Decadal Seasonal Shifts of Precipitation and Temperature in TRMM and AIRS Data

Andrey Savtchenko[1,3], George Huffman[2], David Meyer[3], Bruce Vollmer[3]

[1] ADNET Systems, Inc.
[2] NASA/GSFC, Code 612.0
[3] NASA/GSFC, Code 610.2

Explore satellite data content:

Get a glimpse at data usability for assessing seasonal phase shifts

Basic radar mixing and Doppler phase detection using complex (quadratic) signals:

$$z_m(t) = e^{j[\omega t + \phi(t) + \phi_o]} \cdot e^{-j[\omega t + \phi_o]} = \cos\phi(t) + j\sin\phi(t)$$

Received signal, containing phase information $\phi(t)$

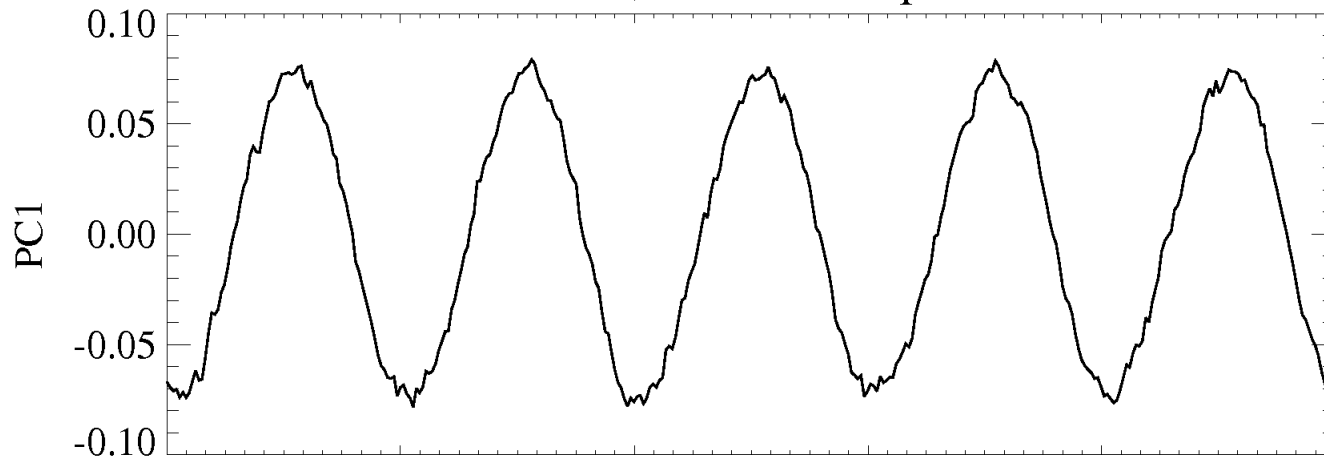Reference signal (stored transmission) with frequency ω and initial phase ϕ_o

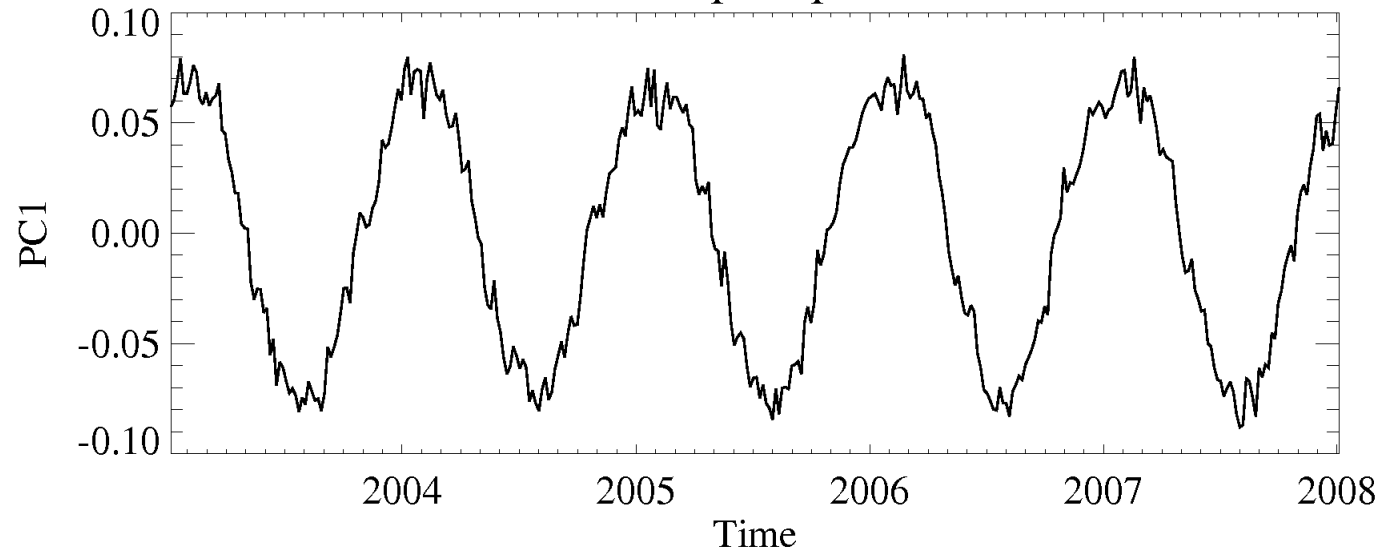$$\phi(t) = \arg(z_m)$$

Extracted phase difference series.

Similar technique can be applied to detect seasonal shifts using Principal Components of Earth Science Data Records

AIRS; SurfAirTemp_A

TMPA; precipitation

PC1 of Pentad (5-day) series carries most of the information, is most strongly related with seasonal variability, and is almost monochromatic.

To check if the technique will work, let's first simulate a seasonal component with nominal period 365.25 days, very slight phase drift, and some "synoptic" phase noise:

$$\Delta\phi = \frac{2\pi}{365.25} \cdot 15 \qquad \text{15-day anomaly (radians)}$$

$$\phi_i = \frac{2\pi}{N_p} i + \frac{\Delta\phi}{10 \cdot N_p} i + \delta(i)$$
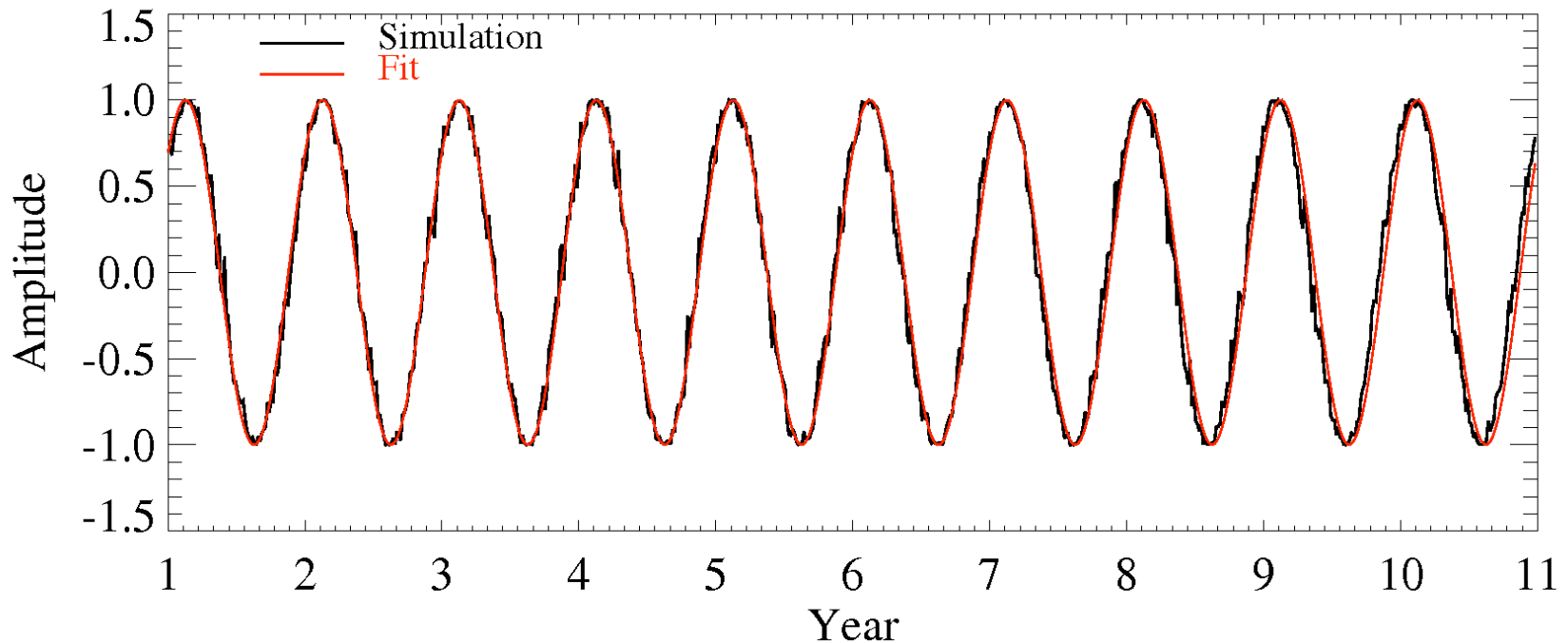
| Nominal seasonal frequency | Increase in the frequency of seasonal variability at a rate of 15 days per 10 years | Normal phase noise |

Thus we can simulate a seasonal observation, starting with ϕ_o, with seasons arriving earlier:

$$\hat{y}_i = \cos(\phi_i + \phi_o)$$

❑ Simulate 10 years of 5-day series:
  • Initial phase: -50 days, arbitrary;
  • Accumulated seasonal earlier arrival, per 10 years: 15 days
  • Normal random phase noise, σ=5 days
❑ Use the first 5 years to learn ϕ_o

Use Hilbert transform to convert the simulated series from real to complex (below, index removed for brevity).

For the fitted series, either use *sin* for the Im part, or do similarly Hilbert.

$$\text{Im}(\hat{y}) = H(\hat{y})$$
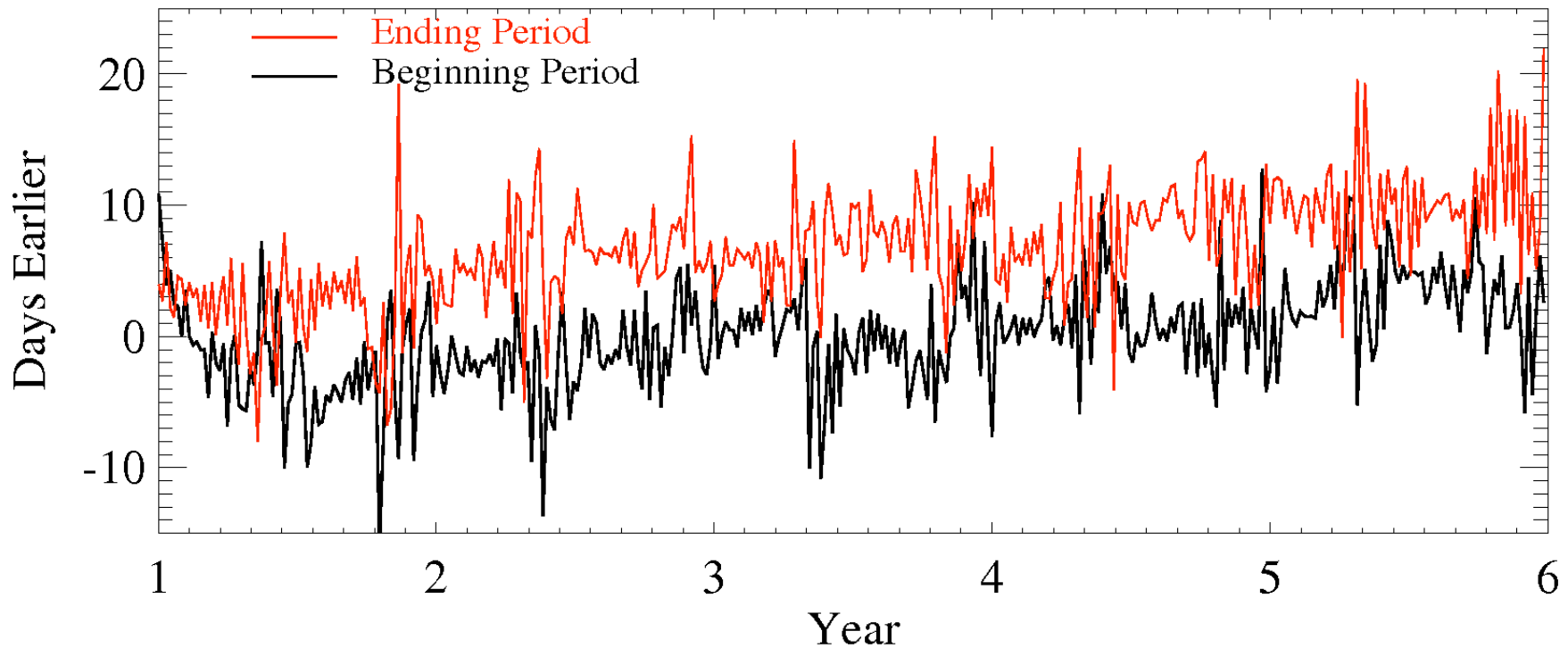
$$\hat{z} = \hat{y} + j\,\text{Im}(\hat{y})$$

$$z_{fit} = \cos(\phi) + j\,\sin(\phi), \qquad \phi = \frac{2\pi}{N_p} + \phi_o$$
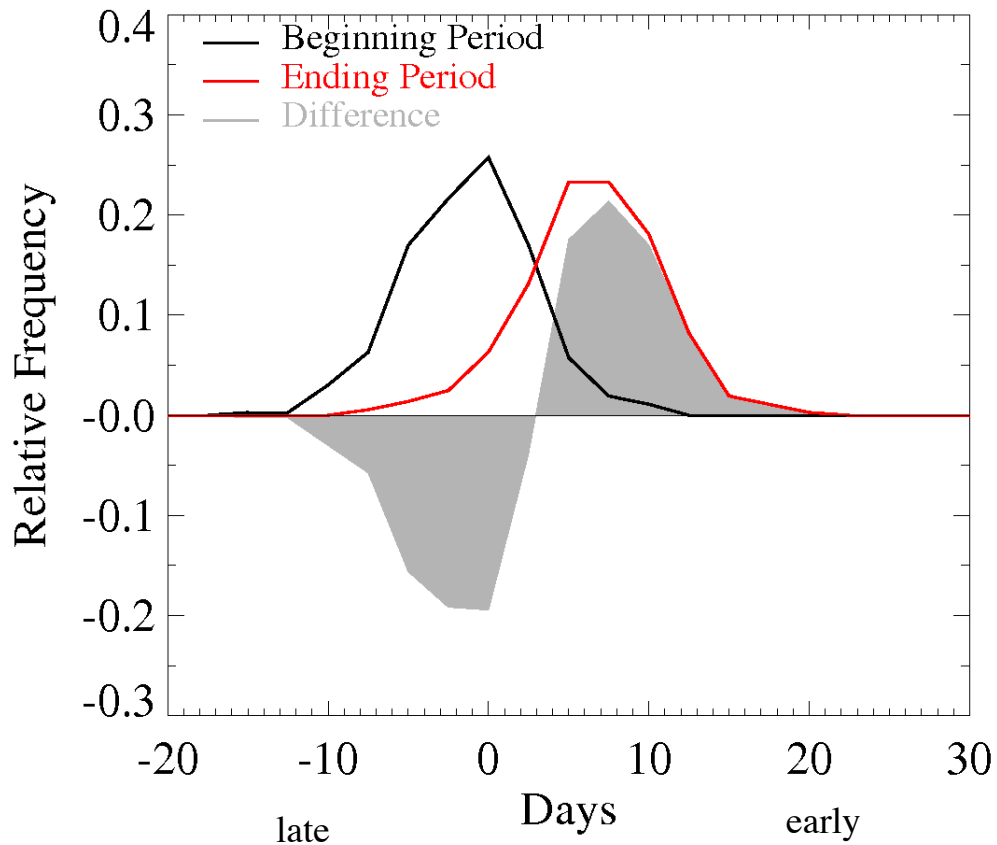
$$z_m = \hat{z} \cdot z_{fit}^{*}$$

"Mixing" removes the monochromatic seasonal frequency component, and the initial phase ϕ_o

$$\Delta\phi = \tan^{-1}(z_m)$$

- Simulated seasonal drift, i.e. seasons arriving earlier, with superimposed 5-day "synoptic" noise.
- The beginning 5-year period serves as learning reference.
- The ending 5-year period reveals simulated earlier arrivals of seasons.

Stddev, and Confidence of the mean at 95%, beginning 5 years:

$\sigma = 4$ days

$\Delta_{95} = 0.4$ days

- Histograms of simulated seasonal drift. The <u>positive</u> shaded area is the probability that seasons in the <u>ending</u> 5 years arrived <u>earlier</u> than in the beginning 5 years.
- Difference in the means (End-Begin) = 7.7 days (early)

Switching to real data…

Data are curated by NASA Goddard Global Change Data Center:

❑ **TMPA**
- ✓ Tropical Rainfall Measuring Mission (TRMM) Multi-Satellite Precipitation Algorithm (TRMM_3B42_Daily v7).
- ✓ Daily grids aggregated to pentad (5-day) series, 1x1 degree; 1998-2016.

❑ **AIRS**
- ✓ Atmospheric Infrared Sounder, Aqua satellite, IR-only retrieval (AIRS3STD v6).
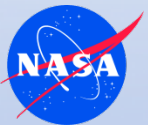- ✓ "SurfAirTemp" Daily grids averaged to pentad series, 1x1 deg; 2003 – 2016; Subset to the TMPA grid (± 50 deg latitude).
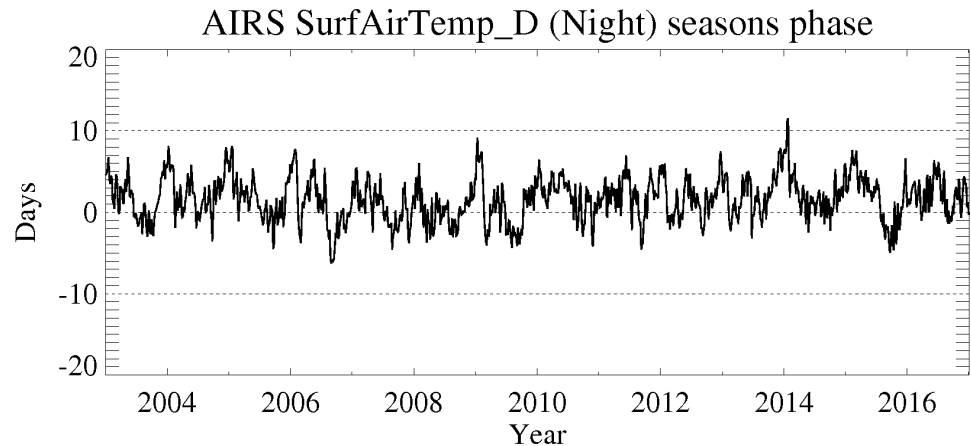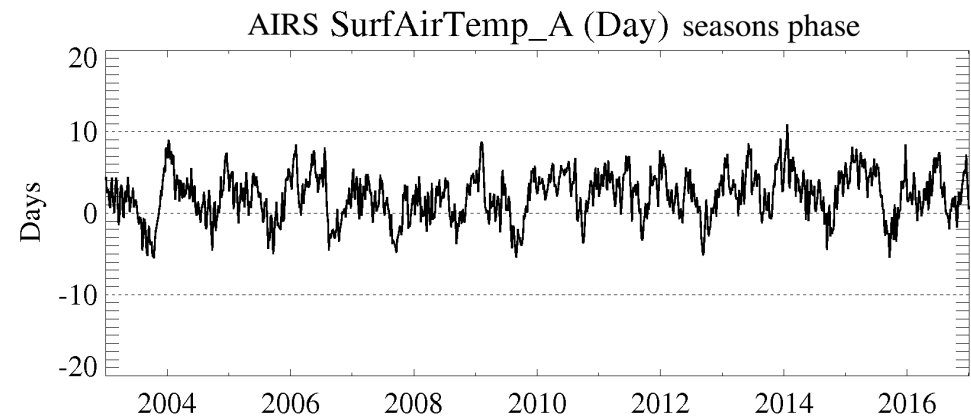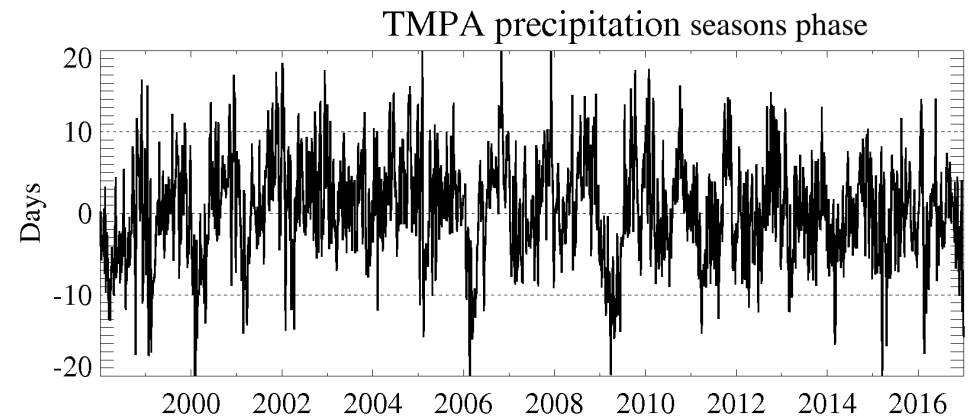
TMPA PC1 and phase-locked fit
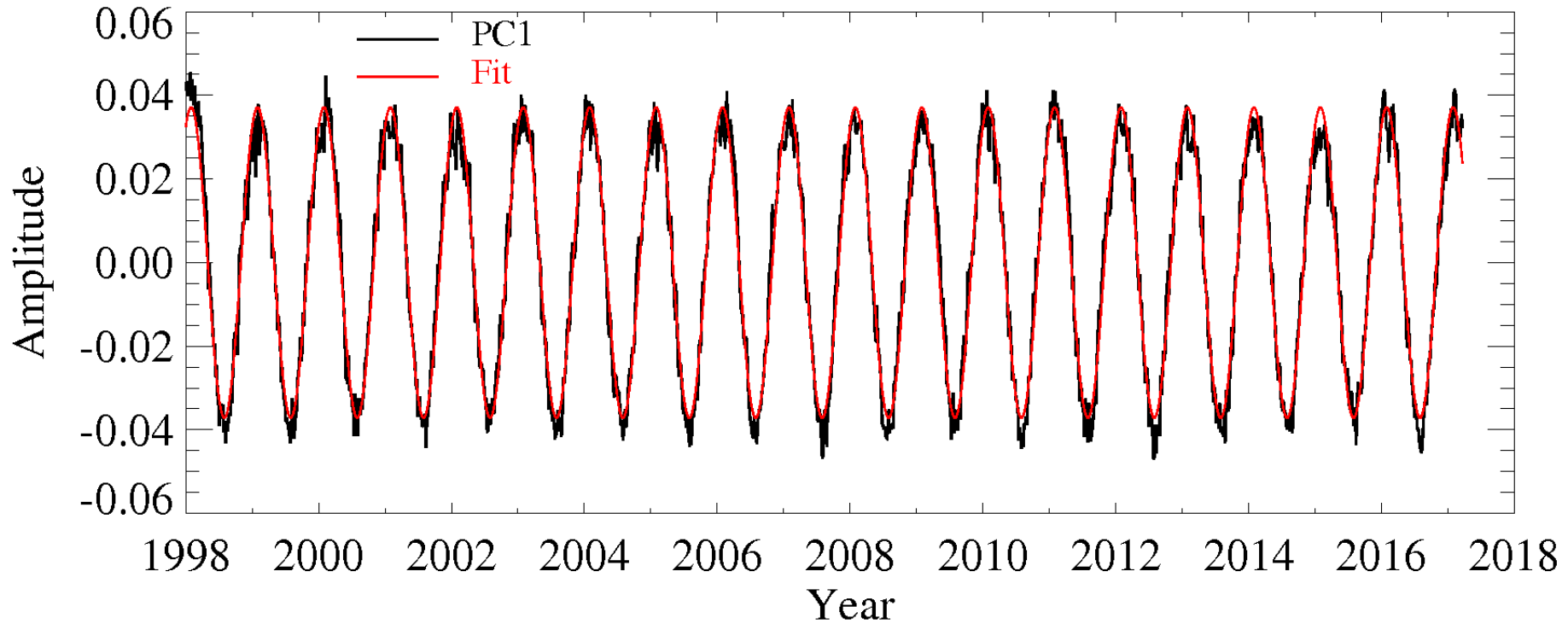
- Fit reference frequency with period 365.25 days

- The fit learns from the first 5 years, then the reference frequency is extended to the end of the observation.

PC1 Phase Variations Δϕ (PC1 – fit)

- TMPA and AIRS PC1 reveal stable global precipitation and surface temperature seasons.

- Still, all have slight but confident tendencies at 95% level

- Positive = Days Earlier

- Negative = Days Delayed

TMPA precipitation seasons phase

AIRS SurfAirTemp_A (Day) seasons phase

AIRS SurfAirTemp_D (Night) seasons phase
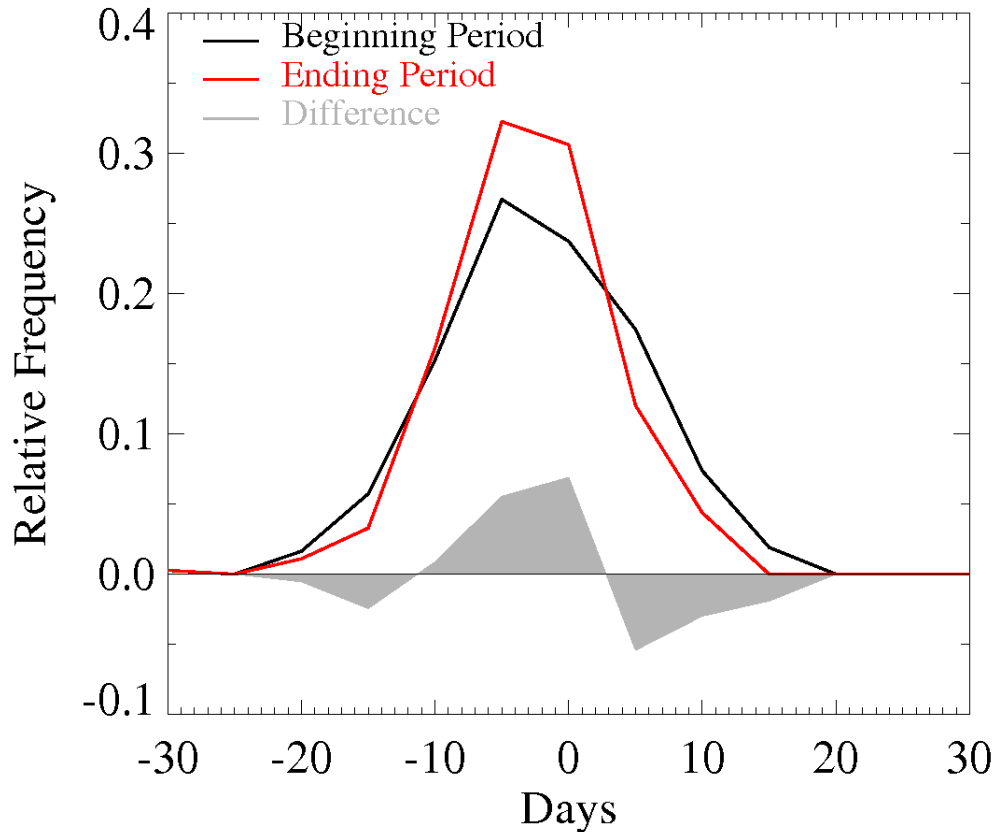
TMPA

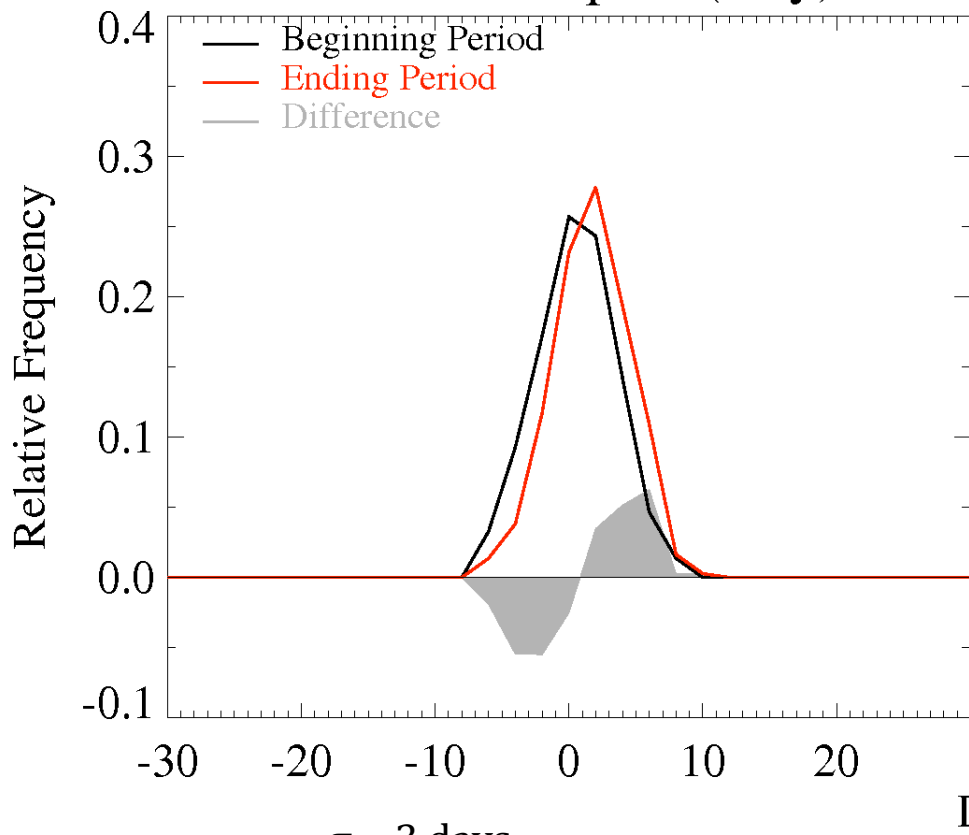Stddev, and Confidence of the mean at 95%, beginning 5 years:

$\sigma = 7.3$ days

$\Delta_{95} = 0.75$ days

TMPA
- Histograms of the phase shifts in PC1, $\Delta\phi$ = (PC1 – fit).
- Beginning period   = 1998-2003 (learning reference for the fit)
- Ending period = 2012-2017
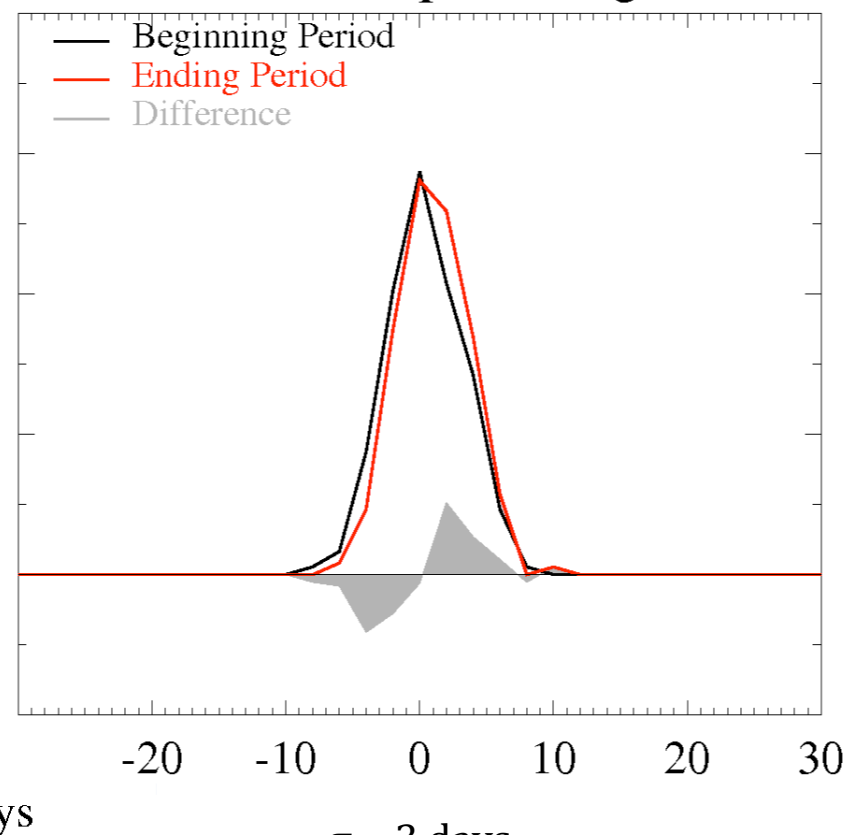- Difference in the means (End-Beg)=-0.74 days (delay), just missing 95% confidence

SurfAirTemp_A (Day)

SurfAirTemp_D (Night)

σ = 3 days
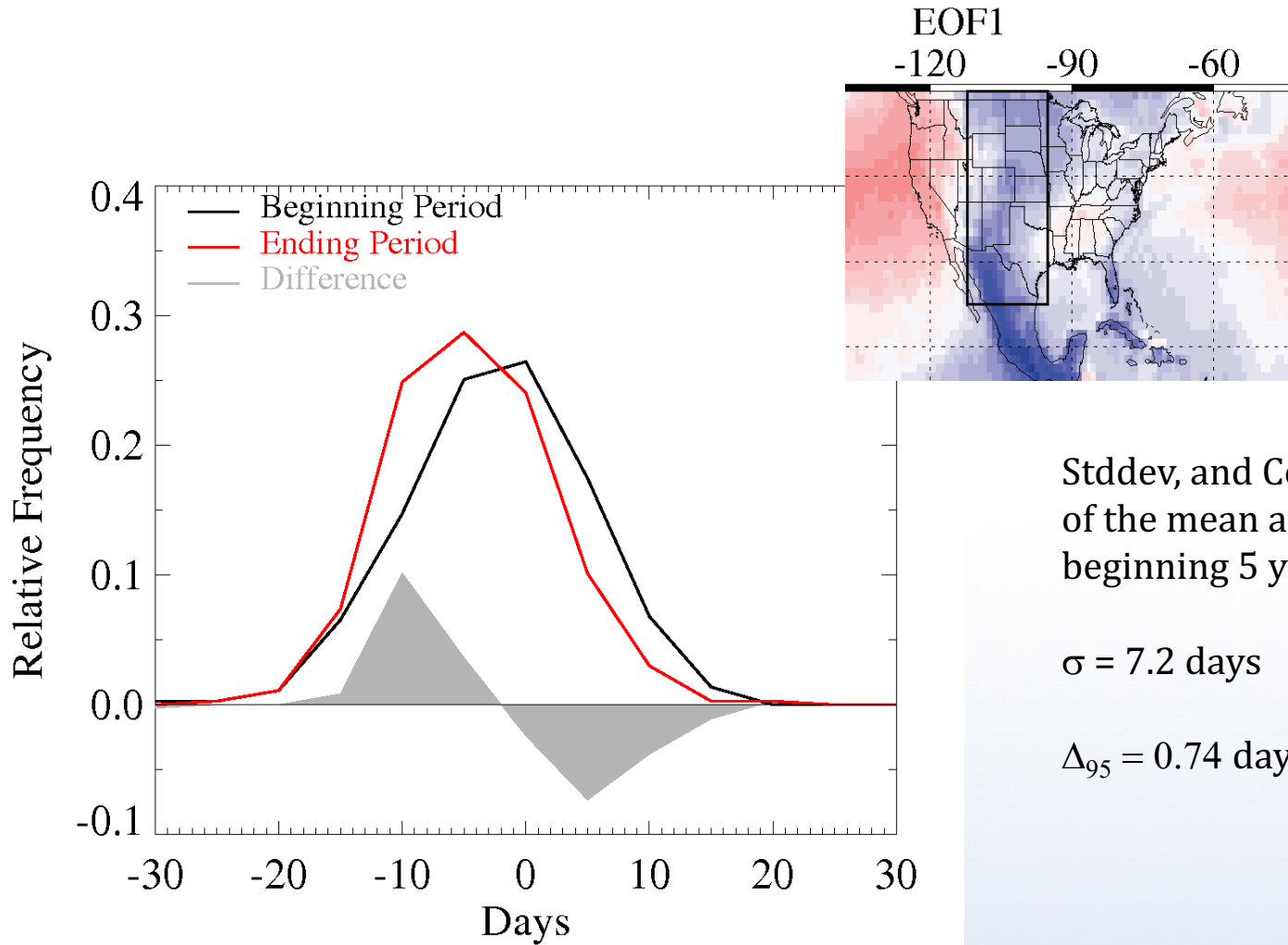Δ_{95} = 0.3 days

σ = 3 days
Δ_{95} = 0.3 days

AIRS
- Histograms of the phase shifts in PC1, $\Delta\phi$ = (PC1 – fit).
- Beginning period   = 2003-2008 (learning reference for the fit)
- Ending period   = 2012-2017
- Difference in the means (End-Beg):
  - SurfAirTemp_A = 1.1 days (earlier)
  - SurfAirTemp_D = 0.6 days (earlier)

TMPA

- EOF (spatial patterns) of principal modes 1 and 2, in terms of normalized covariance.

- Deep colors indicate regions with strong seasonal variability and hence where delayed seasons are most likely felt.

- Lets take as an example the Central North America (includes the North American Monsoon region)

EOF1

EOF2

Norm. Covariance

-0.9 -0.7 -0.5 -0.3 -0.1 0.1 0.3 0.5 0.7 0.9
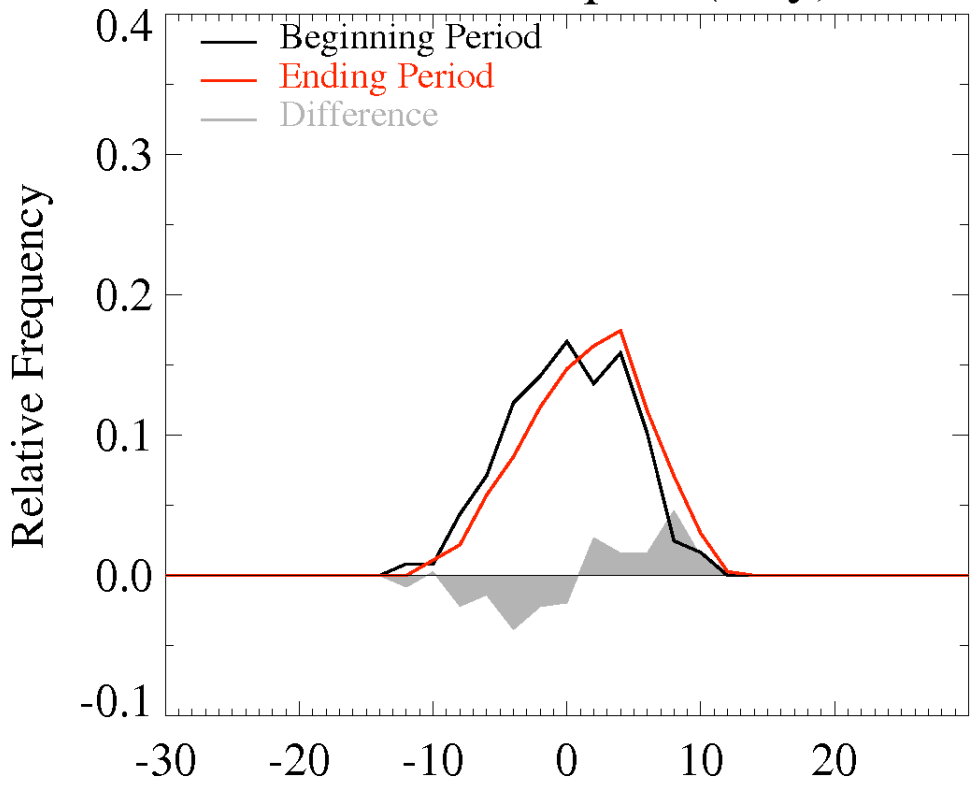
EOF1
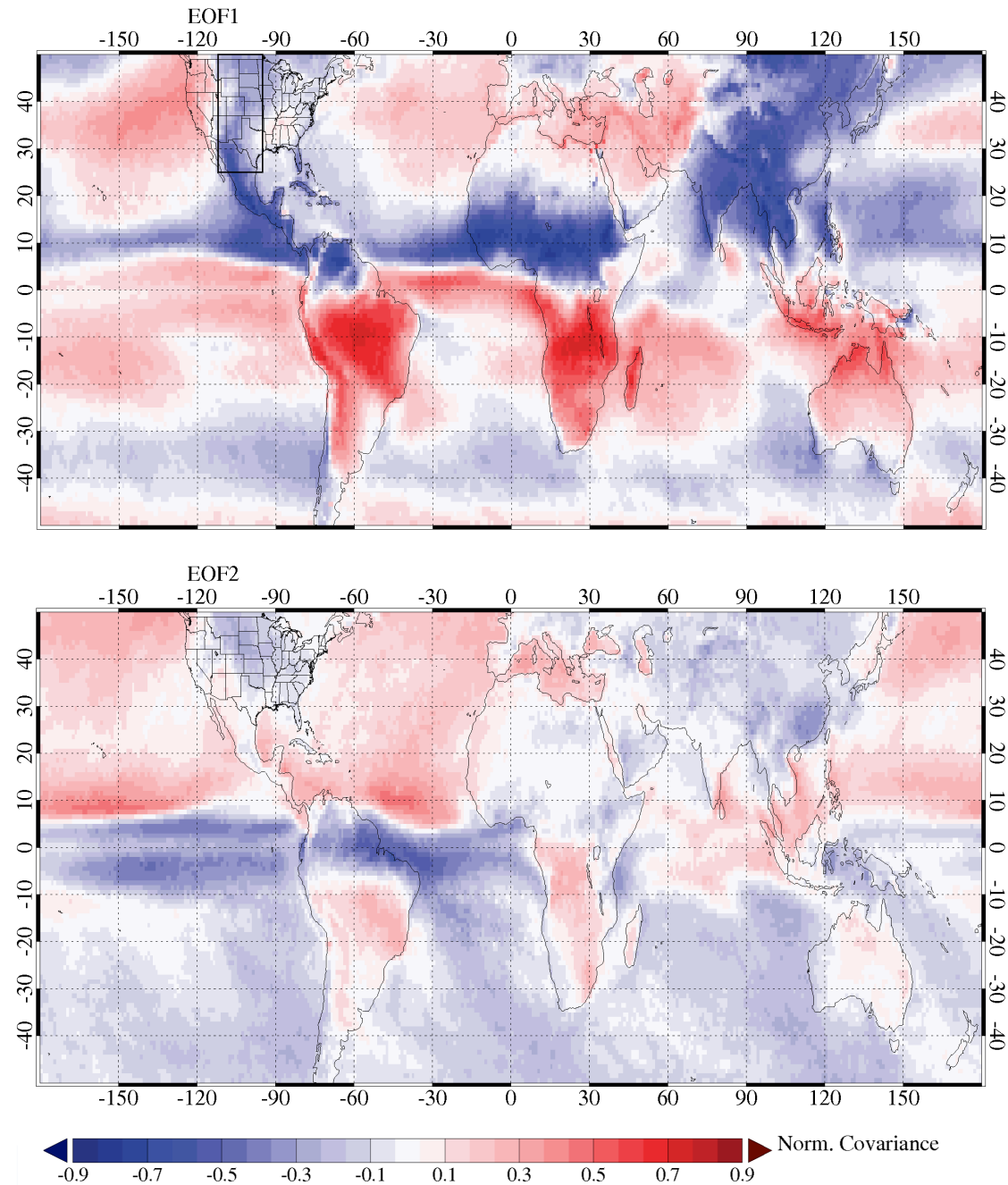
Stddev, and Confidence of the mean at 95%, beginning 5 years:

σ = 7.2 days
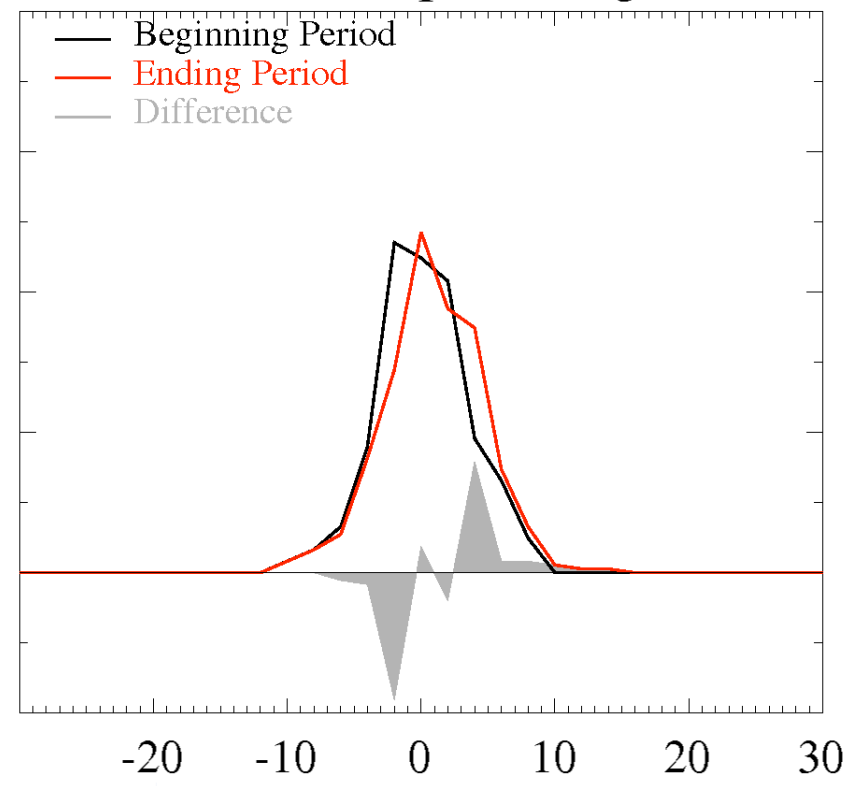
Δ_{95} = 0.74 days

TMPA
- Histograms of the phase drift, $\Delta\phi$, of the area-averaged (see the box) reconstructed PC1,2,3 series.
- Beginning period = 1998-2003 (learning reference for the fit)
- Ending period   = 2012-2017
- Difference in the means (End-Beg)=-2.2 days (delay), a confident anomaly

SurfAirTemp_A (Day)
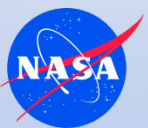
SurfAirTemp_D (Night)

$\sigma = 4$ days

$\Delta_{95} = 0.46$ days

$\sigma = 3$ days

$\Delta_{95} = 0.35$ days

AIRS
- Histograms of the phase shifts, $\Delta\phi$, of the area-averaged reconstructed PC1,2,3 series
- Beginning period   = 2003-2008 (learning reference for the fit)
- Ending period   = 2012-2017
- Difference in the means (End-Beg):
  - SurfAirTemp_A = 1.3 days (earlier)
  - SurfAirTemp_D = 0.7 days (earlier)

SUMMARY

Shown is the utility of using pentad precipitation (5-day) together with principal component analysis to detect seasonal shifts from 20 years of TMPA and 15 years of AIRS data.

Although precipitation and surface air temperature seasons are stable globally, there is slight but confident tendency of <u>delayed</u> arrival of precipitation, and <u>earlier</u> arrival of temperatures seasons.

Regionally, these tendencies can be stronger.

For instance, this pattern is more apparent in large areas of the central US.