Sky and Clear Sky

Emission Scenarios: Constant CO_2 Concentration and A2 Emission

Temporal Sampling: 2000 - 2099 Monthly means

Output Spatial Sampling: 1° x 1° grid

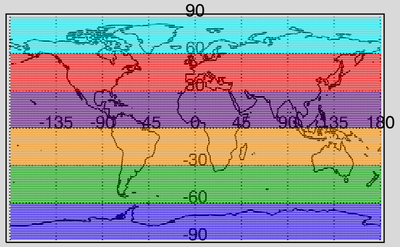
Experiment Setup

Spectral Resolution/Sampling: 10nm FWHM/3nm

Spatial Sampling: Averaged in 30° latitude bands

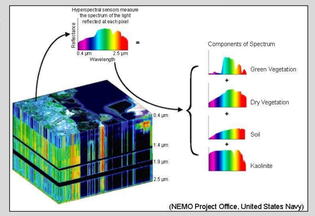
Temporal Sampling: Land and ocean monthly averaged reflectance spectra

- SCIAMACHY: 2002 – 2010
- OSSE: 2000 - 2099



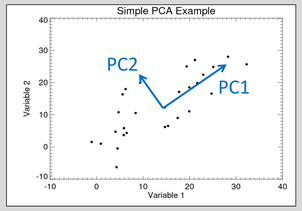
Principal Component Analysis (PCA)

***Idealized* spectral decomposition**

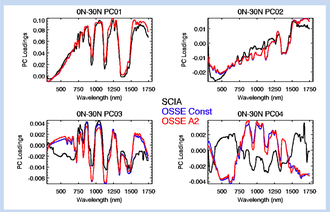


- PCA often reduces the dimensionality of multidimensional data by finding orthogonal variables (PCs) that can explain the majority of the original data's variance.
- **Subspace** – Defined by smallest number of variables that can sufficiently represent an entire data set. In PCA this is determined using the variance contribution of each PC.
- The subspaces for two different data sets can be used to compare the space defined by the dominant spectral variables.

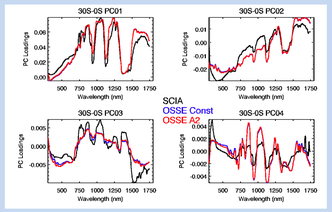
- Each PC is a linear combination of spectral reflectances. One PC typically explains more than one physical variable, often making each component difficult to physically interpret.
- **Graphically:** Each PC represents a new orthogonal axis that explains the remaining variance not explained by previous components.
- **Scores** – the weight that data points have relative to each PC (Black dots projected onto each blue line.)



SCIAMACHY and OSSE Decadal Variability

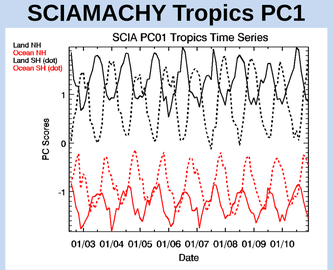


Black - SCIA
Blue – OSSE Const
Red - OSSE A2



- The first four PCs calculated from SCIAMACHY and OSSE reflectance (All Sky, Constant Concentration and A2 Emission Scenarios) between 2002 and 2010.
- The spectral shape of the first and second PCs compare well between SCIA and OSSE, but the spectral shapes of the other PCs differ, implying that they are different variables.
- Between the two emission scenarios, the PCs overlap – the nearly-decadal variability of the reflectance spectra simulated from both cases essentially identical.

SCIAMACHY Tropics PC1

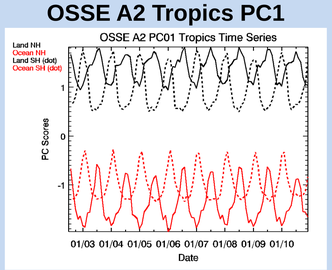


NH: 0°- 30°N
SH: 0°- 30°S

Black – Land
Red – Ocean

Solid – NH
Dotted - SH

OSSE A2 Tropics PC1



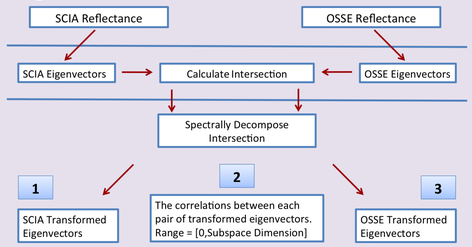
- PC1 land and ocean time series in Tropics bands describe approximate location of the Intertropical Convergence Zone.
- 90° phase difference between NH & SH ocean time series also observed by MODIS Aqua Cloud Fraction between 2002 and 2011 - shows a 3-month difference between maximum cloud fraction in the NH & SH [*King et al.,* 2012].

- Spectral shapes of SCIA and OSSE A2 PC1 are similar in the NH and SH Tropics bands and allows for comparison of their PC1 time series.
- OSSE A2 PC1 time series are similar to the SCIA time series except for the SH ocean, which has 180° phase difference from NH ocean instead of 90°.

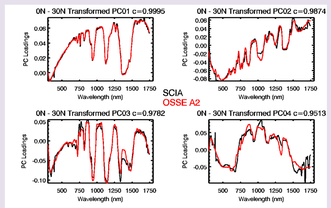
Decadal Variability Summary

- Annual and seasonal patterns of physical variables observed in nearly-decadal observed temporal variability - e.g. ITCZ location
- Hyperspectral reflectance contains information about the temporal variability of Earth's climate system
- Observed temporal variability can be used to evaluate how well model reproduces temporal variability of climate system.

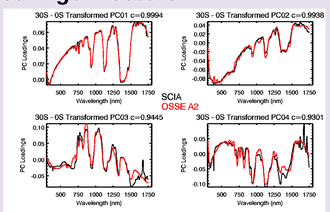
Comparing Observed and Modeled Variability



0°-30°N and 0°-30°S Transformed Eigenvectors

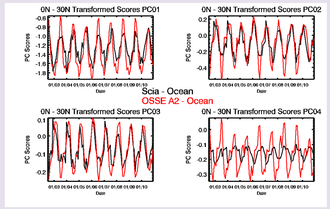


Black - SCIA
Red - OSSE A2

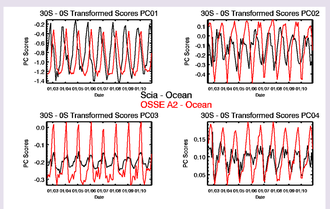


- The first four transformed OSSE and SCIAMACHY eigenvectors, calculated using the subspace intersection (Items 1 and 3 from the flow chart), have high correlations, implying similar spectral shapes.
- The original PC scores calculated from the PCA of SCIAMACHY and OSSE reflectance spectra were projected onto these transformed eigenvectors to determine the corresponding scores.

0°-30°N and 0°-30°S Transformed Ocean Scores



Black - SCIA
Red - OSSE A2

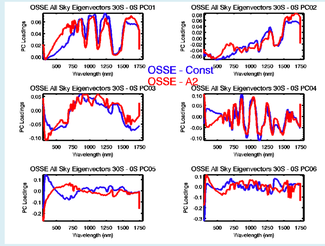


- The SCIAMACHY and OSSE A2 ocean scores calculated using transformed eigenvectors.
- The first SH time series exhibits differences similar to those seen in the original PC1 ocean time series (blue panel, bottom figures), where the time series are 90° out of phase.

Temporal Variability Comparison Summary

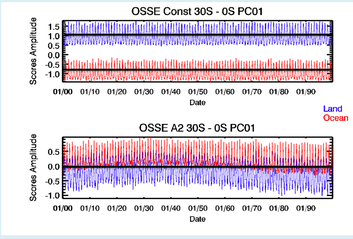
- Subspace intersection enables direct comparison between observed and simulated temporal variability, which illuminates both similarities and differences between data sets
- At the beginning of the 21st century, the OSSE generally reproduces the observed temporal variability

OSSE Centennial Variability



Blue – OSSE Const
Red - OSSE A2

- PCs calculated by including all spectral reflectance spectra averaged in the 0°-30°S latitude band between 2000 and 2099 for both emission scenarios.
- In contrast to the comparison of the nearly decadal PCs, the centennial variability between the two scenarios differs.



Blue - Land
Red - Ocean

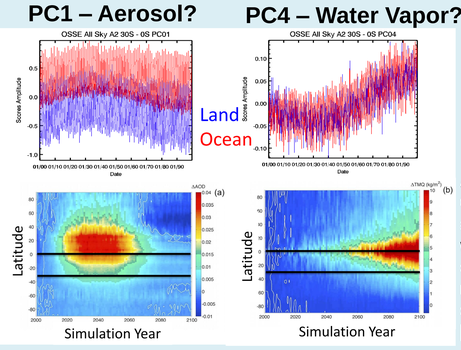
- The constant concentration PC time series ***do not*** exhibit secular trends, as expected; however, the A2 PC time series ***do*** exhibit secular trends throughout the century, based on the simulation input variables.

PC1 – Aerosol?

OSSE A2 PC1 time series exhibits similar pattern to change in aerosol optical depth between 2000 and 2100.

A2 Scenario Input: Change in zonally averaged aerosol optical depth at each time step relative to 2000−2009 decadal average [*Feldman et al.*, 2011].

PC4 – Water Vapor?



OSSE A2 PC4 time series exhibits similar pattern to change in water vapor between 2000 and 2100.

A2 Scenario Input: Change in zonally averaged total column water vapor (kg/m^2) at each time step relative to 2000-2009 decadal average [*Feldman et al.*, 2011].

Centennial Variability Summary

- Centennial variability of forced simulation modeled reflectance exhibits secular trends of physical variables – e.g. Aerosol optical depth and water vapor
- By quantifying the OSSE centennial variability, this method demonstrates its utility in studying changes to the Earth's climate system and linking changes to physical variables.