International Space Station diurnal sampling studies

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International Space Station (ISS) orbit

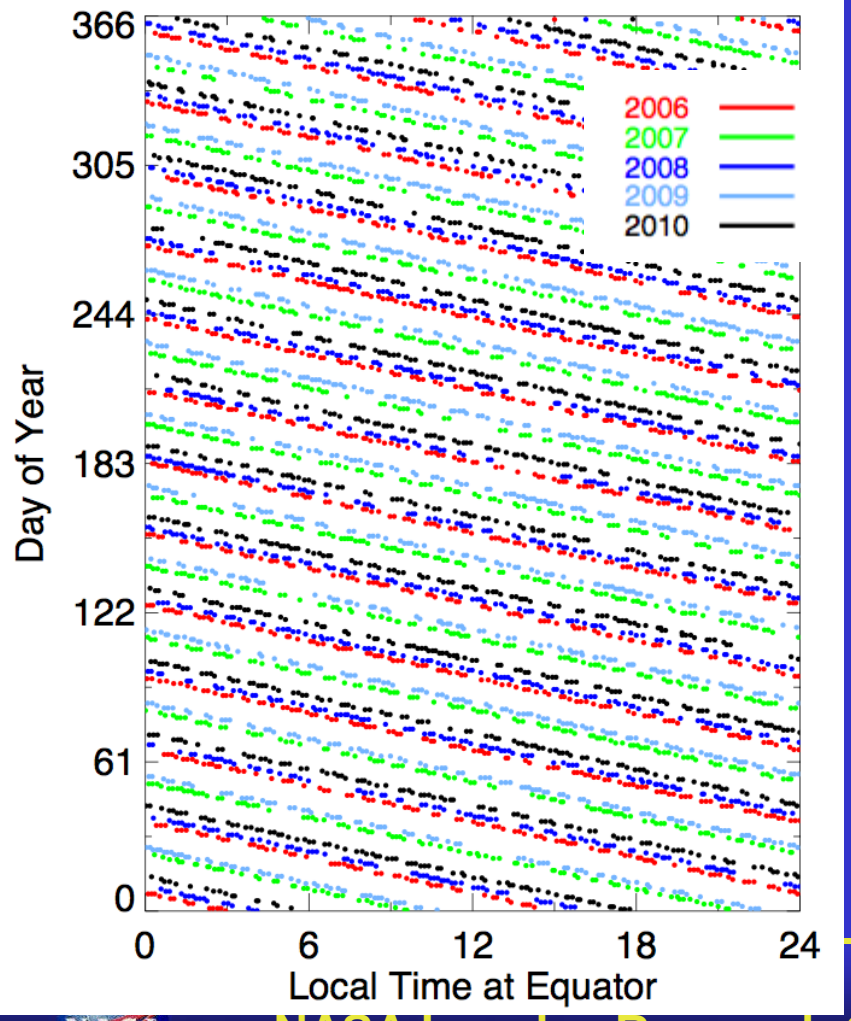
- ISS is in a precessionary orbit that is occasionally maintained for altitude of ~ 400 km and an inclination of 51.5˚ unable to provide global coverage
  - The orbit is not repeated from year to year
- Can CLARREO instruments onboard the ISS provide the sampling necessary for benchmarking?
  - ISS offers a launch vehicle and bus, keeping precious dollars for instrument development
  - These missions are also of short duration (~2years)
- Previous ISS zonal annual mean sampling studies conclude
  - SW sampling needs annual repeatable orbit
  - LW sampling is sufficient on SS, precessionary, and ISS

Can the ISS sample the diurnal cycle?

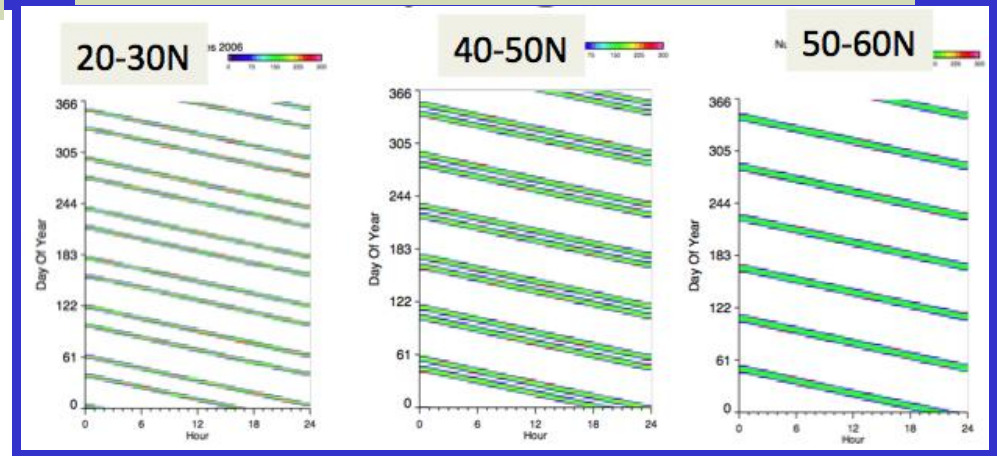
- Use 10-years (2000 to 2010) of hourly, 100km^2 gridded LW fluxes, cloud fractions, and cloud top pressures from the CERES SYNlite product
  - Merged CERES Terra+Aqua+3hourly 5-satellite GEO derived broadband fluxes and cloud properties
  - GEO LW fluxes are normalized to the CERES instrument calibration
  - GEO derived cloud properties are not normalized against MODIS
  - All fluxes and cloud retrievals are temporally interpolated hourly
- Use 9 2-year missions to evaluate statistics
  - Use the actual ISS ground track to determine space and time of nadir only sampling
  - Assume 100^2 km footprint, and 7 measurements per minute
- Compare the sampled parameter statistics to the truth
  - Simply average all measurement for a given bin

ISS sampling

Local equator crossing time



Sampling by latitude



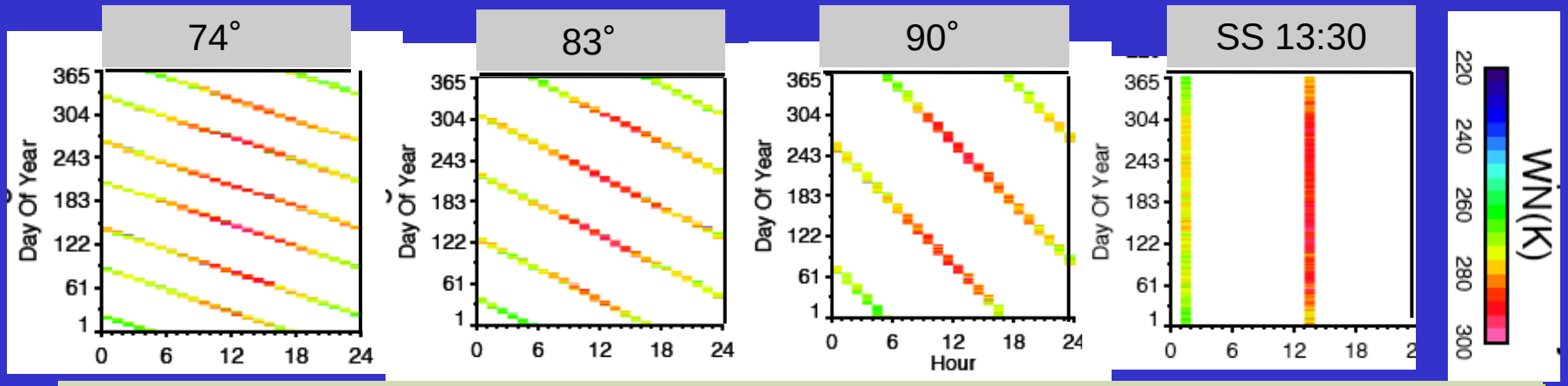
- ISS samples ~ 12 diurnal cycles per year
- ISS orbits do not repeat annually

CLARREO Examined Orbits

Orbit	74˚	83˚	90˚	98˚ (SS)
Diurnal cycles/year	6	4	2	0
Comments	92.5% coverage	98.5% coverage	Global coverage	A-train, JPSS No diurnal coverage

• The precessionary orbit has the advantage of sampling the diurnal cycle through out the year

WN local hour orbit sampling pattern for the 20˚ -30˚ zone over one year



• The inclination of the precessionary orbit determines the number of seasonal cycles sampled through out the year

Trend detection

- Time it takes to detect a signal above natural variability, with a signal to noise ratio of s

Leroy, J Climate 2008

Natural variability term

Measurement error term

$$\Delta t = \{[12s^2 / m_{est}^2]\sigma_{\text{var}}^2 \tau_{\text{var}}^2\} F_t$$

$$F_t = (1 + \sum f_i^2)^{1/3}$$

F_t is the factor that predicts the deviation from a perfect observing system
F =1 for perfect system, and F>1 for observing errors in sampling, calibration, etc.

$$f_i^2 = (\sigma_i^2 \tau_i) / (\sigma_{\text{var}}^2 \tau_{\text{var}})$$

Measurement error is expressed as a ratio between measurement error and natural variability

$$\sigma_i / \sigma_{\text{var}} = \sqrt{[F_t^3 - 1][\tau_{\text{var}} / \tau_i]}$$

Sampling error/natural variability

- Use Leroy τ_{var} = 1.5 years and τ_i = 1.0 years for annual anomaly studies
- If you allow sampling error to be 10% greater than the perfect observing system, then F_t = 1.1 and (σ_i/σ_{var}) = 0.70

F_t	1.02	1.05	1.10	1.20	1.50	2.00
σ_i/σ_{var}(%)	30	50	70	104	190	324

10° Zonal Inter-annual sampling error

Annual	ZONAL					
	SWrad (Wm-2sr-1)		Swflux (Wm-2)		LW (Wm-2)	
	σ_s/σ_{var} (%)	F_t	σ_s/σ_{var} (%)	F_t	σ_s/σ_{var} (%)	F_t
σ_{var} [SS]	.197		.657		.637	
SS 13:30	59	1.07	58	1.07	26	1.01
SS 13:30+10:30	42	1.04	41	1.04	16	1.01
σ_{var} [P90]	.192		.628			
P90-1	70	1.10	65	1.09	25	1.01
P90-2	35	1.03	33	1.02	16	1.01
P90-3	26	1.01	23	1.01	12	1.00

$0.640 Wm^{-2}$ = $0.194^{\circ}K$

- Adding a second satellite reduces the sampling ratio error by 50%, a third another 15%
- Single SS has a slightly reduced **SW** sampling error than on P90, but for two satellites, the P90 orbit is preferred
- All combinations of orbits have a very small F_t **LW** error <1.01 from perfect observing system

Sampling Error/Natural Variability ISS Table

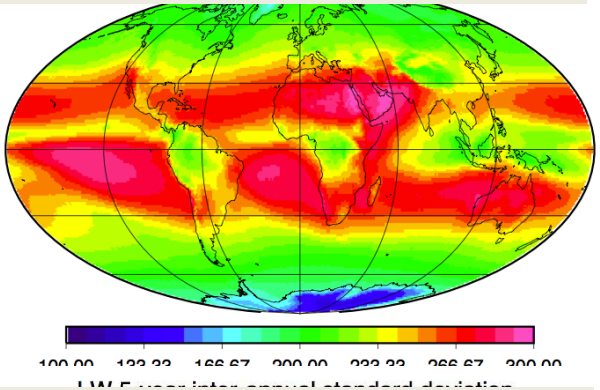
2006-2010 ISS sampling

RMS(SAMP)/TRUTH (%)				
ZONAL 60	Swrad	SWflx	LWflx	WNflx
Annual	98	128	27	29
Semi	111	155	23	27
Quarter	120	142	43	59
GLOBAL 60	Swrad	SWflx	LWflx	WNflx
Annual	109	209	22	19
Semi	154	313	23	24
Quarter	129	213	35	45
ZONAL 30	Swrad	SWflx	LWflx	WNflx
Annual	95	114	26	27
Semi	80	120	20	23
Quarter	78	98	28	38
GLOBAL 30	Swrad	SWflx	LWflx	WNflx
Annual	37	117	10	11
Semi	45	120	14	13
Quarter	66	134	15	15

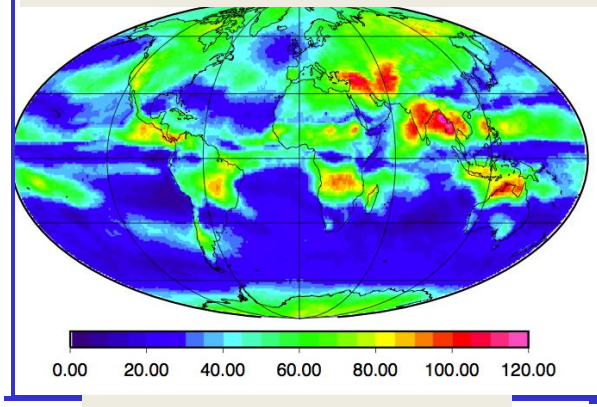
- The LW sampling results are similar to the SS and 90° precessionary (P90) cases
- The SW sampling results are greater than than SS and P90 (~70% for zonal)

LW flux natural variability (10-year)

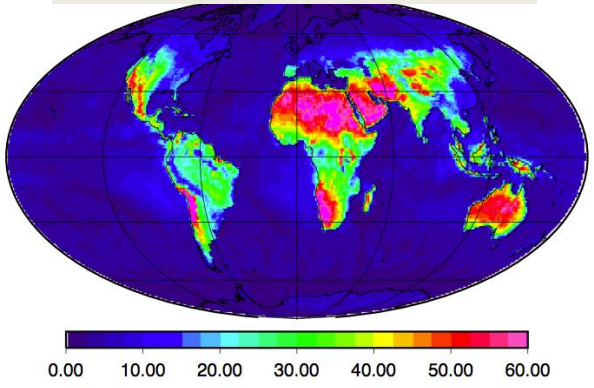
LW 5-year mean



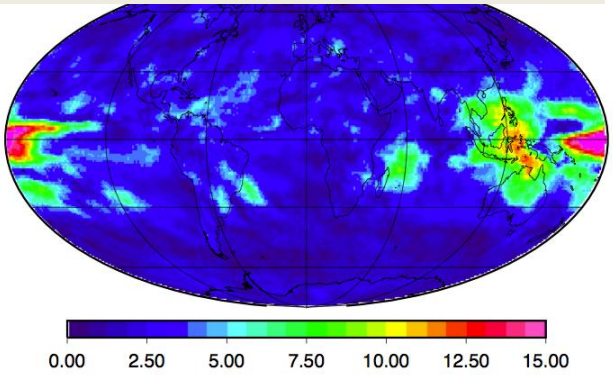
Seasonal Range



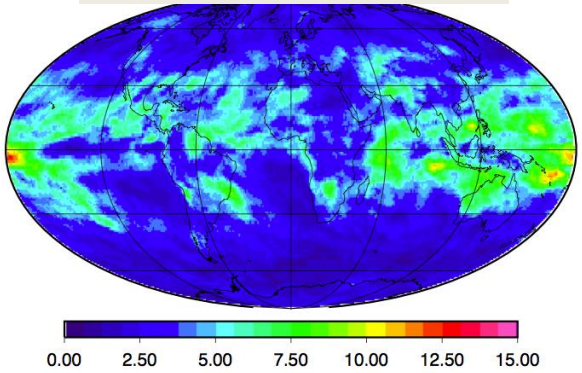
Diurnal Range



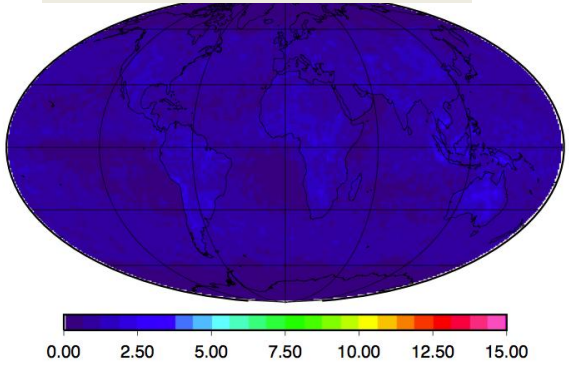
Inter-annual sigma



Seasonal sigma



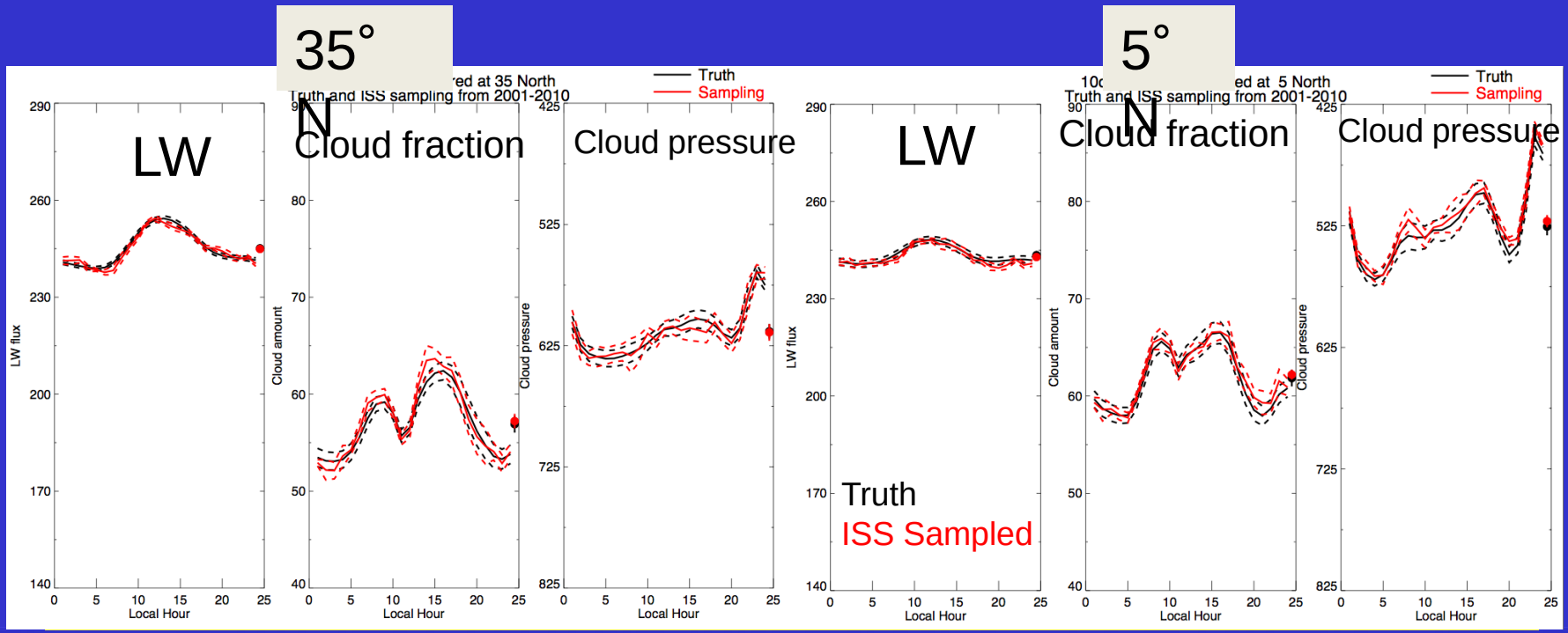
Diurnal sigma



- Can the ISS sample the diurnal cycle without seasonal cycle aliasing
- The greatest inter-annual cycle is the ENSO

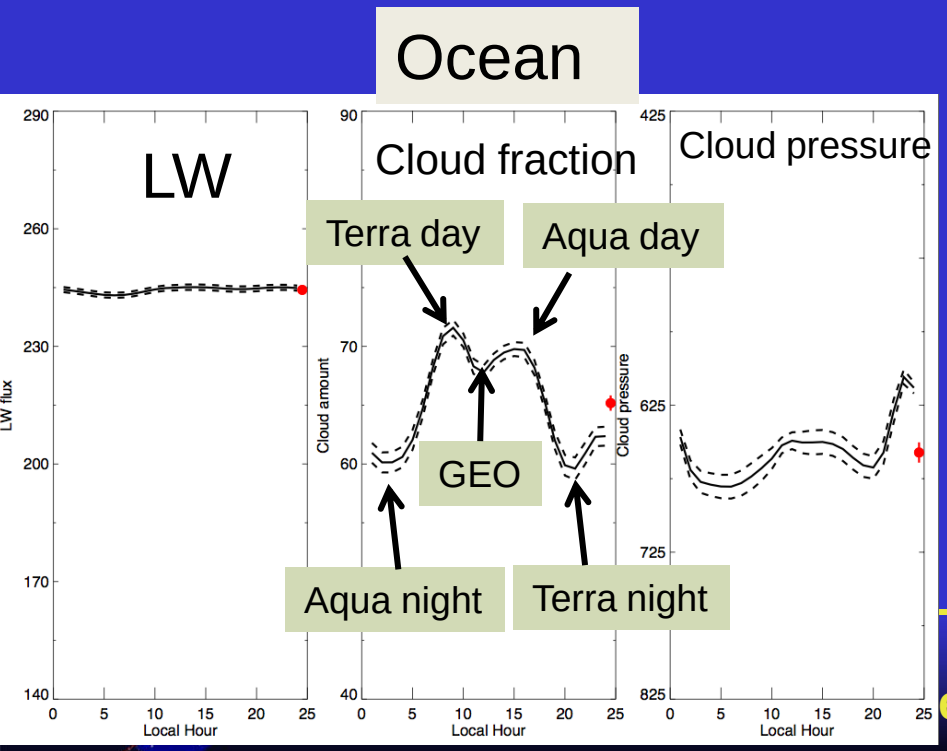
Bi-annual diurnal zonal ISS sampling

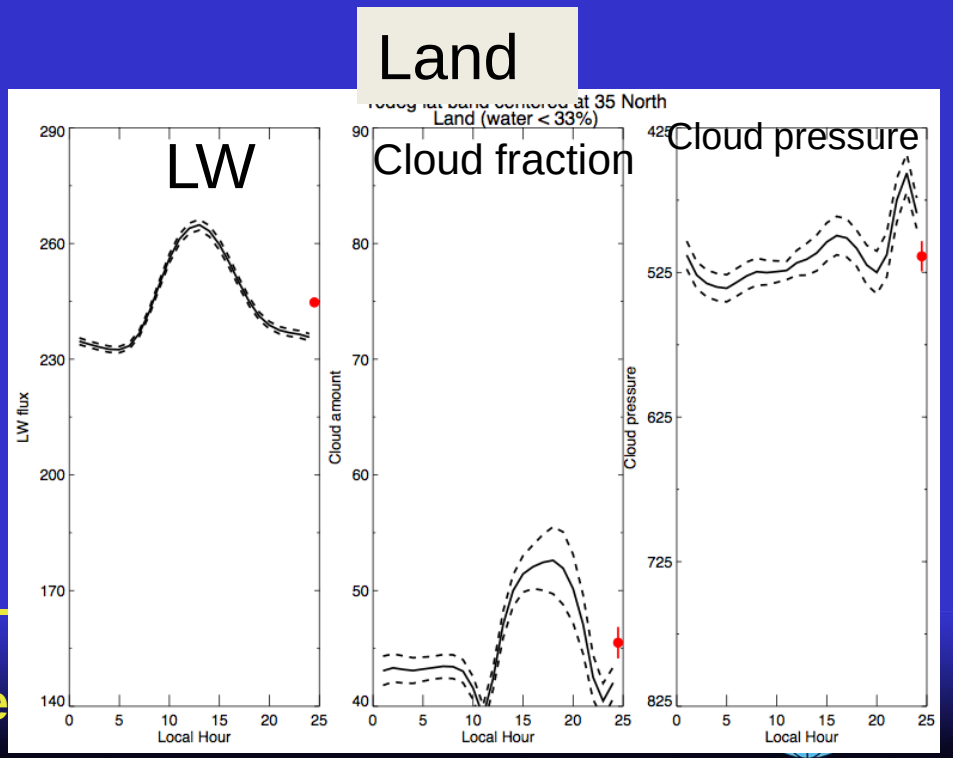
- 1-k error bars based on 9 2-year ISS datasets
- The bi-annual ISS sampling faithfully reproduces the truth dataset on a zonal spatial scale



Bi-annual diurnal zonal ISS sampling

- The truth cloud fraction and cloud top pressure diurnal signal maybe caused by cloud retrieval artifacts
- The LW flux has been normalized with CERES measurements
- Although the cloud diurnal signal may not reflect nature, the ISS sampling still reproduces the signal





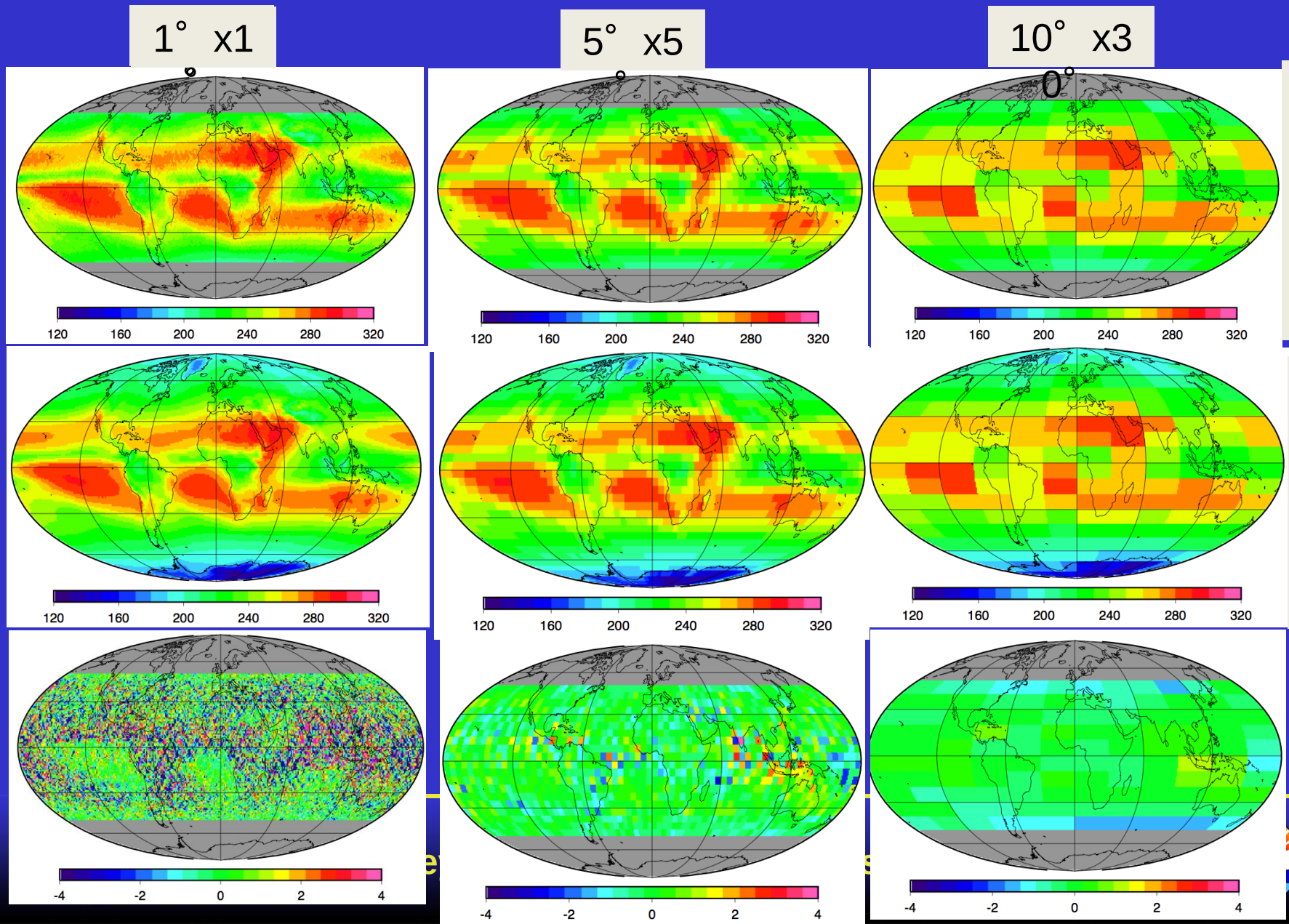
Examine higher spatial scales

- Large spatial scales can be confidently sampled with LEO satellites
- How much information can retrieved at higher spatial scales?
  - Many small scale spatial features are lost at the 10˚ by 30˚ regional level

region	Truth, hours/year	ISS obs/year
10˚ zonal	31536000	109500
10˚ by 30˚ lat/lon	2628000	9125
5˚ by 5˚	219000	760
1˚ by 1˚	8760	30

The ISS sampling/truth ratio = 1/288

LW mean

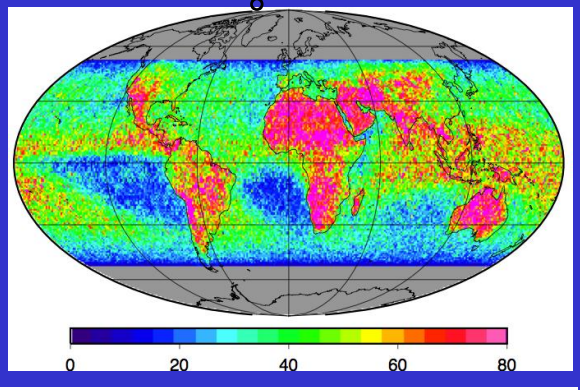

1° x1°
5° x5°
10° x3°
ISS sampled
truth
difference
120 160 200 240 280 320
-4 -2 0 2 4

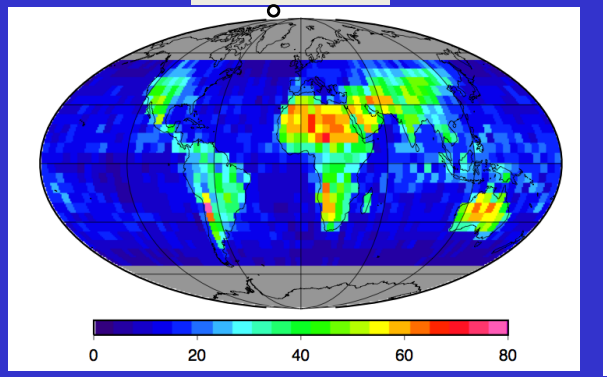
LW range

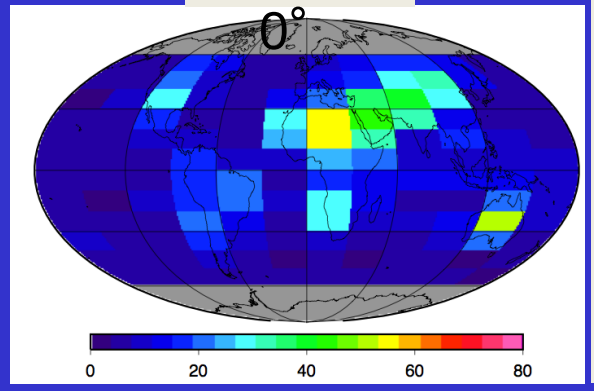
1° x1

5° x5

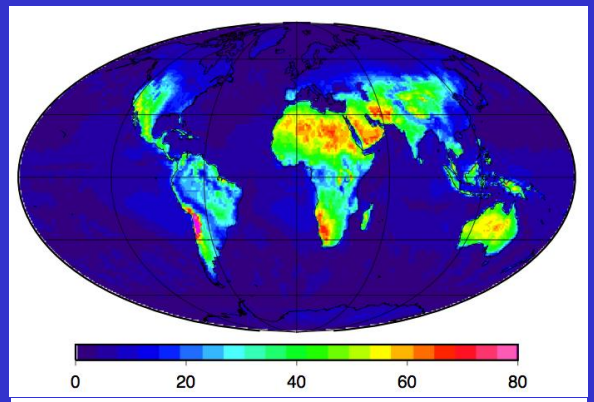
10° x3

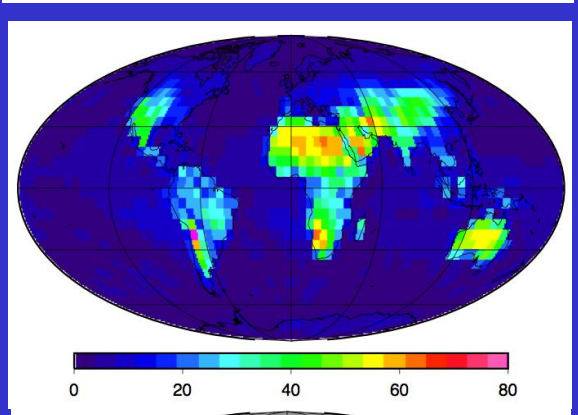


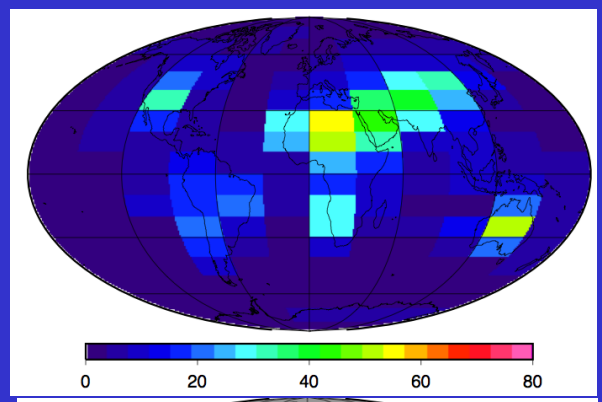




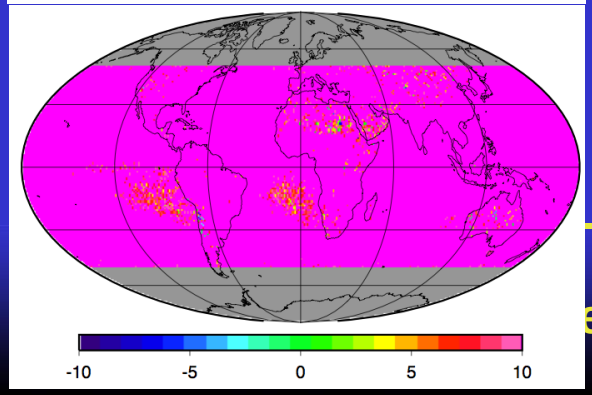
ISS sampled

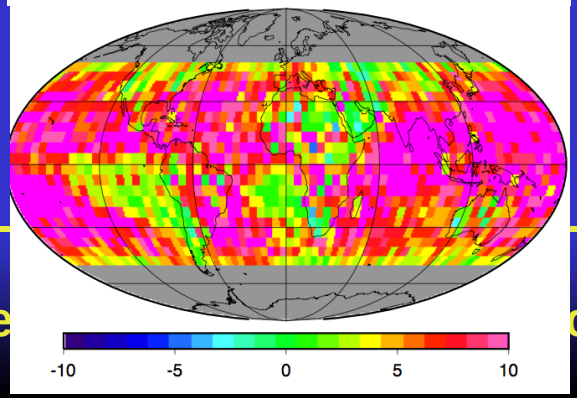


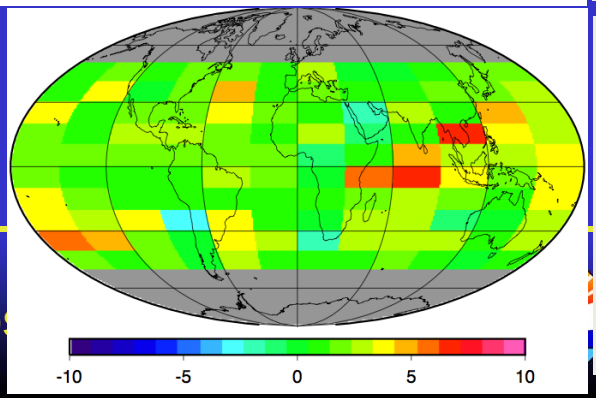




truth







difference

LW range

5° x5° 1hr steps

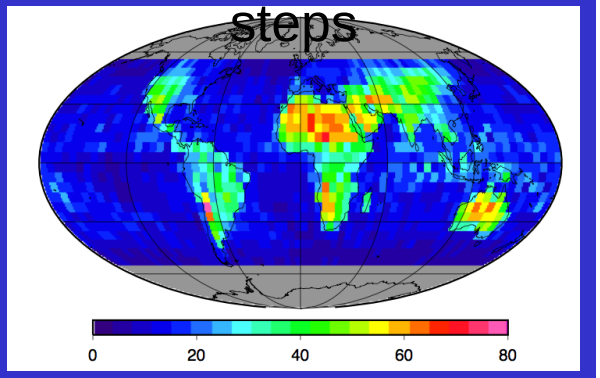
5° x5° 3hr steps

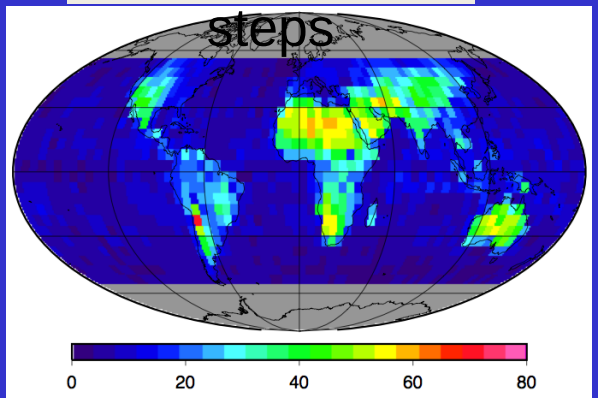
10° x3 0°

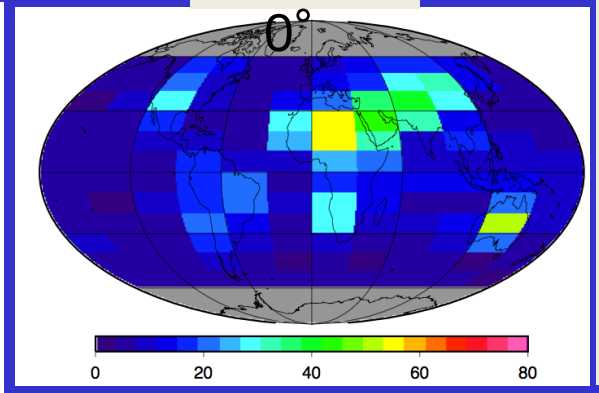
ISS sampled

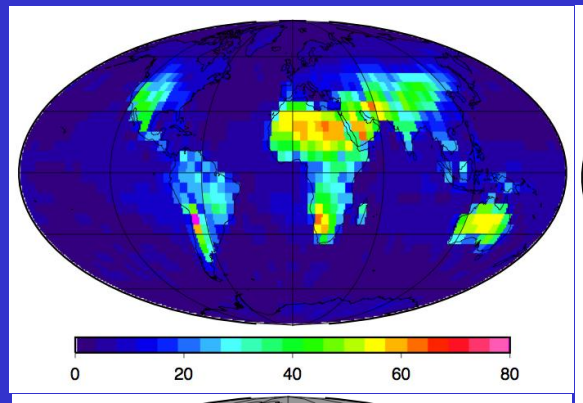
truth

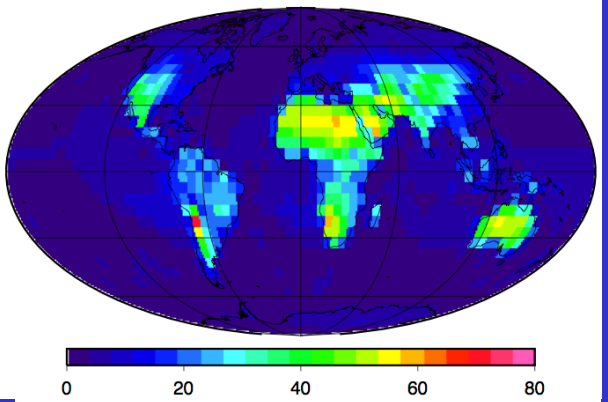
difference

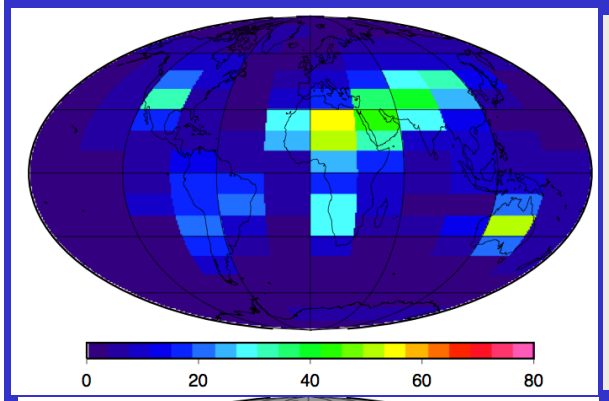


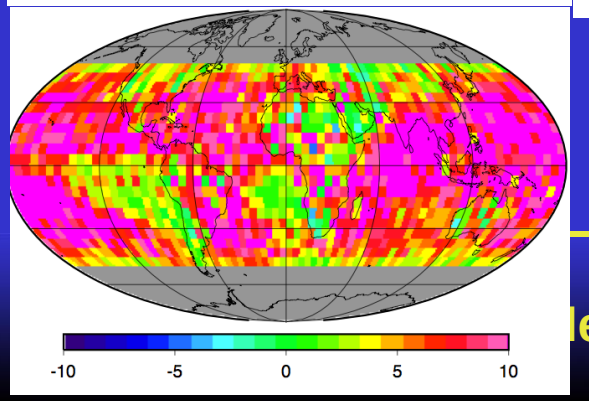


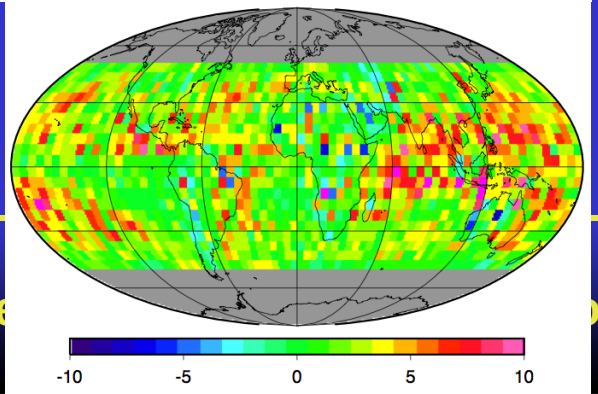


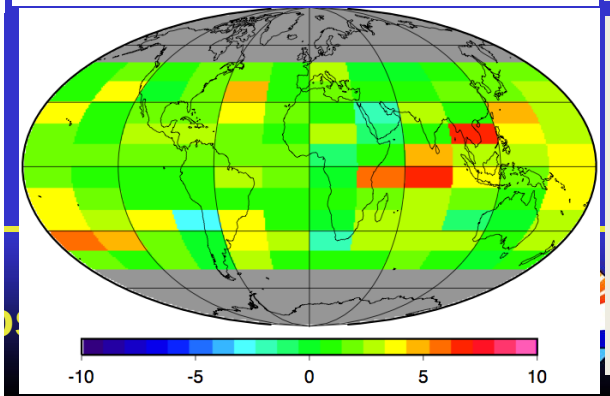


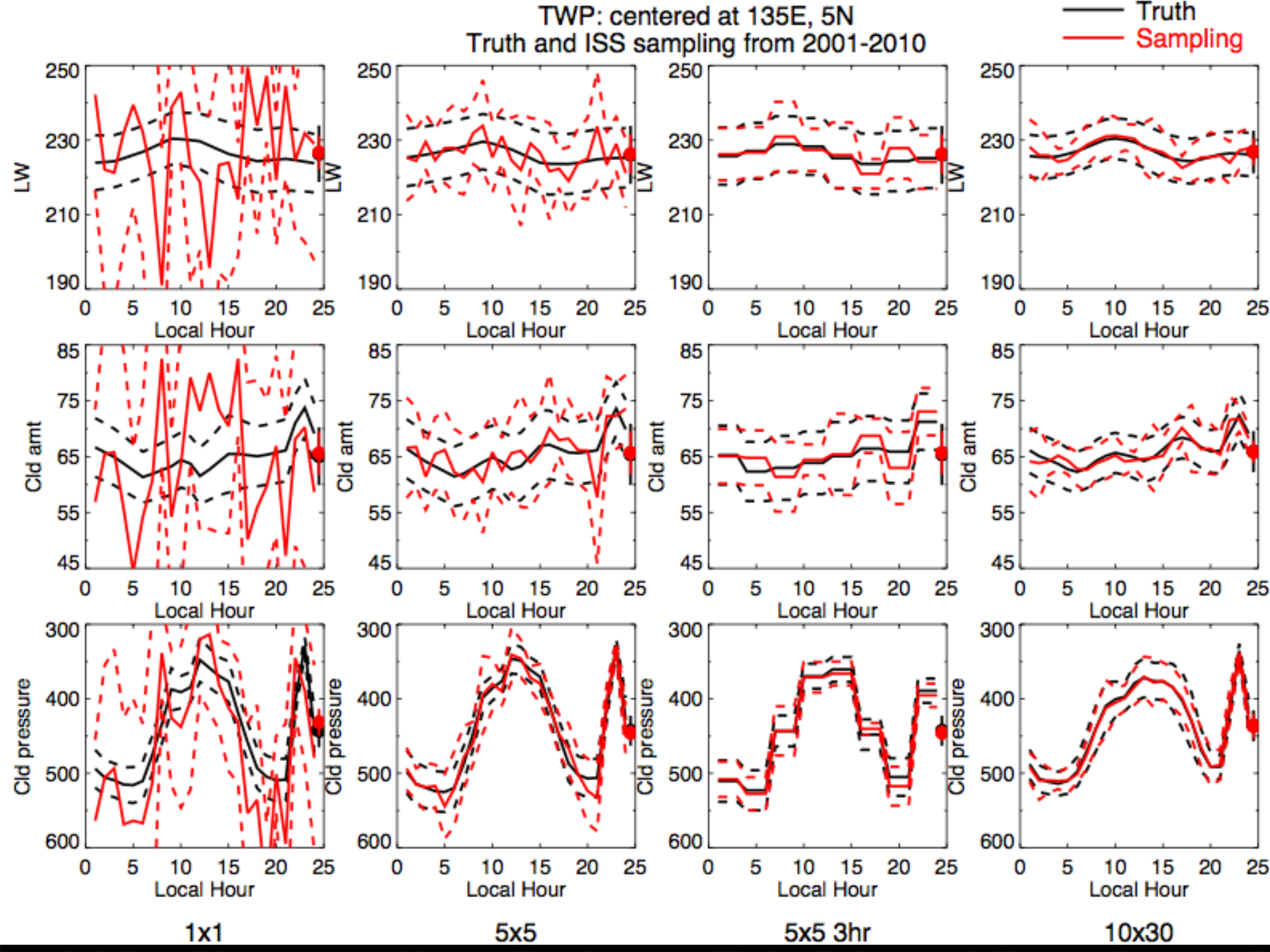






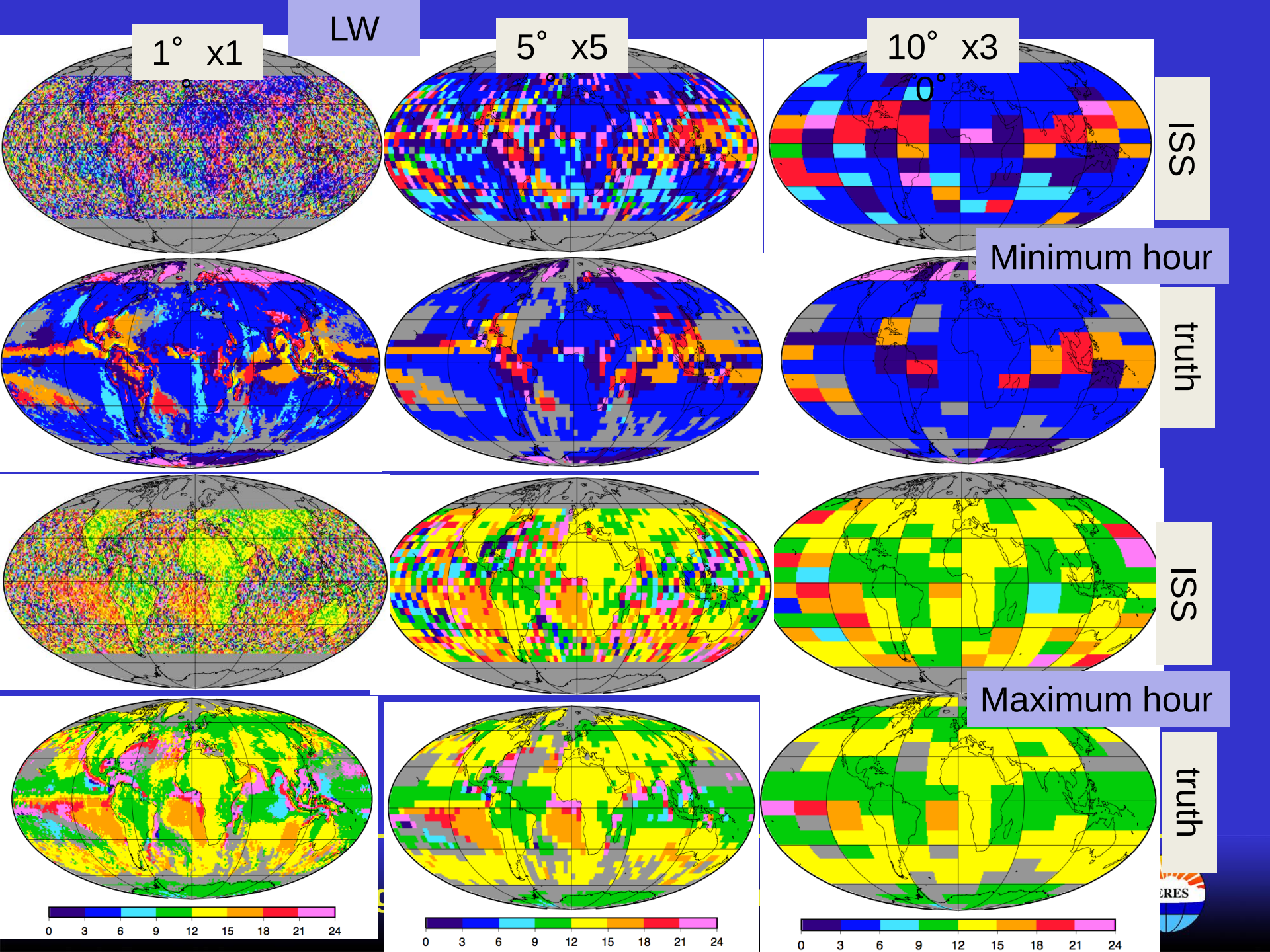




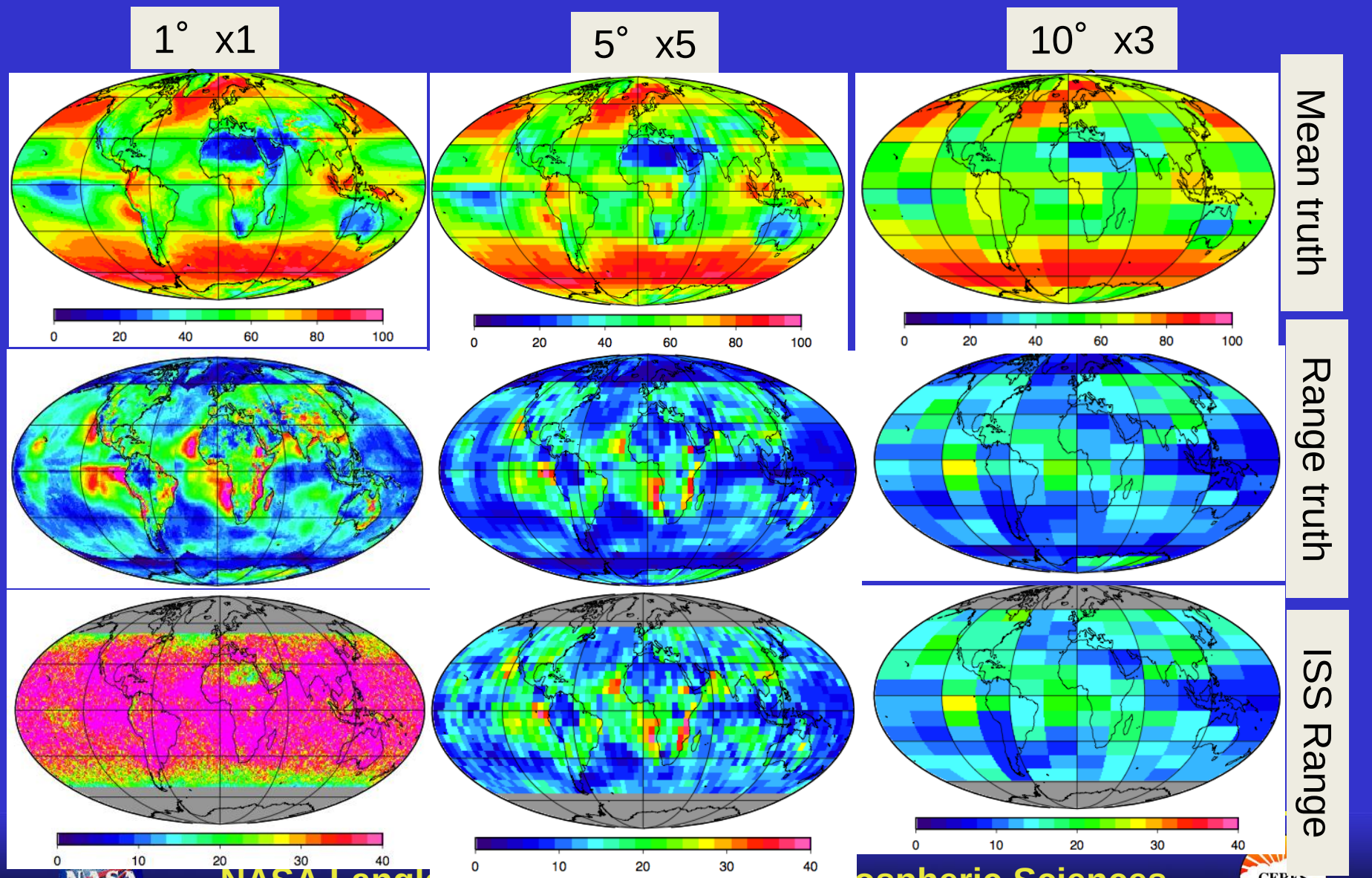

TWP: centered at 135E, 5N
Truth and ISS sampling from 2001-2010
Truth
Sampling
LW
Cld amt
Cld pressure
Local Hour
1x1
5x5
5x5 3hr
10x30

ISS sampling – truth statistics

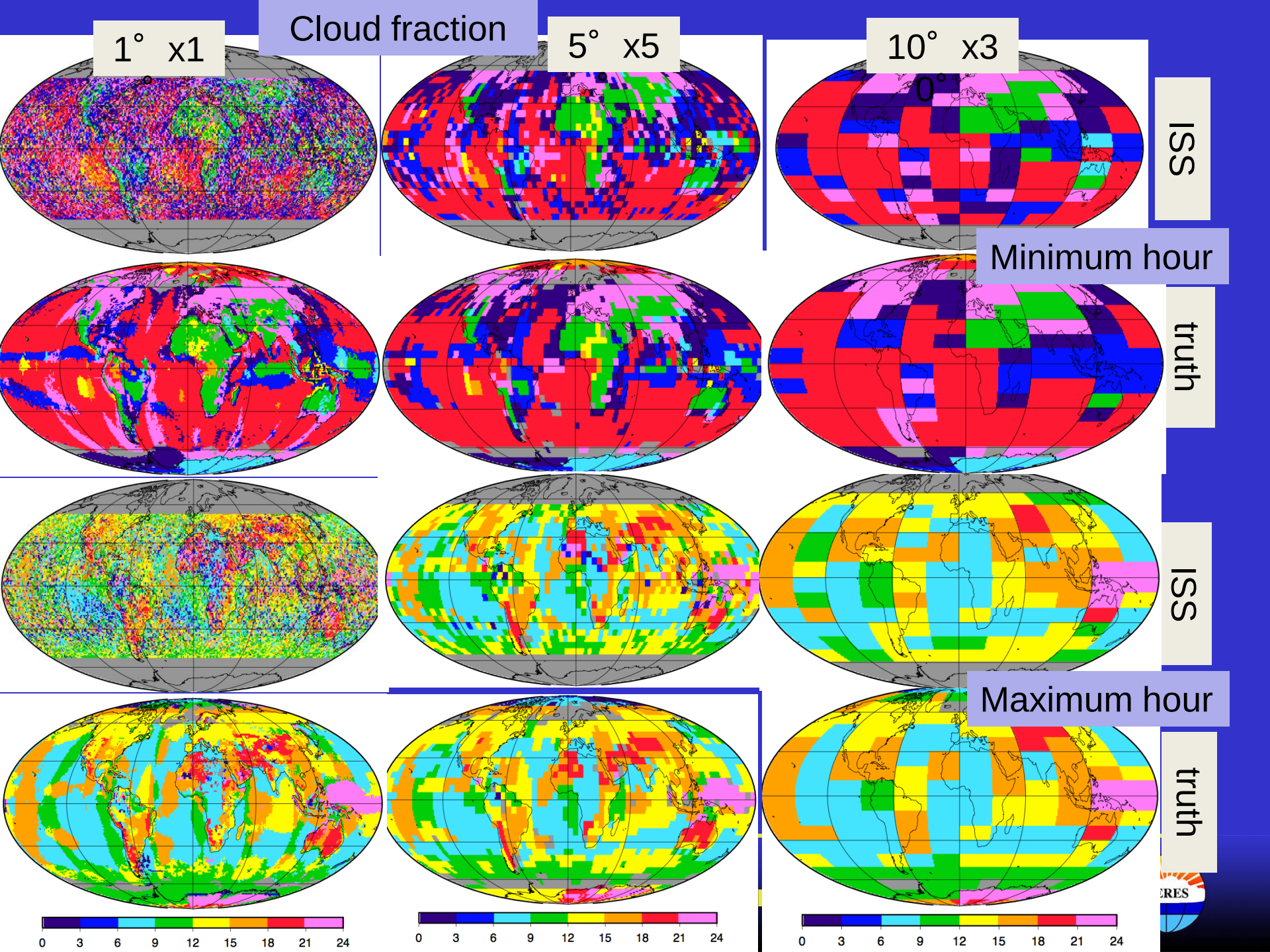
parameter	truth	1x1		5x5		5x5 3hr mean		10x30		zonal	
±50° zone		rms	bias	rms	bias	rms	bias	rms	bias	rms	bias
LW range	~11.5	33.1	29.9	8.0	6.8	3.3	2.3	2.5	1.9	0.3	.04
LW mean	249.5	2.0	-.02	0.9	.09	0.9	.09	0.6	-0.3	.04	.02
Fraction range	~14.5	22.9	20.9	4.7	3.7	2.3	1.1	1.6	1.1	0.5	0.3
Fraction mean	58.4	1.7	-.01	0.7	-.05	0.5	.03	0.3	0.1	.08	-.07
Pressure range	~100	139	127	31	24	15	7	11	7	3.5	.9
Pressure mean	620	12.2	.14	4.5	.02	3.8	.04	1.9	.08	.75	-.69


LW
1° x1°
5° x5°
10° x30°
ISS
Minimum hour
truth
ISS
Maximum hour
truth
0 3 6 9 12 15 18 21 24
0 3 6 9 12 15 18 21 24
0 3 6 9 12 15 18 21 24

Cloud fraction



Cloud fraction

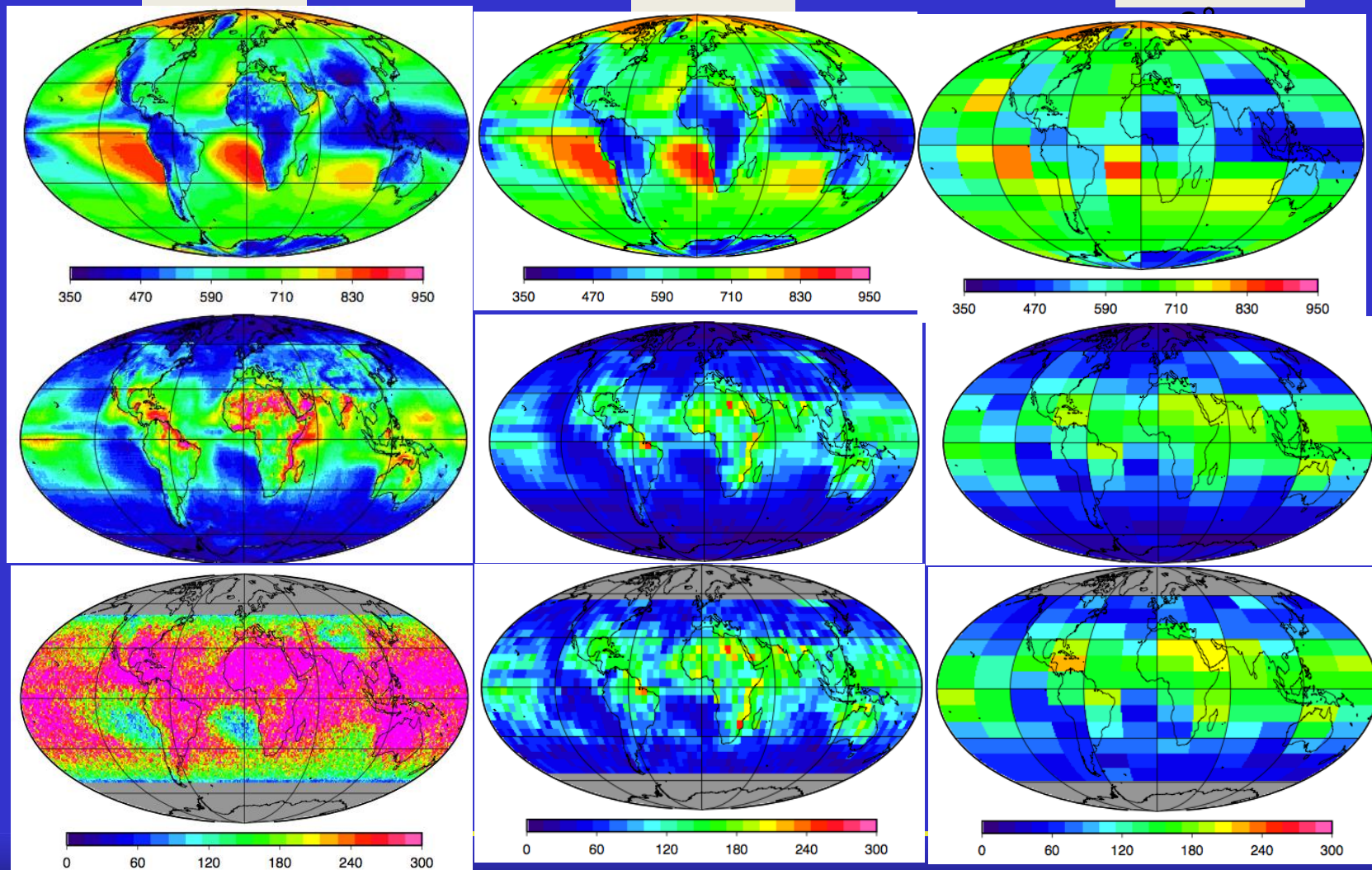


Cloud top pressure

1° x1

5° x5

10° x3

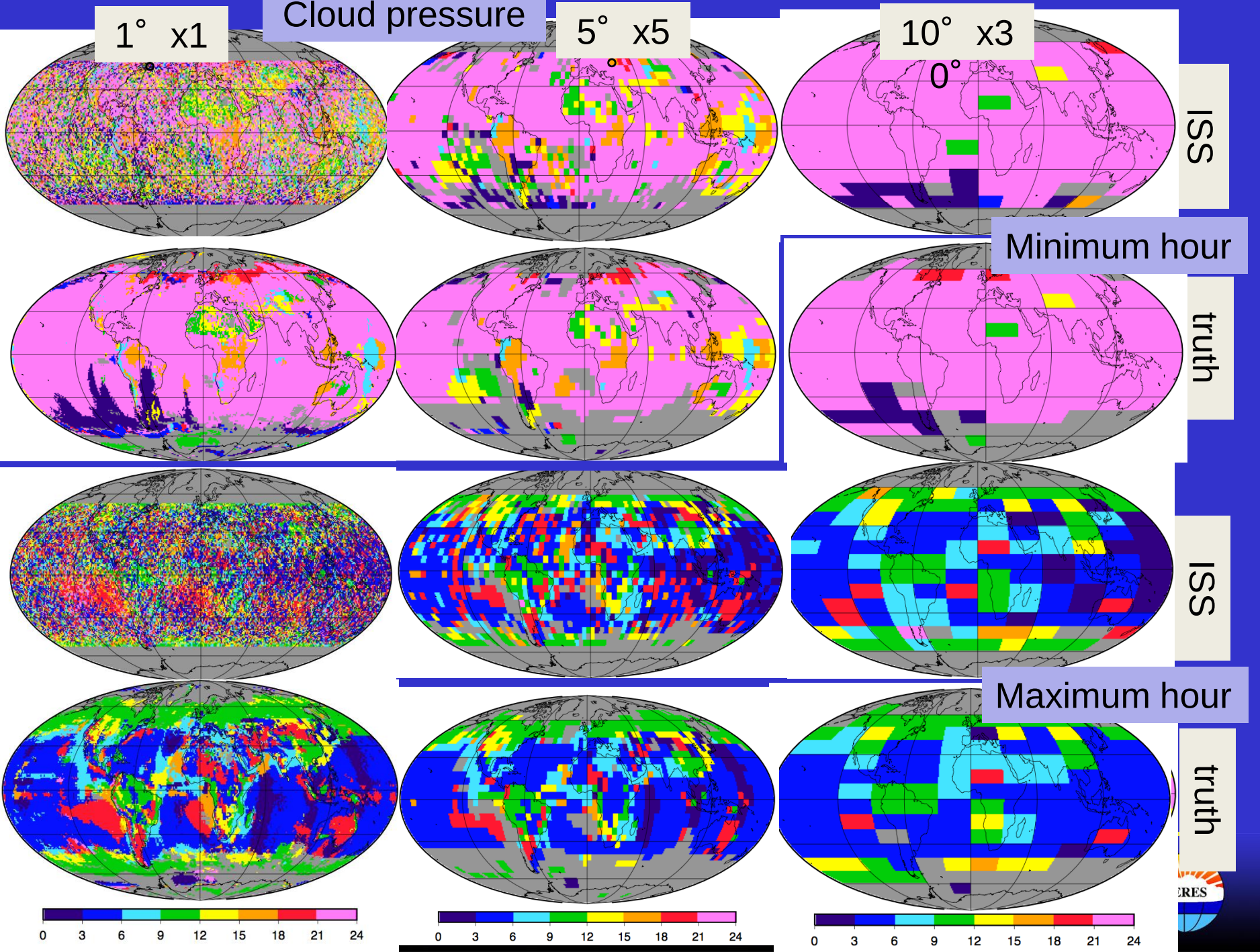


Mean truth

Range truth

ISS Range

Cloud pressure



Conclusions

- SW flux ISS nadir sampling results in at least a 20% time degradation in trend detection
  - Due to non-repeatable annual orbit
- LW flux ISS nadir sampling results in ~ 2% time degradation in trend detection
- Diurnal cycle for LW fluxes, and some cloud properties, based on 2-years of ISS nadir observations, can be resolved on the global, 10˚ zonal, and 10˚ by 30˚ lat/lon regions
- Higher spatial diurnal analysis looks promising using temporal or spatial smoothing using ISS nadir sampling