Current PMC Trends Derived from SBUV Measurements

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Modeling Polar Mesospheric Cloud Trends

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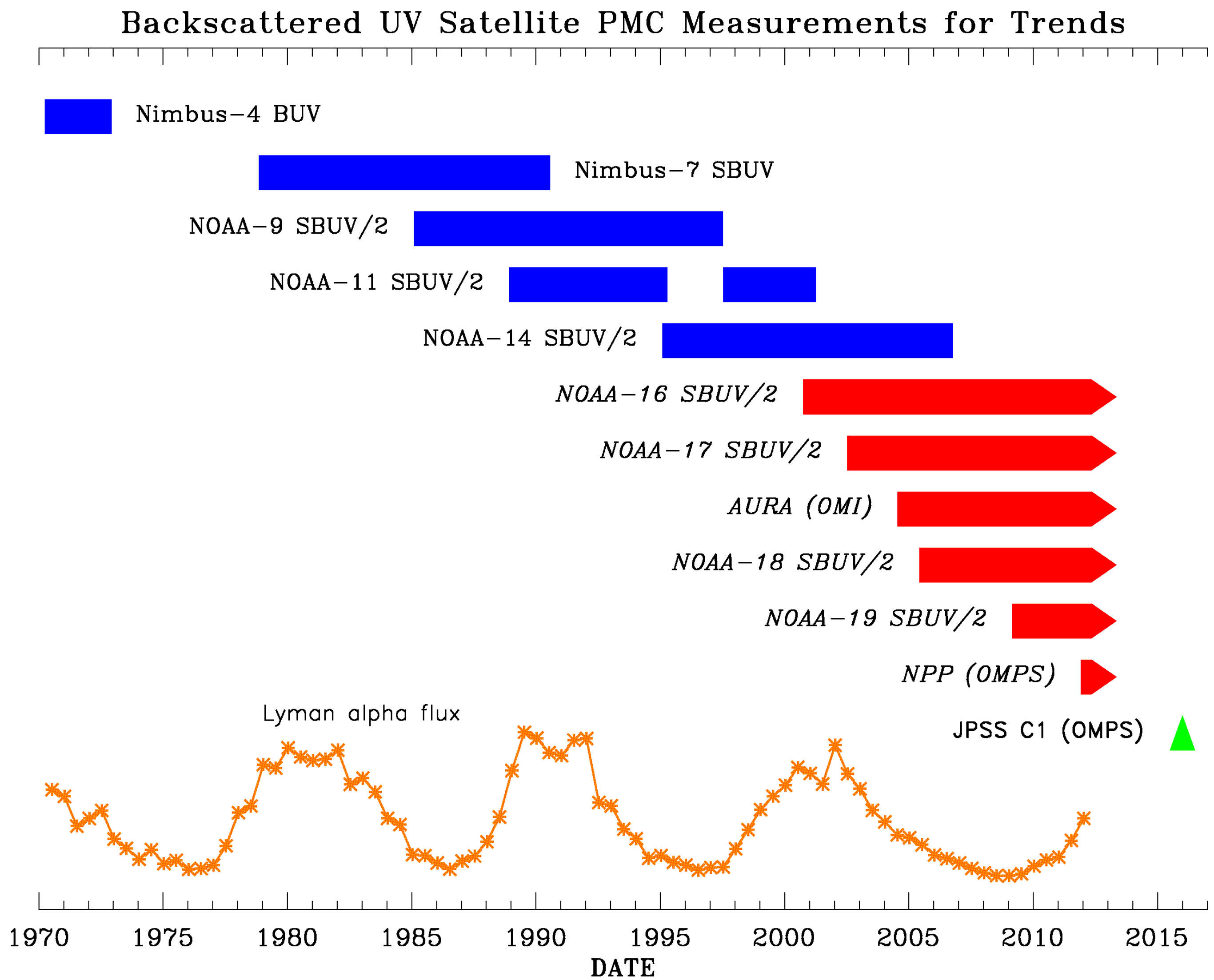
Introduction

- Solar Backscatter Ultraviolet (SBUV) instruments have observed PMCs continuously from satellites for more than 30 years. This long data record has demonstrated solar cycle variations and secular trends in both occurrence frequency and brightness.
- Data from 8 separate instruments, with changing viewing conditions, different local times of observation, and drifting orbits, must be combined to create a single data set for trend analysis.
- The magnitude and latitude dependence of the PMC trends observed in the brightest clouds by SBUV are sensitive to the analysis methodology.
- This presentation will try to illustrate some aspects of this complex process.

PMC Measurement Timeline

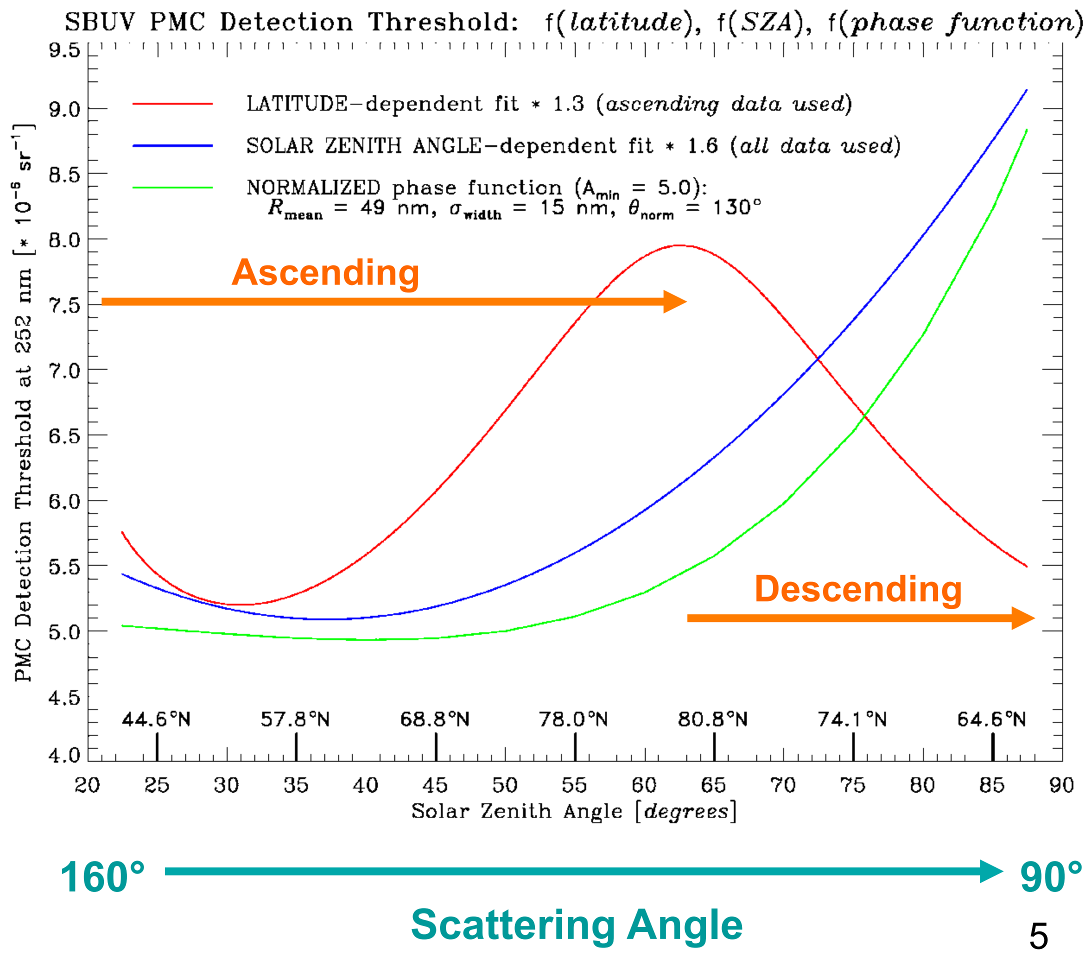


Processing/Trend Analysis Issues for SBUV Data

- Functional form for PMC detection threshold test.
- Normalization of PMC albedo for phase function effects.
- Local time dependence adjustments (amplitude, phase, diurnal *vs*. semi-diurnal, latitude variation).
- Method to combine individual satellite data sets for trend calculation.
- Temporal break point in multiple regression fit.
- *And many more!*

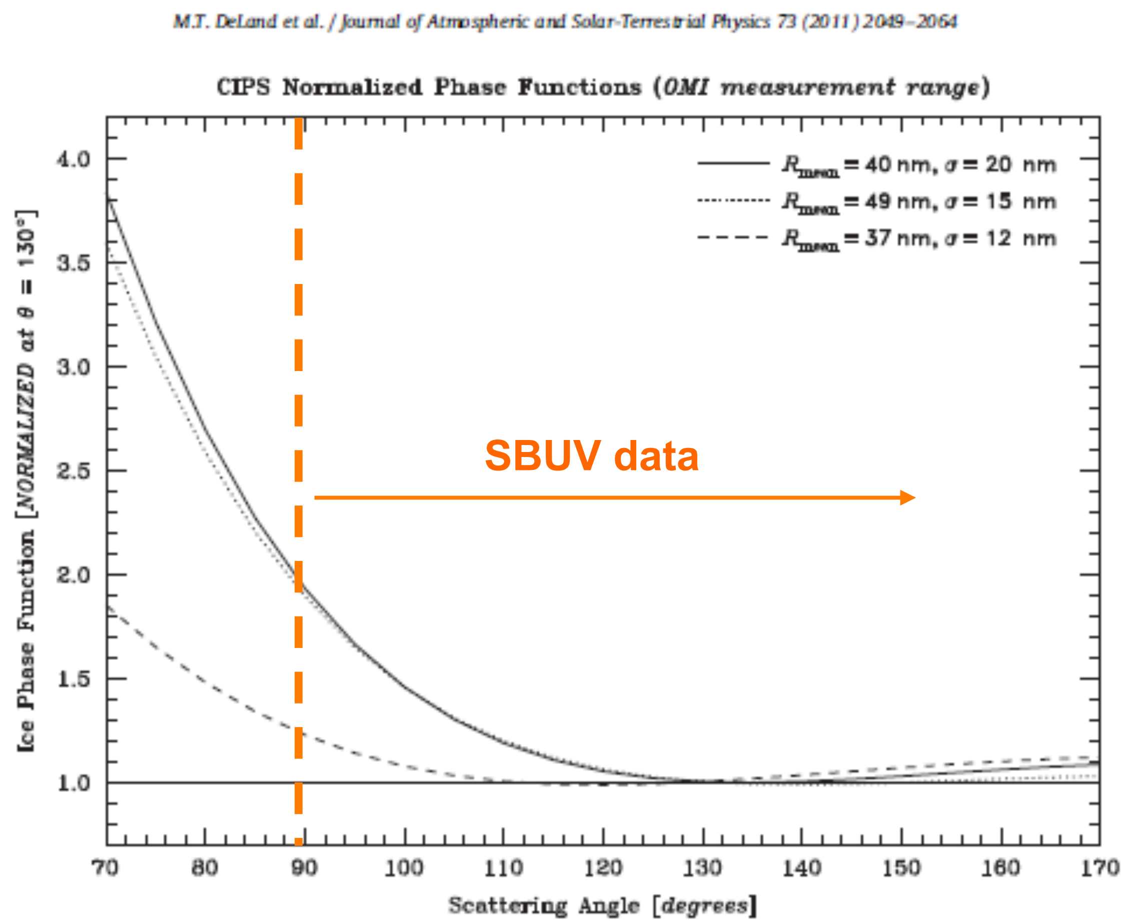
PMC Detection Threshold

- Minimum albedo threshold has largest influence on SBUV PMC detection.
- Scaling value chosen to get zero PMC frequency at end of season.
- Note similarity of SZA-dependent fit to phase function → use this approach to investigate SBUV response to SCA dependence.



Phase Function (SCA > 90°)

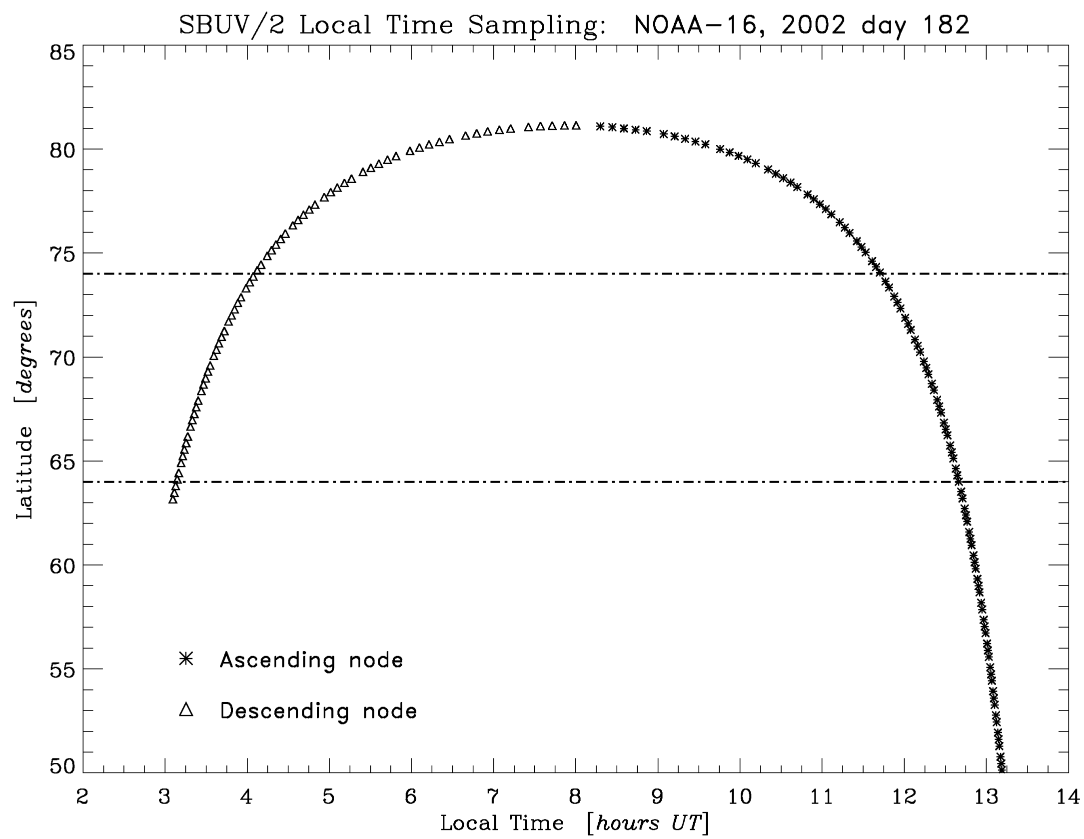
- Phase function variations for SBUV are small compared to forward scattering, but still significant.
- No treatment for this effect in "public" SBUV PMC data processing.
- Test normalization of PMC albedo values to θ = 130° after using detection algorithm.
- ALOMAR "strong" case examined here.



DeLand *et al.* [2011]

Local Time Sampling - Orbit

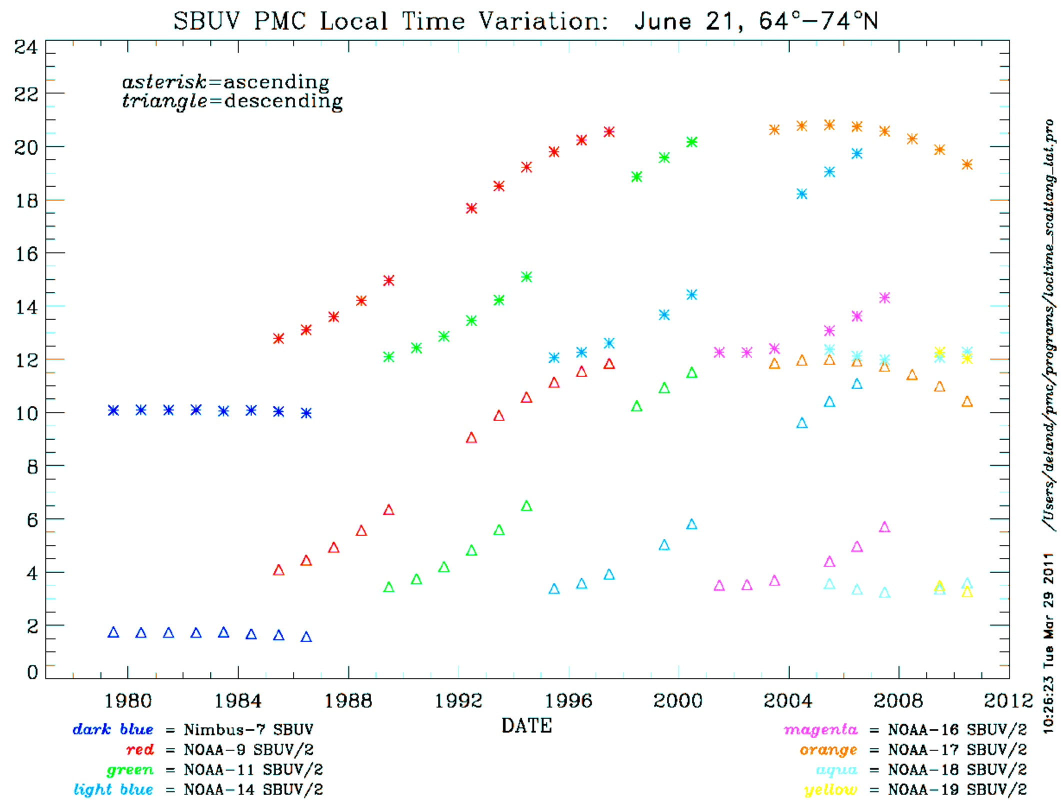
- Sun-synchronous orbit provides data on both ascending and descending nodes at high latitude during summer.
- Separation is ~9 hr in local time (~30° in scattering angle) at 70°N.
- Orbit drift will decrease scattering angle separation, but local time separation remains constant.



DeLand *et al.* [2007]

Local Time Drift (64°-74°N)

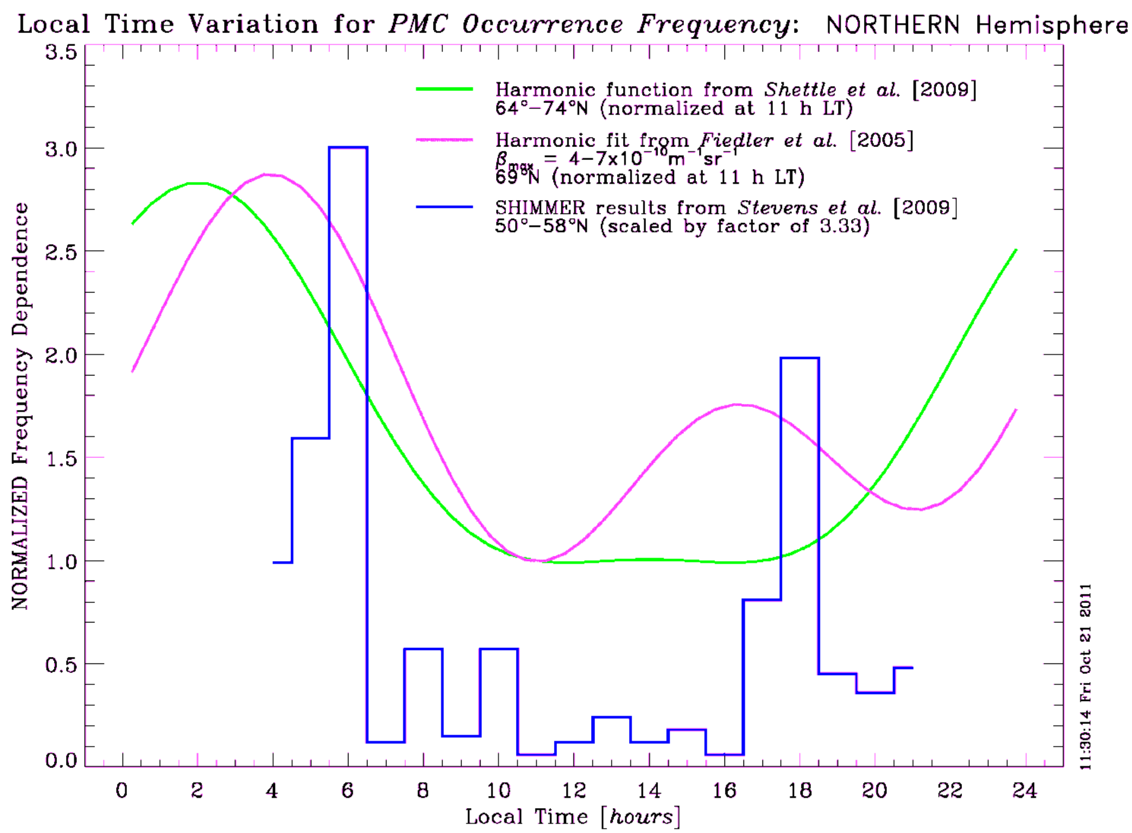
- Most SBUV instruments have experienced significant drift in local time *(better performance with recent instruments*).
- Lidar data show large PMC variability with local time in both hemispheres.
- Adjustments are needed to reconcile overlapping seasonal average data sets.



Updated from DeLand *et al.* [2007]

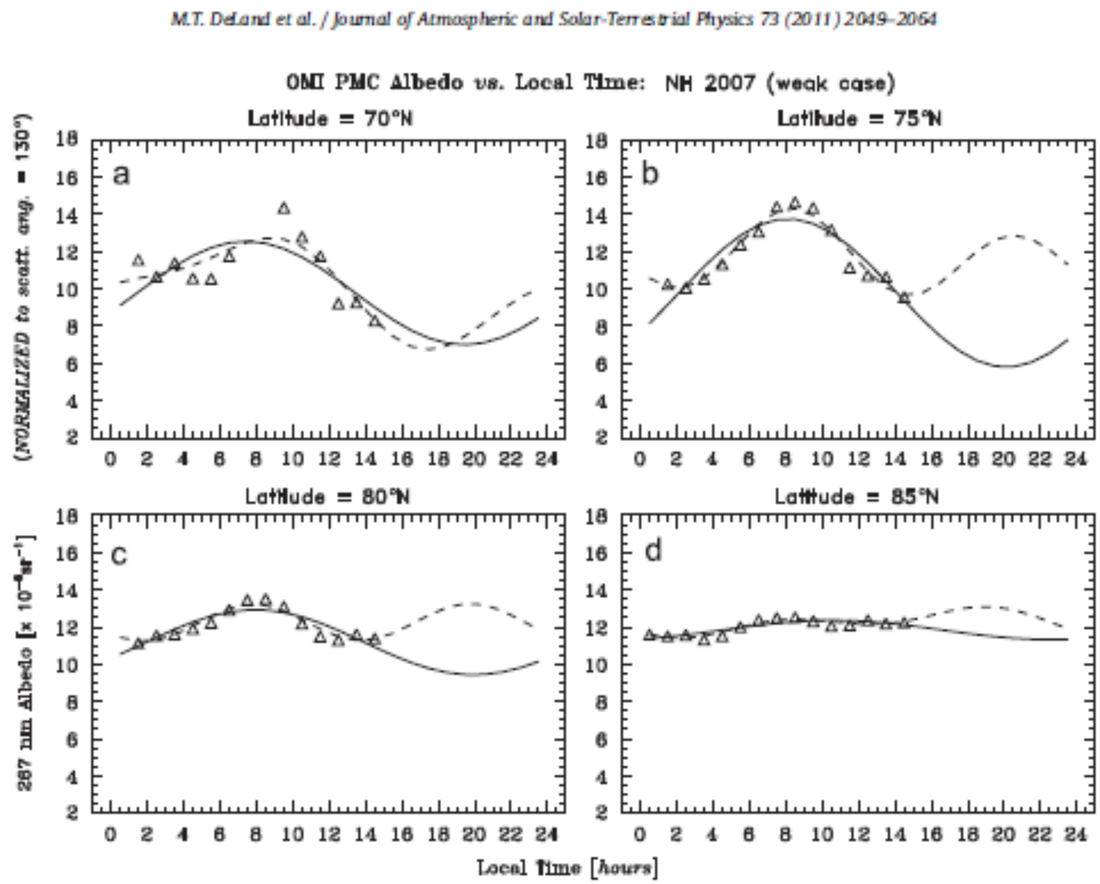
Local Time Adjustments

- Published results cover different locations, latitude bands.
- SBUV local time adjustment function is difficult to derive directly from measurements.
- OMI PMC data provide extended coverage at high latitude *(see next slide*).



OMI Local Time Results - NH

- Overlapping swaths at high latitude give continuous coverage for 12-14 hours every day.
- NH results give consistent peak at ~8 hrs LT. SH results give minimum at 19-20 hrs LT.
- Amplitude decreases at higher latitude.
- OMI data cannot verify presence of semi-diurnal term.

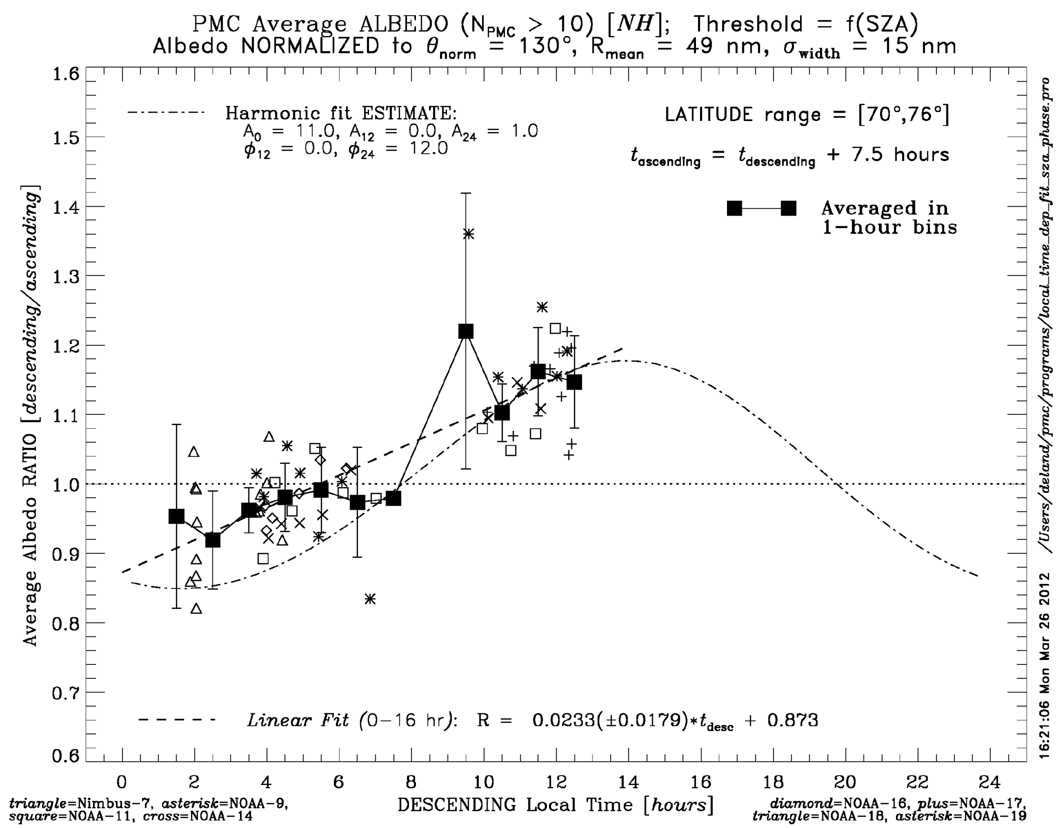


DeLand *et al.* [2011]

SBUV Local Time – Data

- SBUV orbit drift is too slow to use data directly for local time dependence (except at highest latitude).
- Take ratio of descending node to ascending node data (ΔLT = 7-9 hours) for each instrument in each season.
- Albedo values give consistent variation with changing LT.

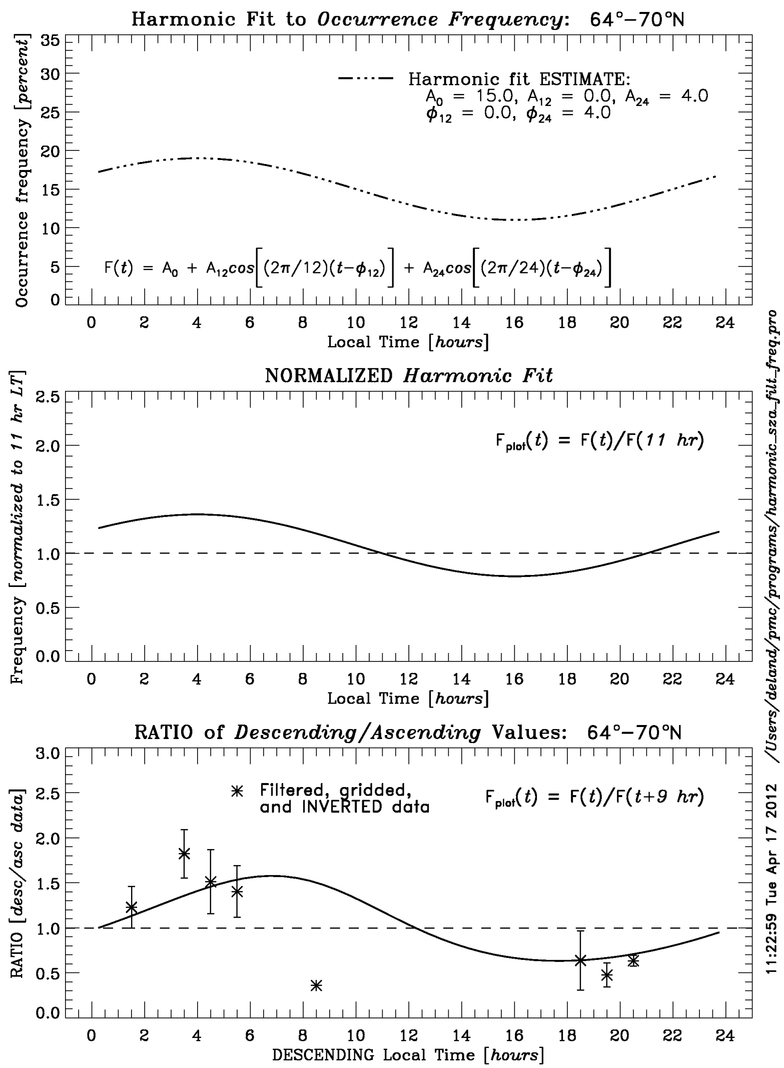
Brightness - NH



Updated from DeLand *et al.* [2007]

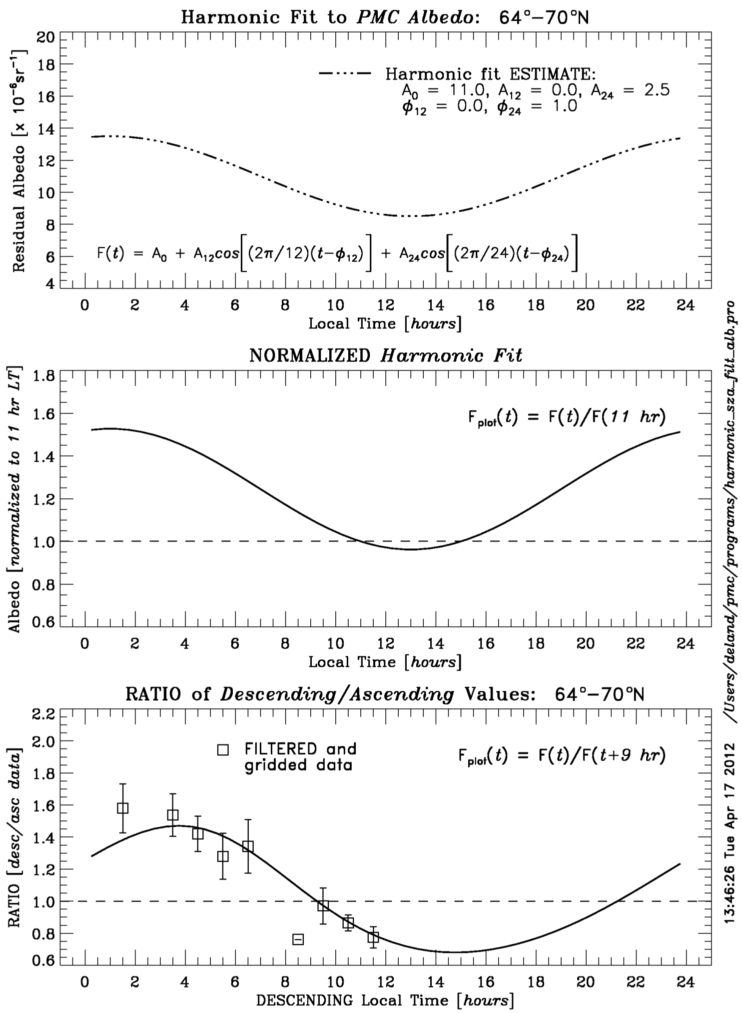
SBUV Local Time – Fit (1)

- Specify harmonic fit values (diurnal only), evaluate using "ratio" form *vs.* observations.
- Chosen function is not necessarily unique.
- Frequency curves have phase of +4-5 hr in both hemispheres.
- Albedo curves have phase of +1 hr using "raw" data, +8-9 hr when phase function normalization is applied.

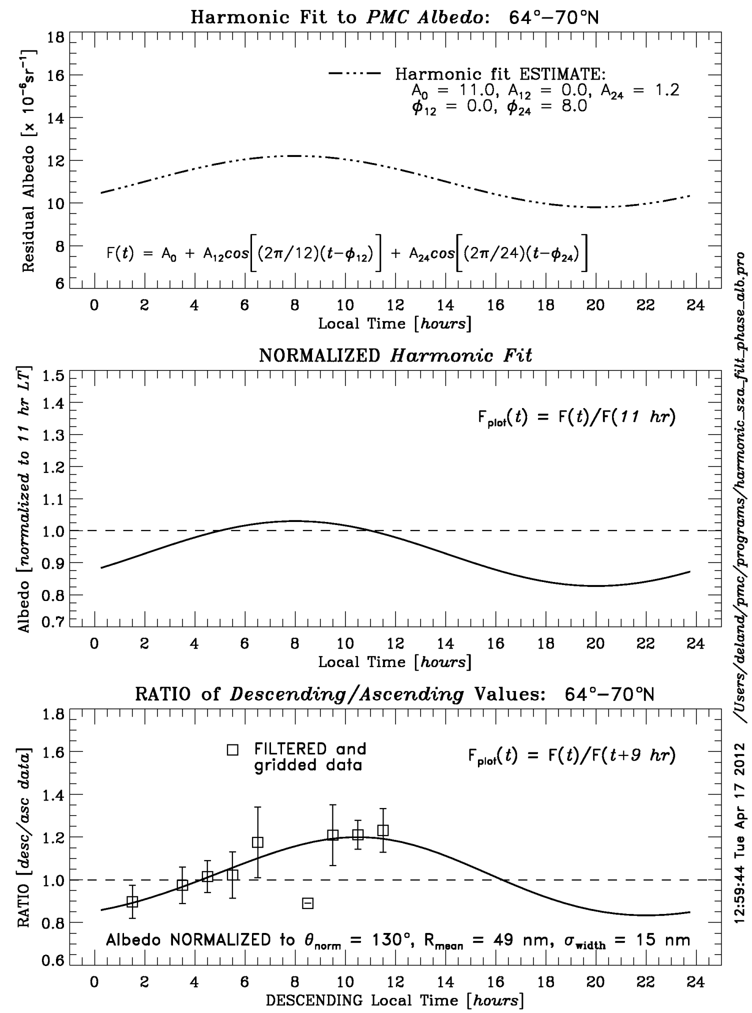


Frequency - NH

SBUV Local Time – Fit (2)

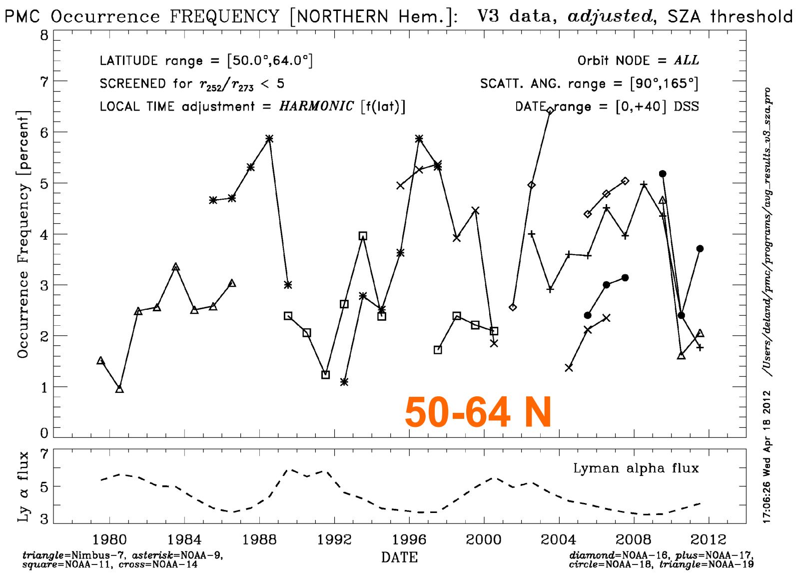


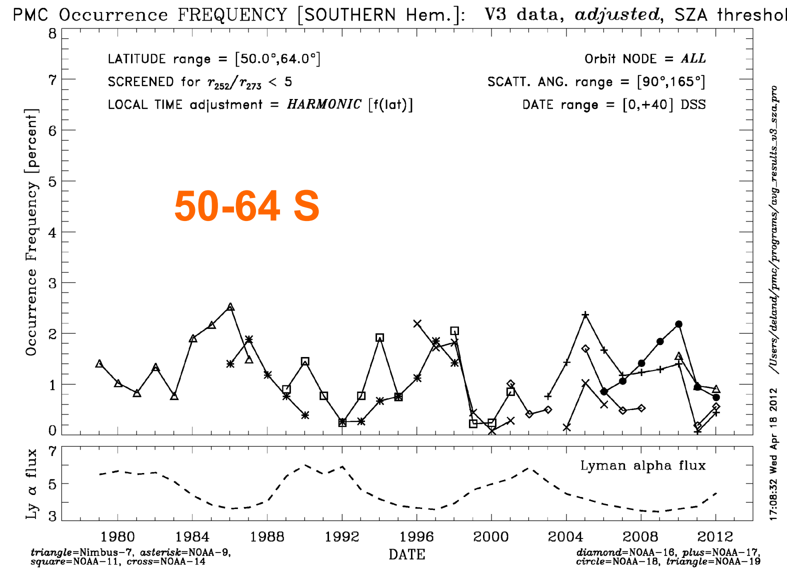
Albedo (raw) - NH

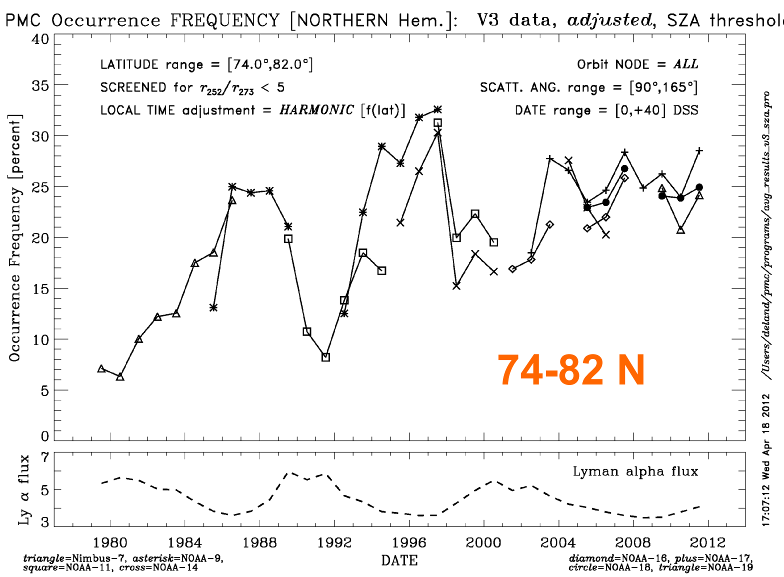


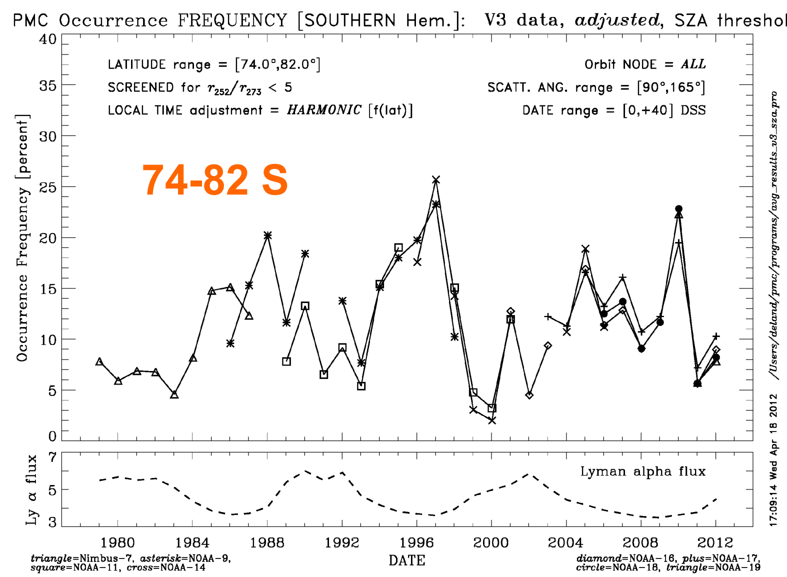
Albedo (normalized) - NH

All SBUV Data - *Frequency*

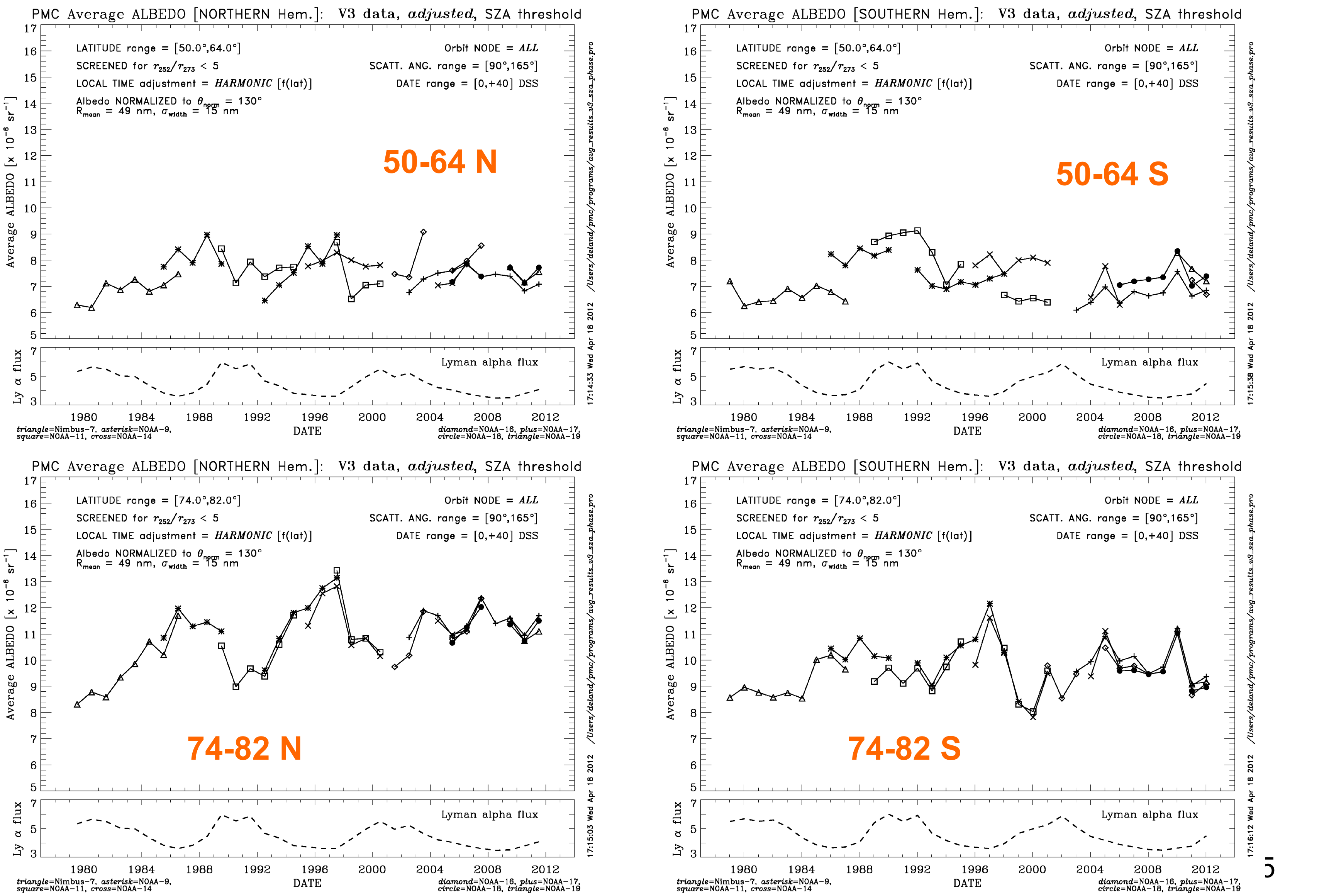






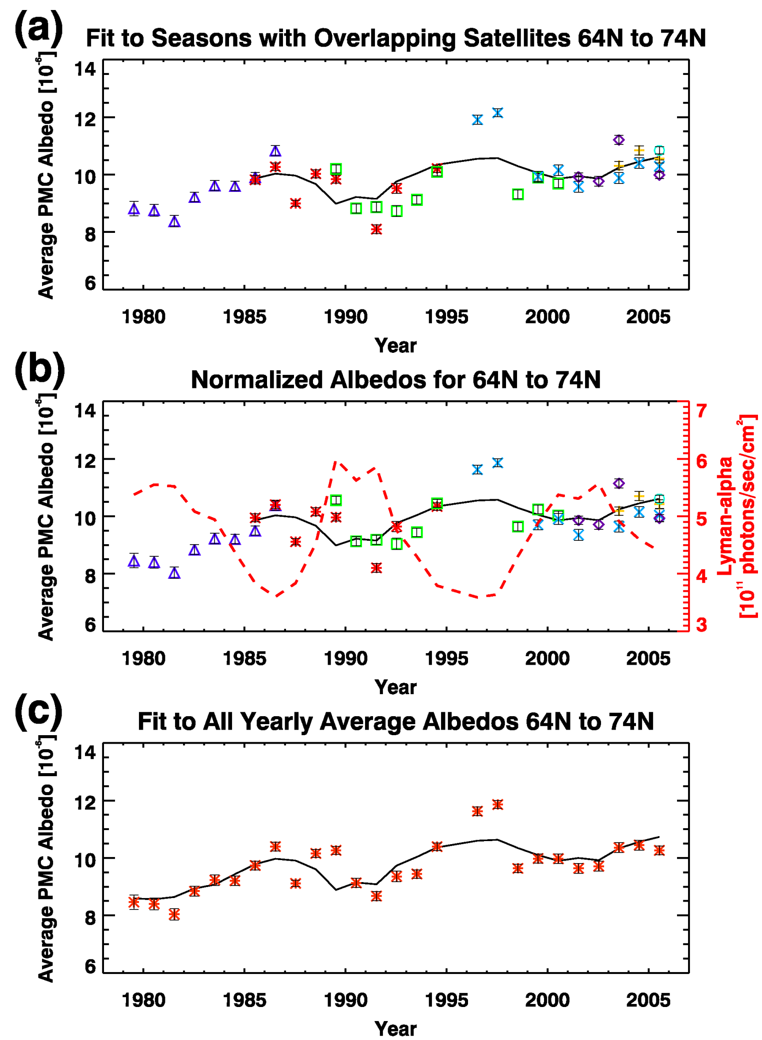


All SBUV Data - *Albedo*



SBUV PMC Trend Analysis

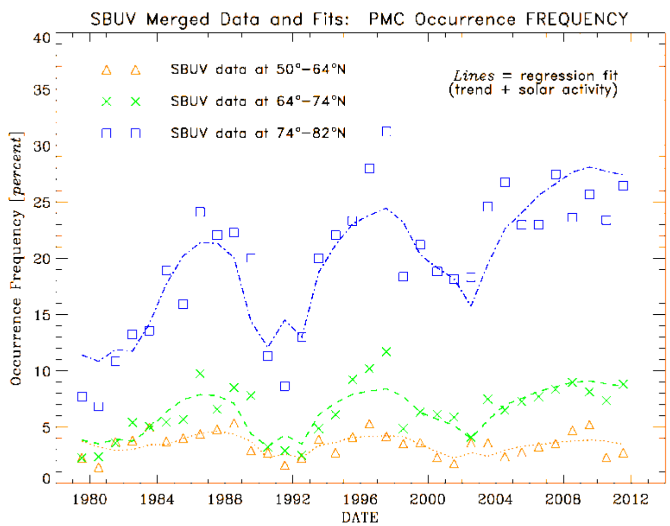
- Reference level established using multiple regression fit to period with overlapping instruments in each year (1985-2011).
- Derive overall normalization factor for each instrument before averaging within each season.
- **Scaling factors** can be <u>calculated</u> separately for each latitude band (*2007, 2009 papers*) or <u>fixed</u> based on single band (*e.g.* 50°-82°) and applied consistently to all latitudes. Can also apply <u>no</u> scaling adjustment.



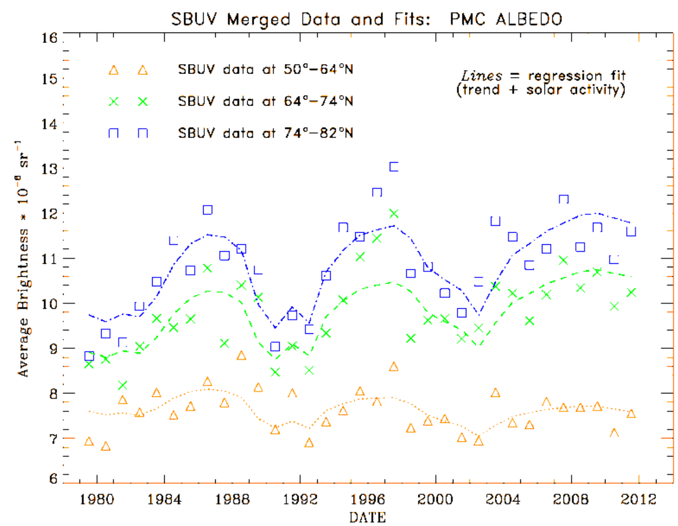
DeLand *et al.* [2007], Shettle *et al.* [2009]

Merged Data+Fits – *One Case*

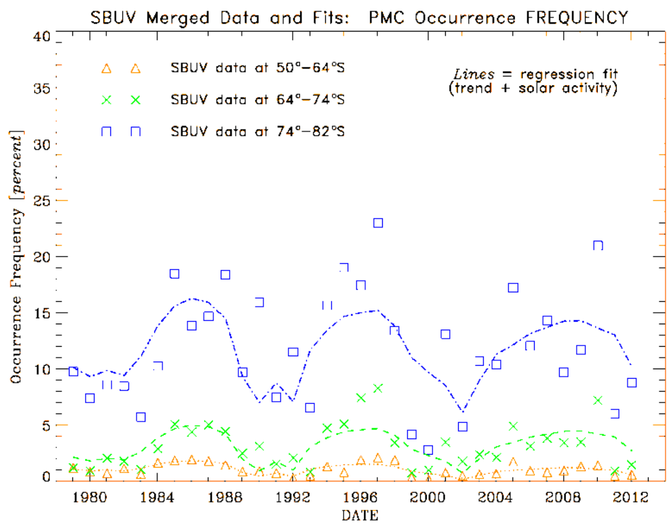
Frequency NH



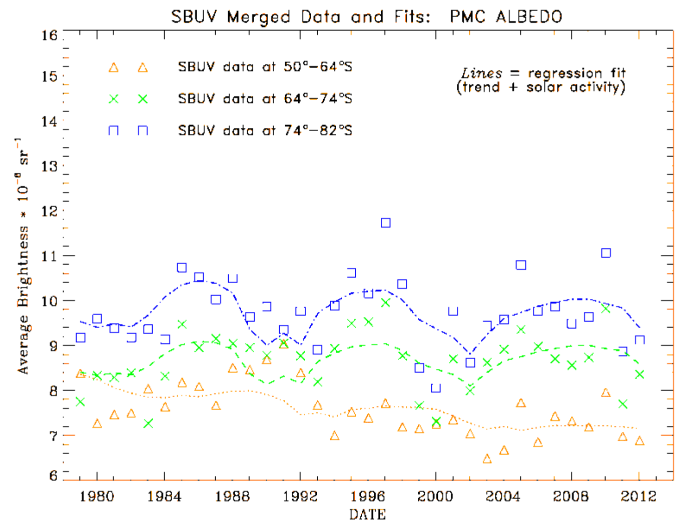
Albedo NH



Frequency SH



Albedo SH



Trend Values – *One Case*

Latitude	Frequency			Albedo		
	A(±dA) [%/dec]	*Corr.*	*Lag*	*A(±dA)* [%/dec]	*Corr.*	*Lag*
50-64 N	***–12.3(±5.1)***	–0.06	1.0	***–2.4(±1.1)***	–0.10	0.5
64-74 N	6.0(±4.6)	0.48	0.5	**1.6(±1.2)**	0.47	0.5
74-82 N	**13.2(±3.3)**	0.68	0.5	1.4(±1.1)	0.48	0.5
50-82 N	**10.7(±3.5)**	0.62	0.5	**2.1(±1.1)**	0.53	0.5
50-64 S	***–28.9(±6.5)***	–0.20	0.0	***–4.9(±1.2)***	–0.54	2.5
64-74 S	*–10.8(±9.2)*	0.14	0.0	*–0.8(±1.3)*	0.12	0.0
74-82 S	***–9.4(±6.8)***	0.05	0.0	***–2.2(±1.3)***	–0.01	0.0
50-82 S	***–10.4(±6.9)***	0.06	0.0	***–2.1(±1.2)***	–0.03	0.0

$$X = A^*(\text{Year} - 1979) + B^*(\text{Lyman-}\alpha - \text{lag}) + C$$

- Latitude-dependent local time adjustment applied.
- Calculated scale factors at each latitude band used for merging satellites.
- Albedo values normalized to $\theta = 130°$.
- Fit coefficients normalized to average of full time series.
- **Bold** = statistically significant trend (95%) using *DeLand et al*. [2007] formula.

Possible Reasons for Changes in Trend Values

- Change in detection threshold (latitude-dependent → scattering angle-dependent).
- Change in length of season used for trend analysis.
- Accuracy of (revised) local time dependence adjustment functions. This includes change from semi-diurnal function to diurnal-only function.
- Scaling factors used to merge multiple satellites within single season. This includes actual value and choice of method.
- Addition of "flat" recent data to linear regression fit (also affects scaling factors).
- Screening of detections for high residual ratio.
- *Other items?*

Model Temperature Trends

- Results from LIMA model studies suggest inflection point in mesospheric temperature trends.
- Derive trends from SBUV PMC data using multiple regression fits and two segments (each covering 1+ solar cycles).
- Large variations in PMC frequency and albedo during 1996-2000 means that calculated trends are likely to be sensitive to choice of break point.

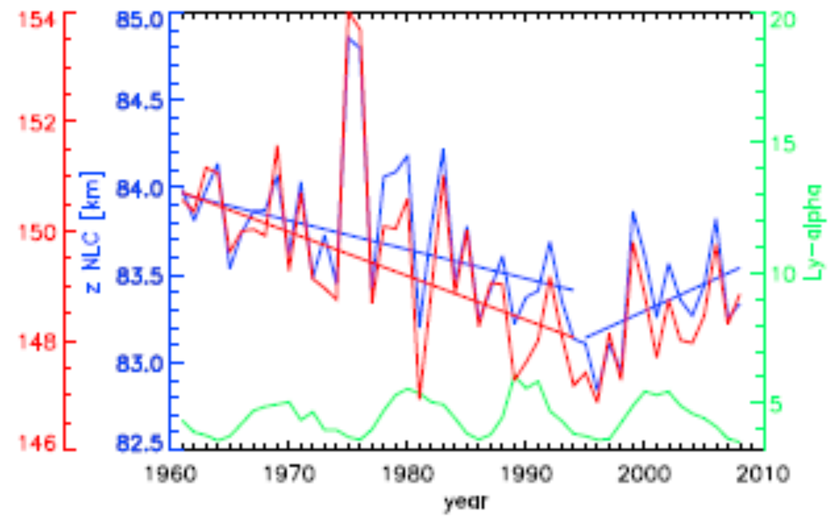


Figure 4. Time series of zonal mean July (1–31) temperatures (red) at 83 km and seasonal mean (6 June to 21 July) centroid NLC heights (blue) at 69°N. The straight lines indicate linear fits. The 1975/1976 data points have been ignored when calculating fits. The solar cycle variation of Ly-α radiation is also shown (green line, right axis in 10^{11} photons/(cm^2 s^{-1})).

Lűbken *et al.* [2009]

Trend Results – *Segments*

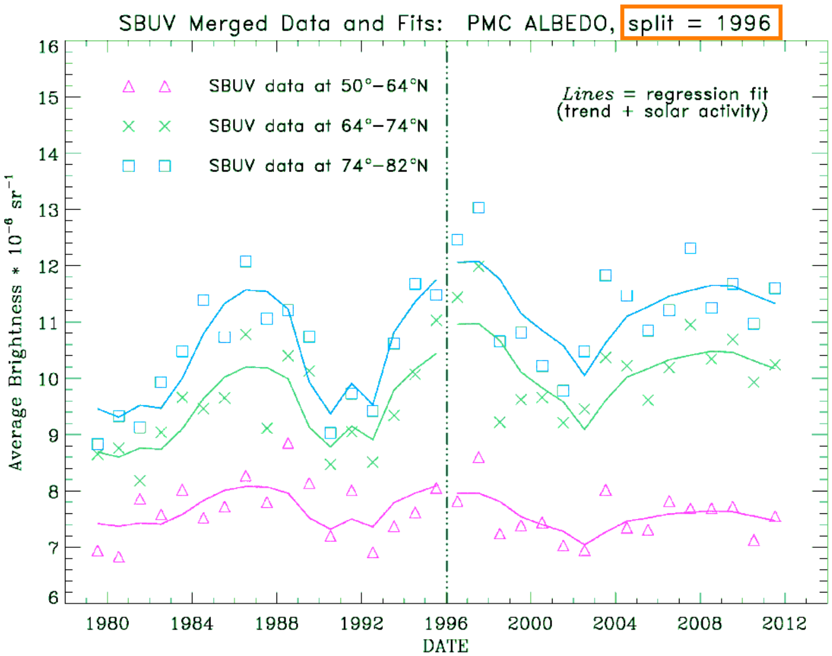
Latitude	**1979-1995**			**1996-2011**		
	A(±dA)	*Corr.*	*Solar*	*A(±dA)*	*Corr.*	*Solar*
50-64 N	0.8(±2.6)%/dec	0.20	10.9%	*−4.1(±2.6)%/dec*	−0.15	11.2%
64-74 N	**4.1(±3.2)%/dec**	0.41	17.9%	***−4.8(±3.3)%/dec***	−0.07	17.8%
74-82 N	**3.7(±2.9)%/dec**	0.40	24.2%	*−3.9(±3.0)%/dec*	−0.02	17.8%
50-82 N	**4.4(±3.0)%/dec**	0.44	21.9%	*−3.7(±3.1)%/dec*	−0.02	16.3%

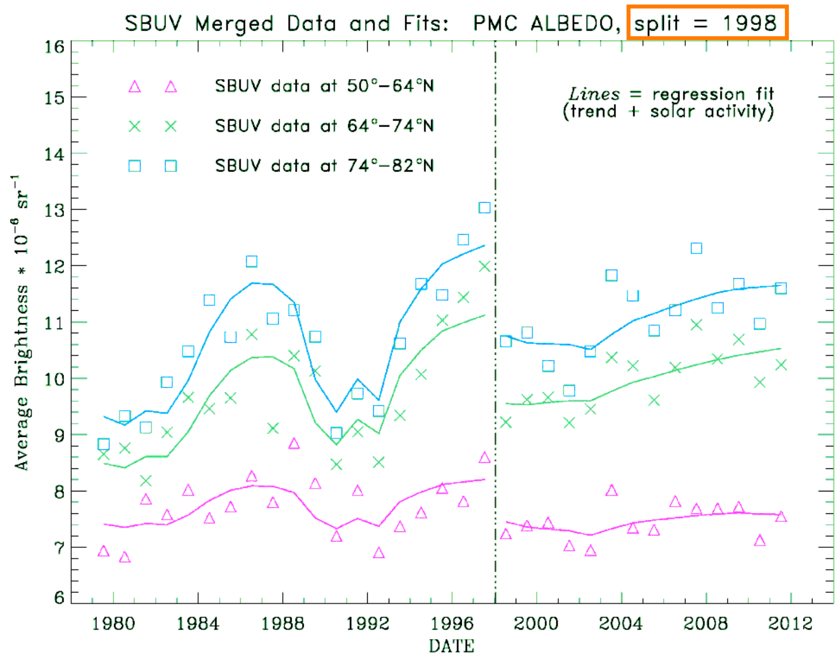
Latitude	**1979-1997**			**1998-2011**		
	A(±dA)	*Corr.*	*Solar*	*A(±dA)*	*Corr.*	*Solar*
50-64 N	1.1(±2.4)%/dec	0.32	11.0%	1.2(±4.7)%/dec	0.34	4.7%
64-74 N	**6.8(±2.8)%/dec**	0.62	20.0%	**7.4(±5.2)%/dec**	0.69	3.2%
74-82 N	**5.3(±2.6)%/dec**	0.59	25.3%	**5.9(±4.8)%/dec**	0.60	6.0%
50-82 N	**6.4(±2.6)%/dec**	0.63	23.3%	**6.9(±4.8)%/dec**	0.62	3.5%

- **Albedo, Northern Hemisphere**.
- Latitude-dependent local time adjustment.
- Calculated scale factors at each latitude band.

Segment Fits – *Two Cases*

Albedo NH





Summary and Next Steps

- Scattering angle dependence has been implemented for SBUV PMC detection threshold.
- Evaluate phase function normalization of albedo for detected clouds.
- Revised local time dependence has different amplitude and phase. Current harmonic function varies with latitude, but not with time.
- Trend magnitude (and sign) can be affected by method used to combine data sets.
- Agreement between SBUV instruments is better at higher latitude.
- SH trends are generally smaller than NH trends.
- Less solar cycle signal since ~2000; why?
- Multi-part trend fit calculation just implemented. Results are sensitive to choice of break point.
- ***Any other suggestions?***

THANKS FOR YOUR ATTENTION!

Backup Slides

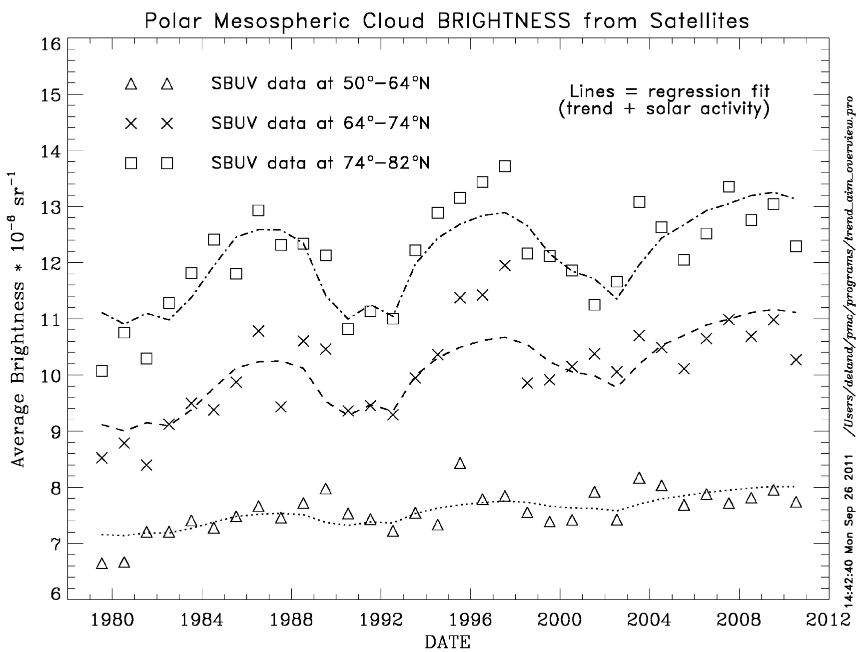
Trend Values – *Another Case*

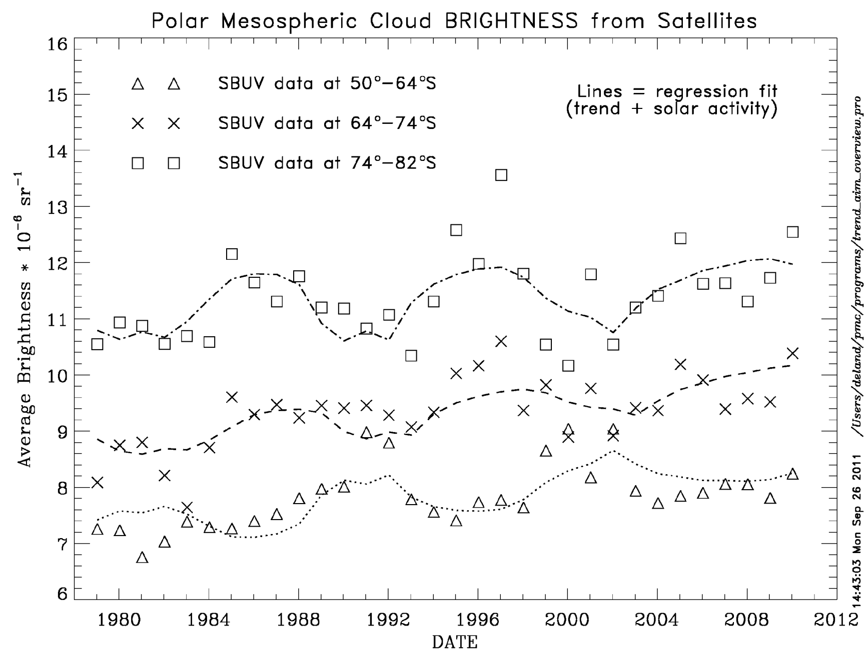
Latitude	Frequency			Albedo		
	A(±dA) [%/dec]	*Corr.*	*Lag*	*A(±dA)* [%/dec]	*Corr.*	*Lag*
50-64 N	*–1.3(±5.1)*	0.26	1.0	0.4(±1.1)	0.25	0.5
64-74 N	1.2(±4.6)	0.39	0.5	1.8(±1.2)	0.48	0.5
74-82 N	**12.2(±3.3)**	0.64	0.5	**2.6(±1.1)**	0.54	0.5
50-82 N	**9.7(±3.5)**	0.59	0.5	**2.9(±1.1)**	0.56	0.5
50-64 S	***–28.9(±6.5)***	–0.23	0.0	*–0.1(±1.2)*	0.07	2.5
64-74 S	*–4.9(±9.2)*	0.22	0.0	0.5(±1.3)	0.27	0.0
74-82 S	*–4.4(±6.8)*	0.16	0.0	*–0.4(±1.3)*	0.21	0.0
50-82 S	*–5.1(±6.9)*	0.18	0.0	*–0.2(±1.2)*	0.22	0.0

X = A*(Year - 1979) + B*(Lyman-α – lag) + C

- Latitude-dependent local time adjustment applied.
- No scaling used for merging satellites.
- Albedo values normalized to θ = 130°.
- Fit coefficients normalized to average of full time series.
- **Bold** = statistically significant trend (95%) using *DeLand et al*. [2007] formula.

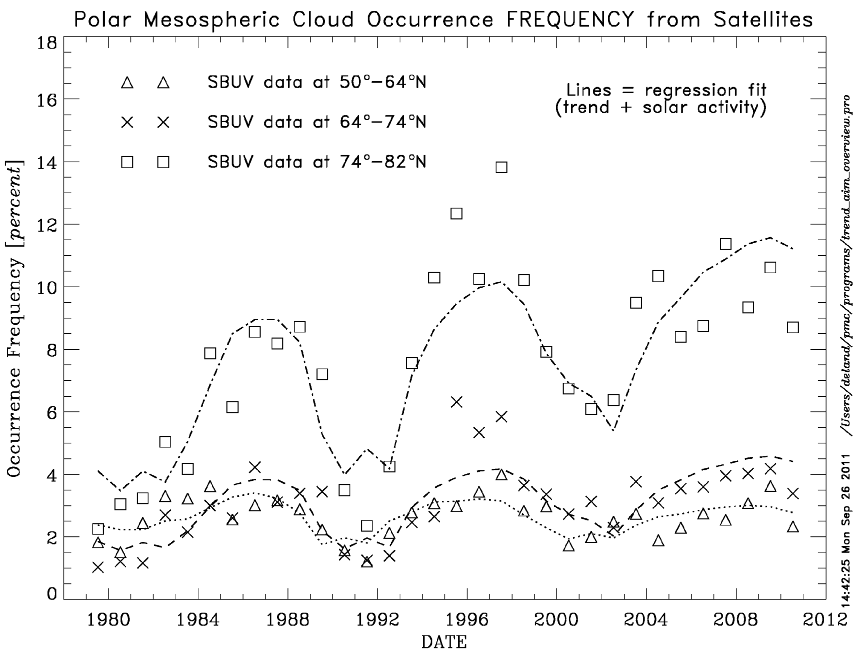
Current Data - Brightness

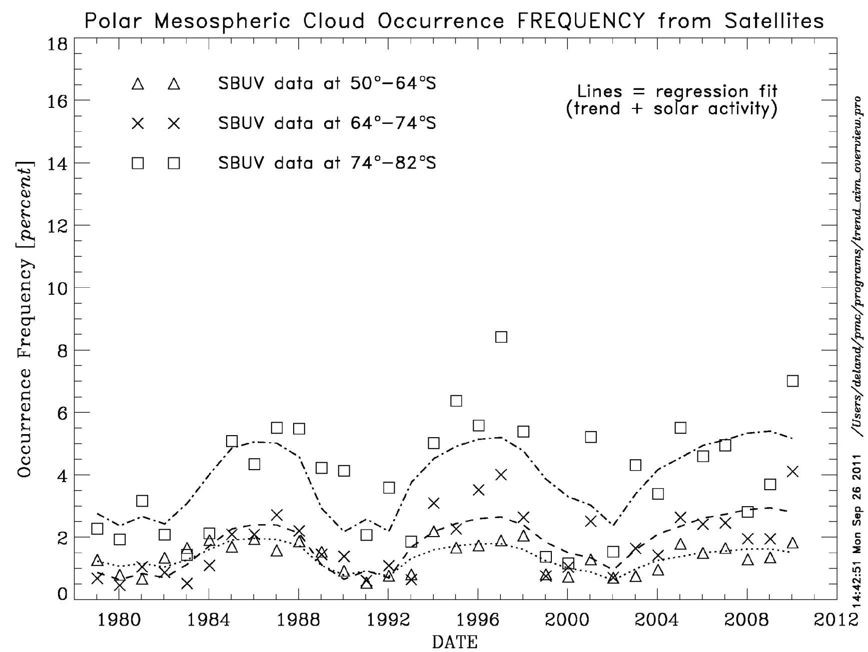




- Figures extended through NH 2010, SH 2009-2010 seasons.
- Brightness lower in SH, trends are smaller.
- All NH bands have statistically significant trends. SH trends are only significant at 50-64 and 64-74.
- Positively correlated solar term at 50-64 S has low correlation coefficient ($R_{solar} = 0.19$).

Current Data - Frequency

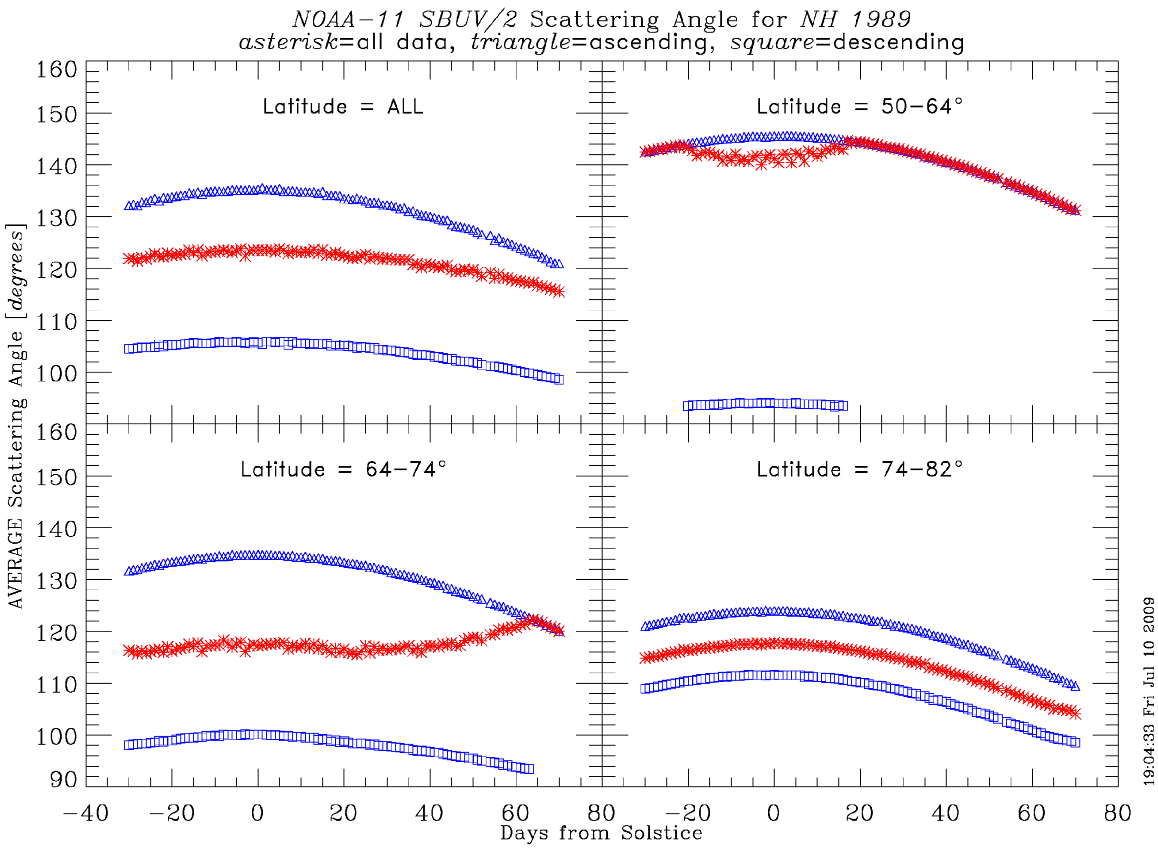




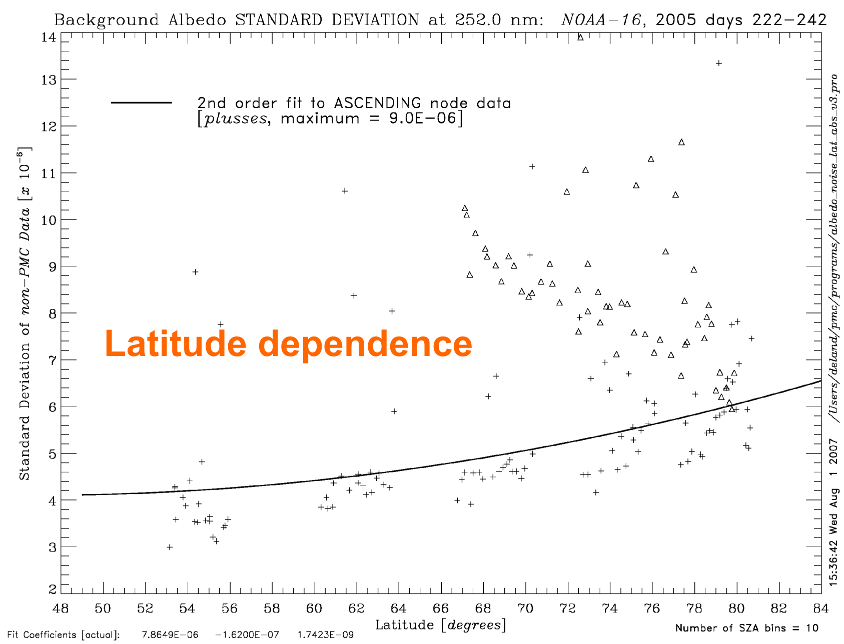
- Occurrence frequency values are larger in NH (DSS = [-30,+70]).
- SH trend analyses were not presented in *Shettle et al*. [2009] paper due to difficulties in establishing local time adjustment.
- Calculated trends at 50-64 N and 50-64 S are negative and significant, but with low correlation coefficient (R_{time} < 0.2).

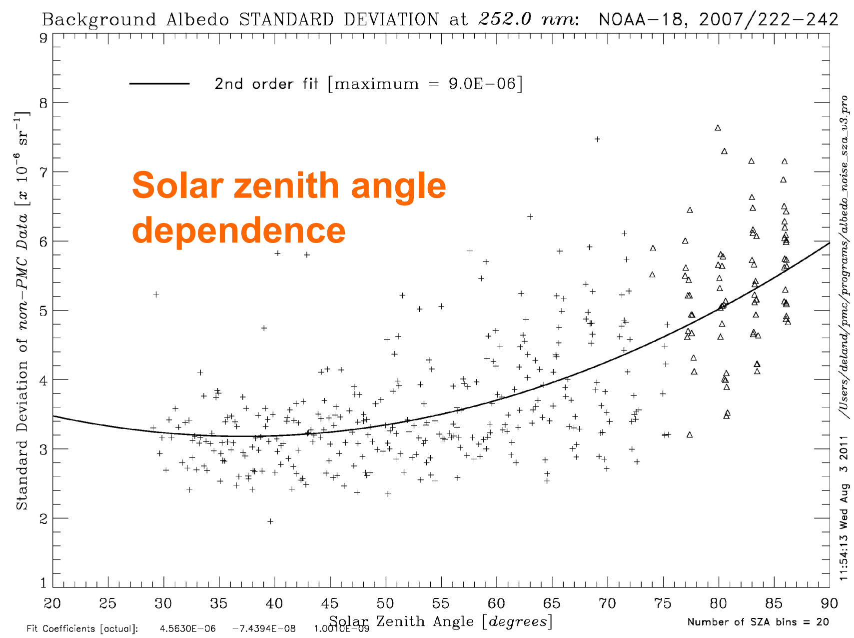
Scattering Angle Variation

- Scattering angle has modest variations during season, larger range within latitude band.
- Orbit drift has small effect on average SCA, larger effect on sampling.
- Impact on trend analysis depends on shape of ice phase function at $\theta = 100°\text{-}140°$.



Background Noise

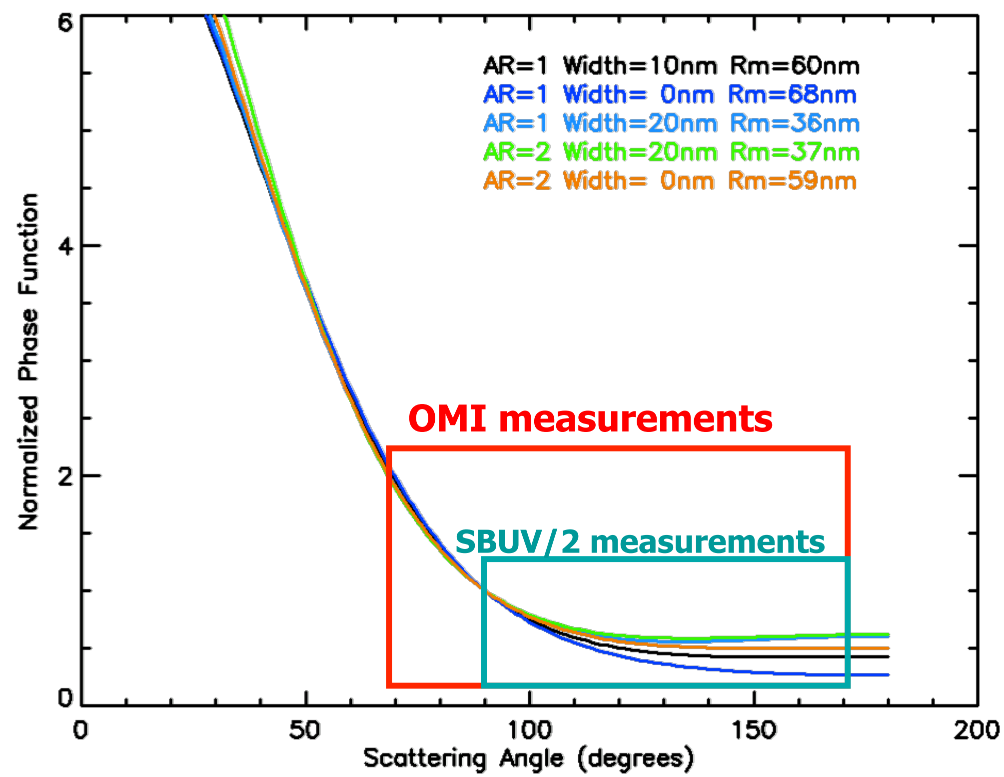




- Assume that albedo variability outside main PMC season (DSS = [+50,+70] represents background noise for PMC detection.
- Current algorithm parameterizes variation *vs*. latitude to capture ozone changes and zonal mean symmetry. Only ascending node data used in fit.
- These measurements can also be fit *vs*. solar zenith angle.

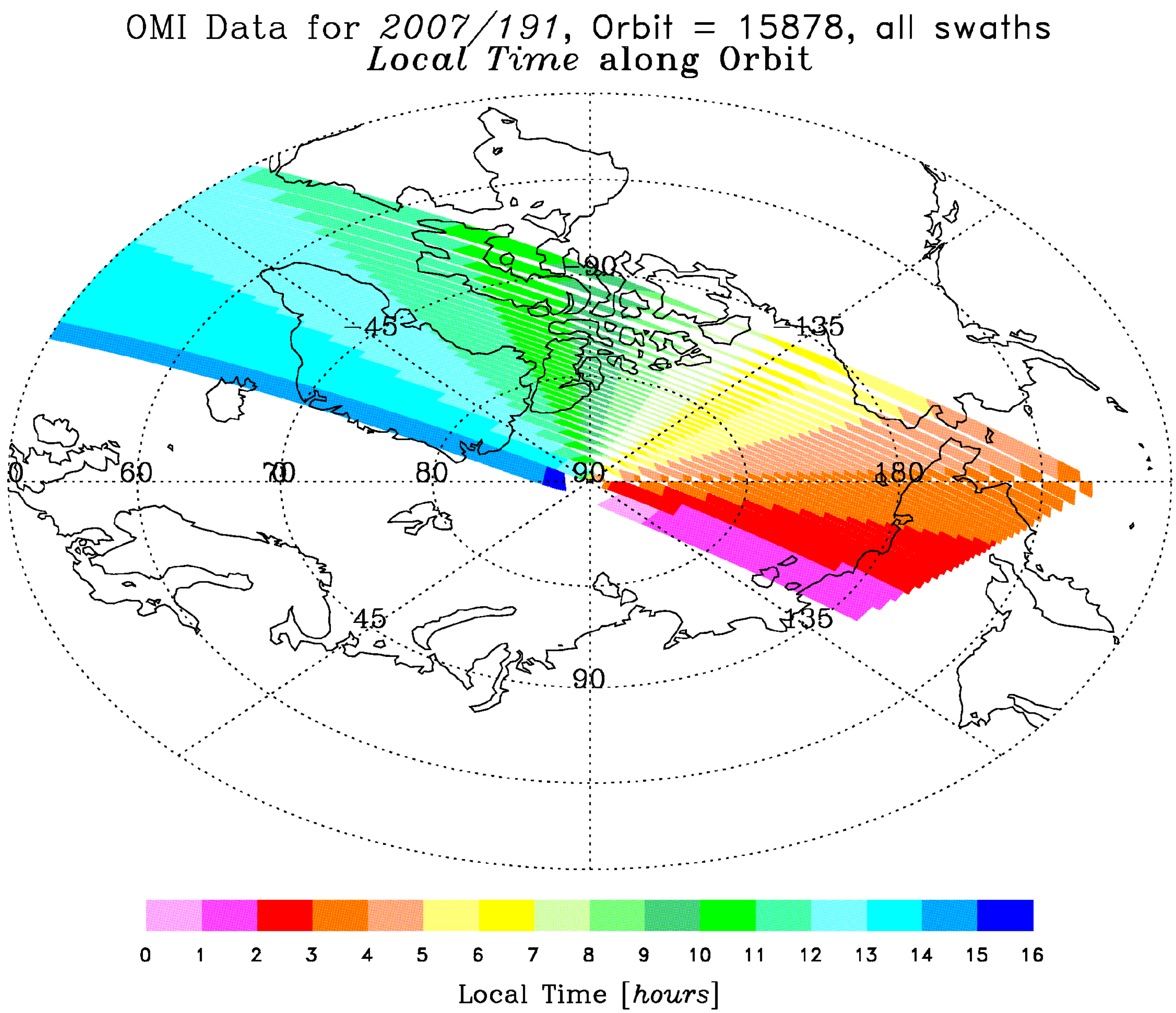
Scattering Angle Matters!

- PMC particles governed by Mie scattering for UV instruments → large asymmetry in scattering phase function.
- OMI has forward scattering in off-nadir swaths → more sensitivity to details of function.
- Appropriate function depends on distribution of particles (mean radius, shape, width, aspherical effects).
- CIPS data (emphasizing small scattering angles) shows variability within every orbit.



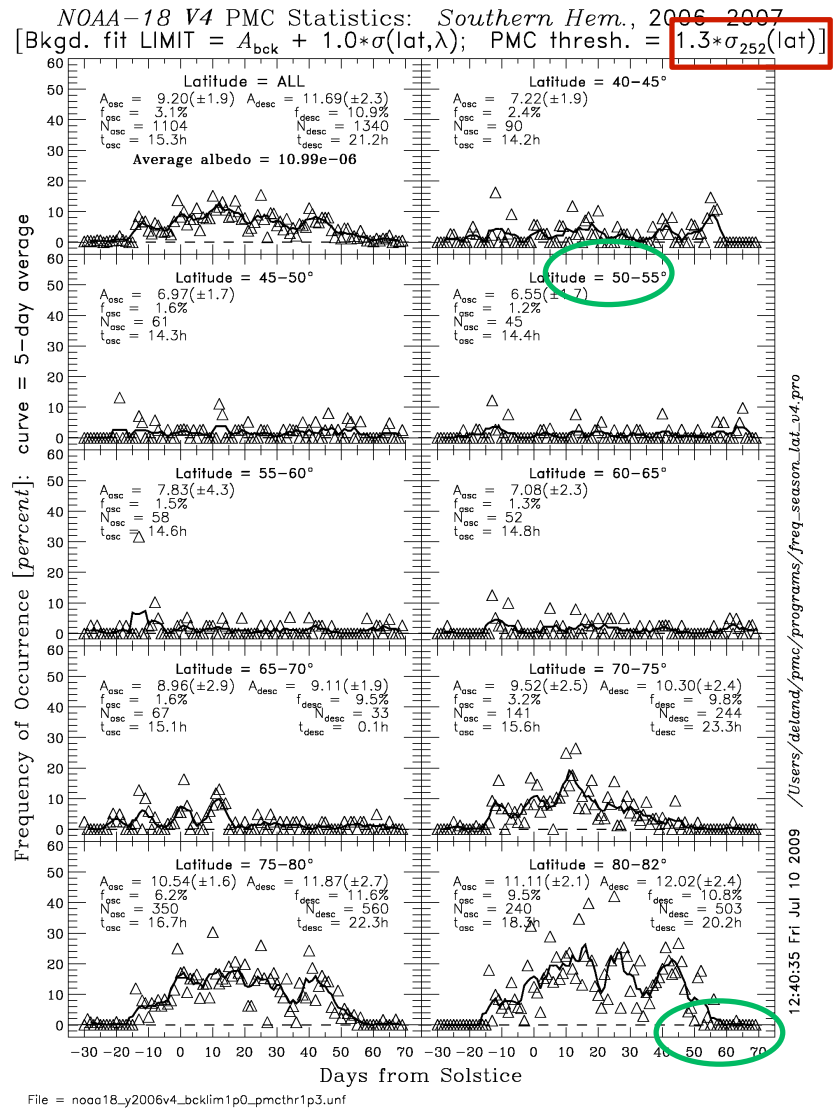
Bailey et al. [2009]

OMI Data – *Local Time*

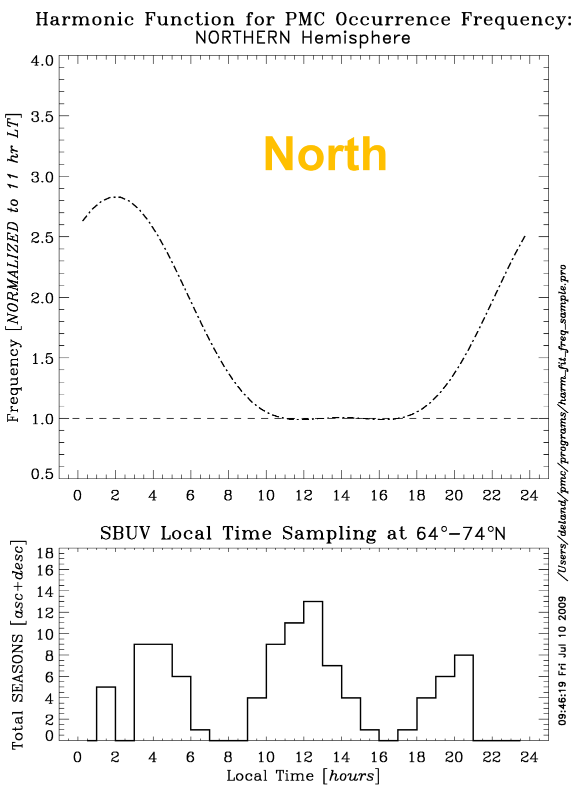


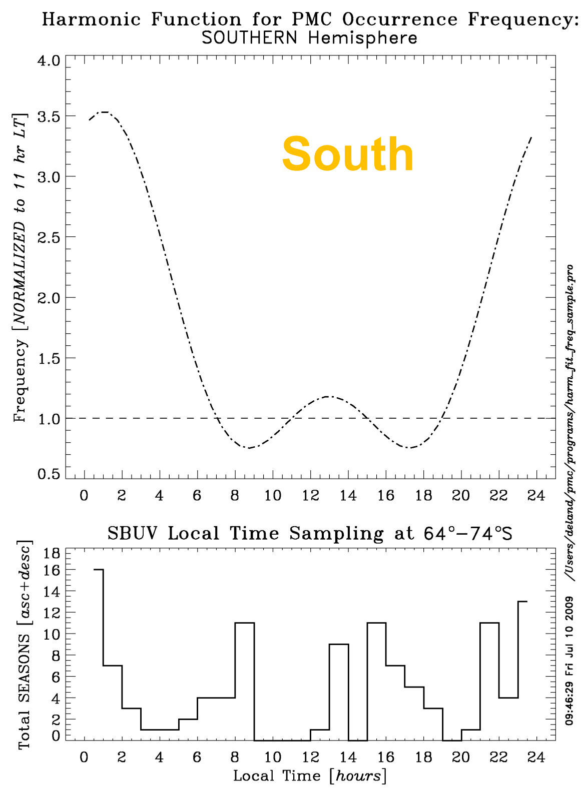
Threshold Scaling

- SBUV only sees bright PMCs → expect few detections at low latitudes, start/end of season.
- Scale detection threshold to achieve these results.
- Reducing scaling value gives higher occurrence frequency, lower average albedo for seasonal and zonal averages.



Local Time – Trend Impact



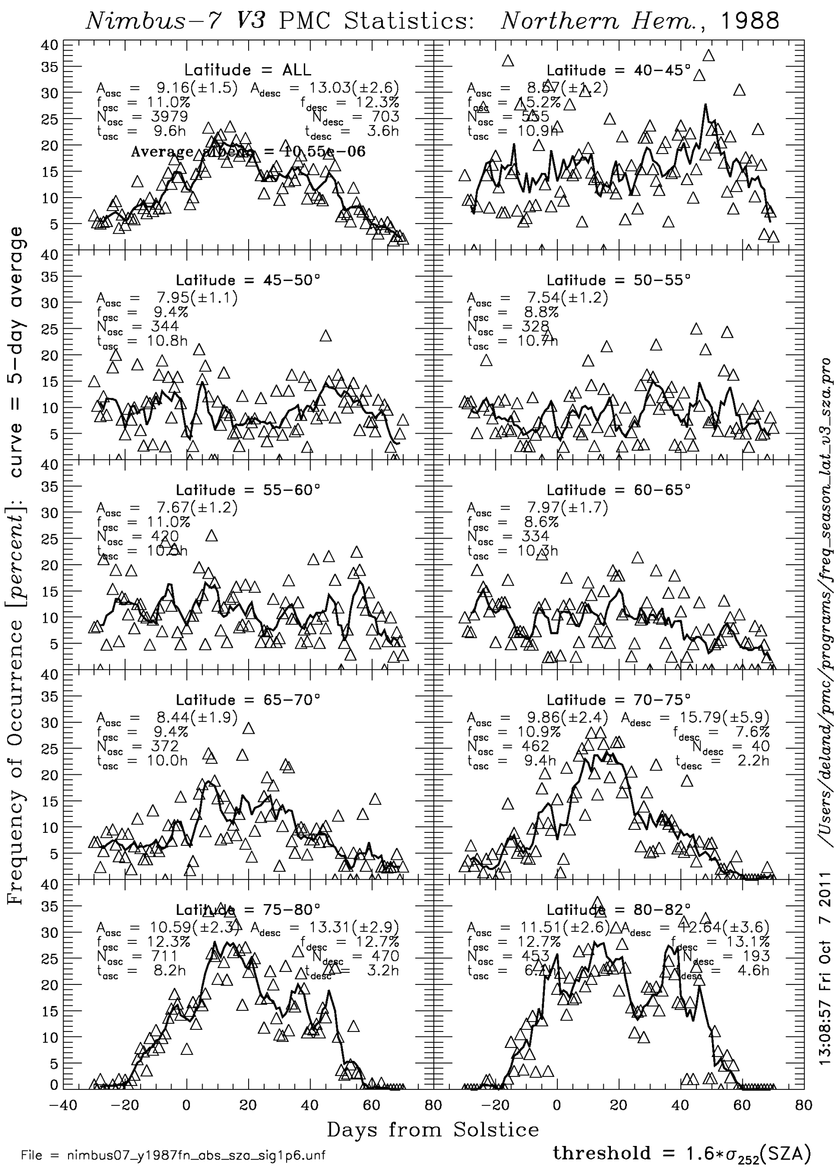


- Many NH seasons occur where normalized LT adjustment is small.
- More SH seasons occur near maximum of LT adjustment function.
- Frequency adjustments are larger (relative to long-term change) than albedo adjustments.

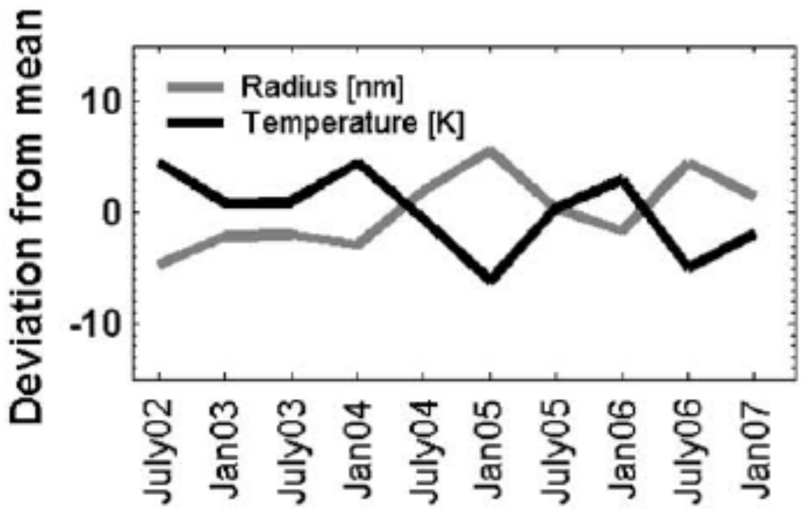
Combine Multiple Data Sets

- Use all seasonal average data as is (*many years have multiple instruments*).
- Average seasonal values within each year (*what about instrument bias?*).
- Normalize data to reference instrument (*requires chain for full trend period*).
- Normalize data to reference level (*how to define?*).

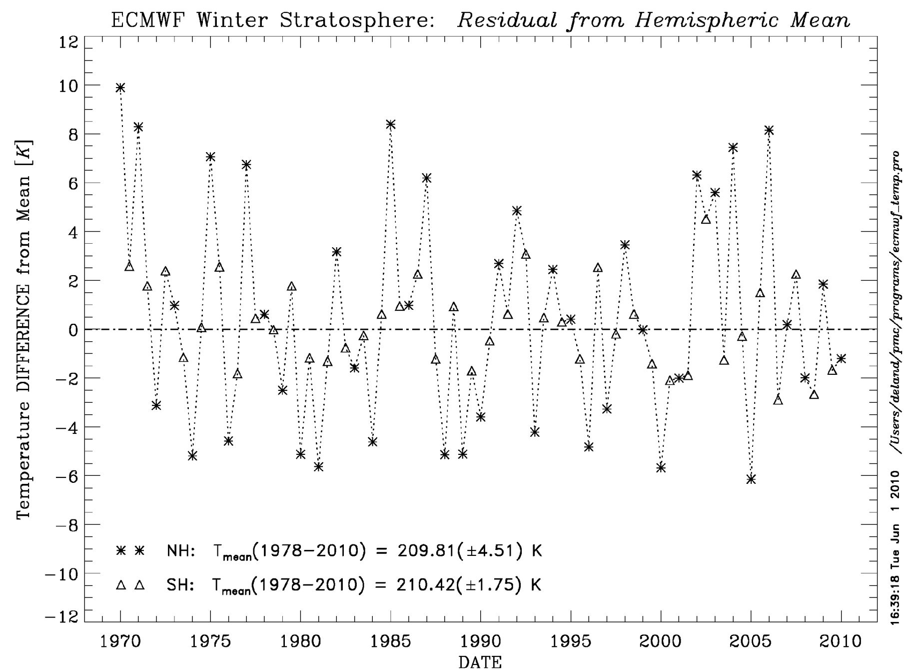
Nimbus-7 Non-Sync Data



Interhemispheric Forcing



Karlsson *et al.* [2007]



- Interhemispheric forcing shown to explain significant interannual variability in OSIRIS data.
- Extended time series of temperature data has been created for SBUV use, but not applied for trend results discussed here.
- Residual formulation will not affect trend values.