Sub-pixel characterization of HIRS spectral radiances using cloud properties from AVHRR

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Three research thrusts

- Cloud typing High Resolution Infrared Radiation Sounder (HIRS) spectral radiances using Advanced Very High Resolution Radiometer (AVHRR) cloud characterization

- Cloud typing AIRS spectral radiances using MODIS cloud characterization

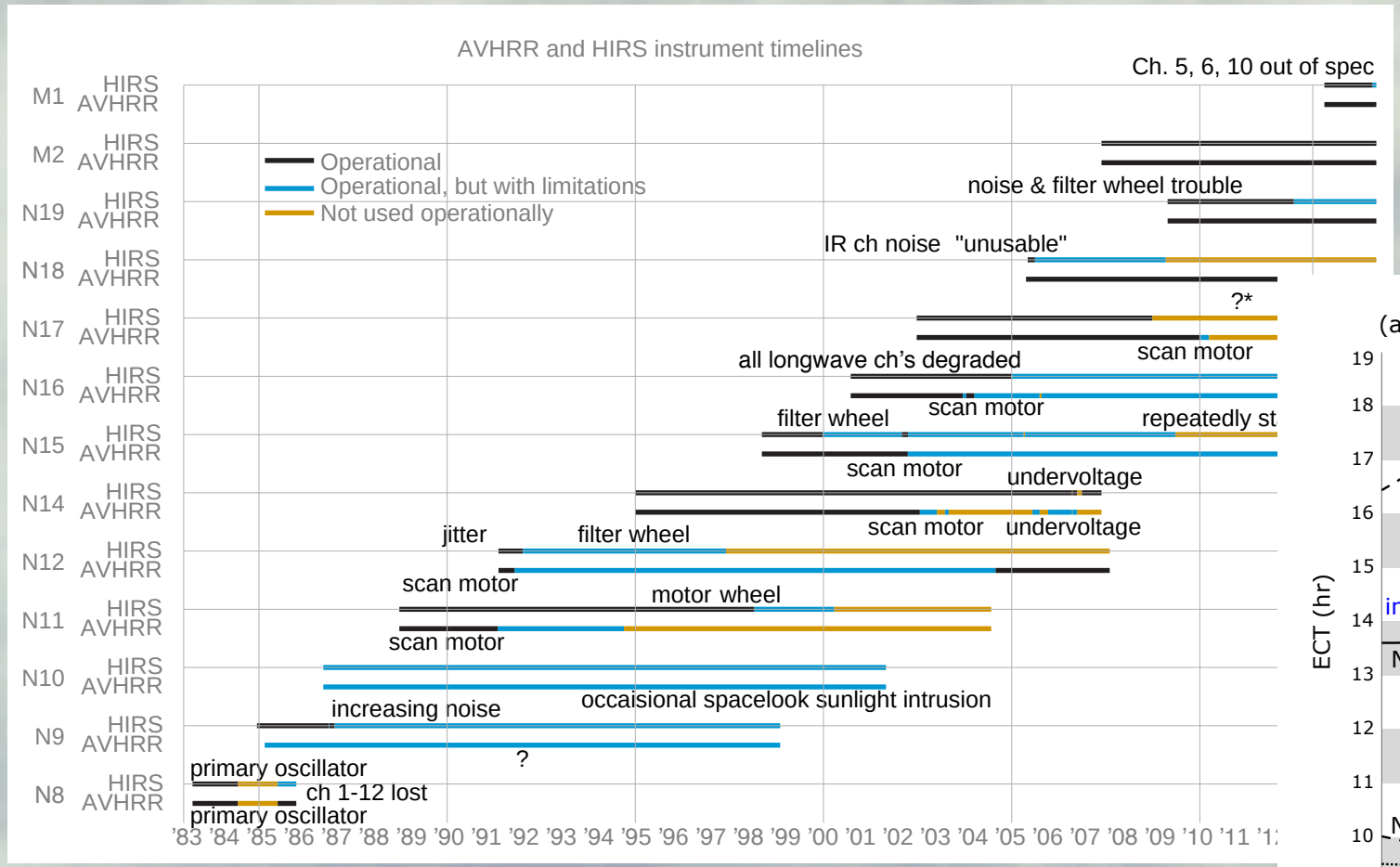
- Linking together AIRS/MODIS and HIRS/AVHRR at pixel scale

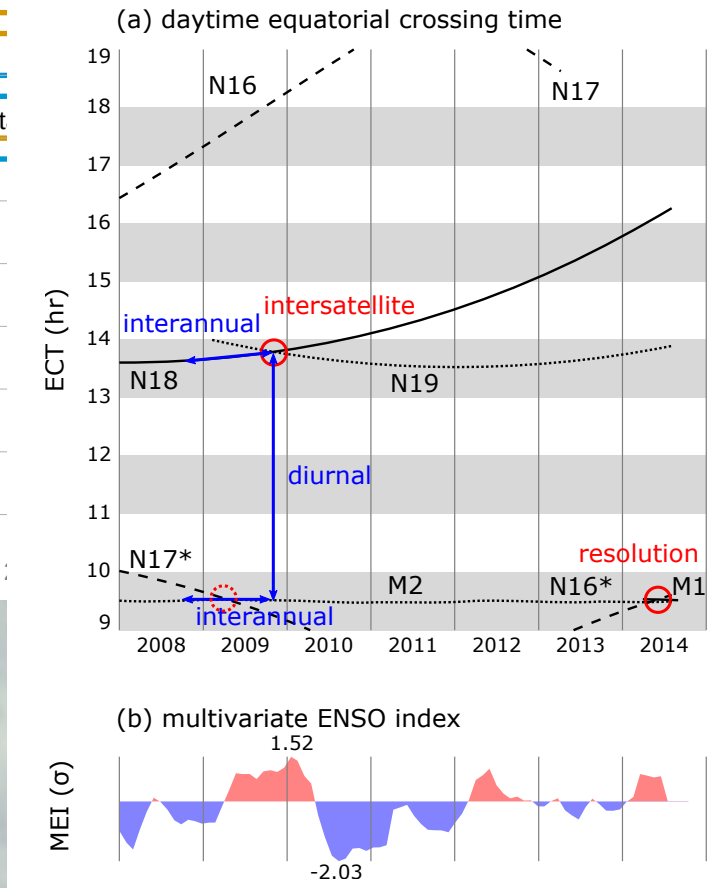
What is the point of this talk?

- Summarize use of HIRS and AVHRR
  - Matching of AVHRR pixels within HIRS footprint
- Cloud-type determination for every HIRS footprint
  - Two types of cloud classification: CLAVR-x versus ISCCP
- Investigate particular NOAA and MetOp satellite intersects
  - Inter-satellite differences (N18 vs. N19, same configuration)
  - HIRS spatial resolution changes (N16 vs. MetOp-B, 20 km vs. 10 km)
  - Diurnal variability/changes (MetOp-A vs. N19, 930 am vs. 130 pm)
  - Transition from La Niña to El Niño (N18 in 2008 vs. 2009)
- Lay groundwork for extending record back through 1979
  - Better estimates of cloud-type trends at regional scales

HIRS/AVHRR mechanical problems/noise

Some useful coincidences between polar orbiters

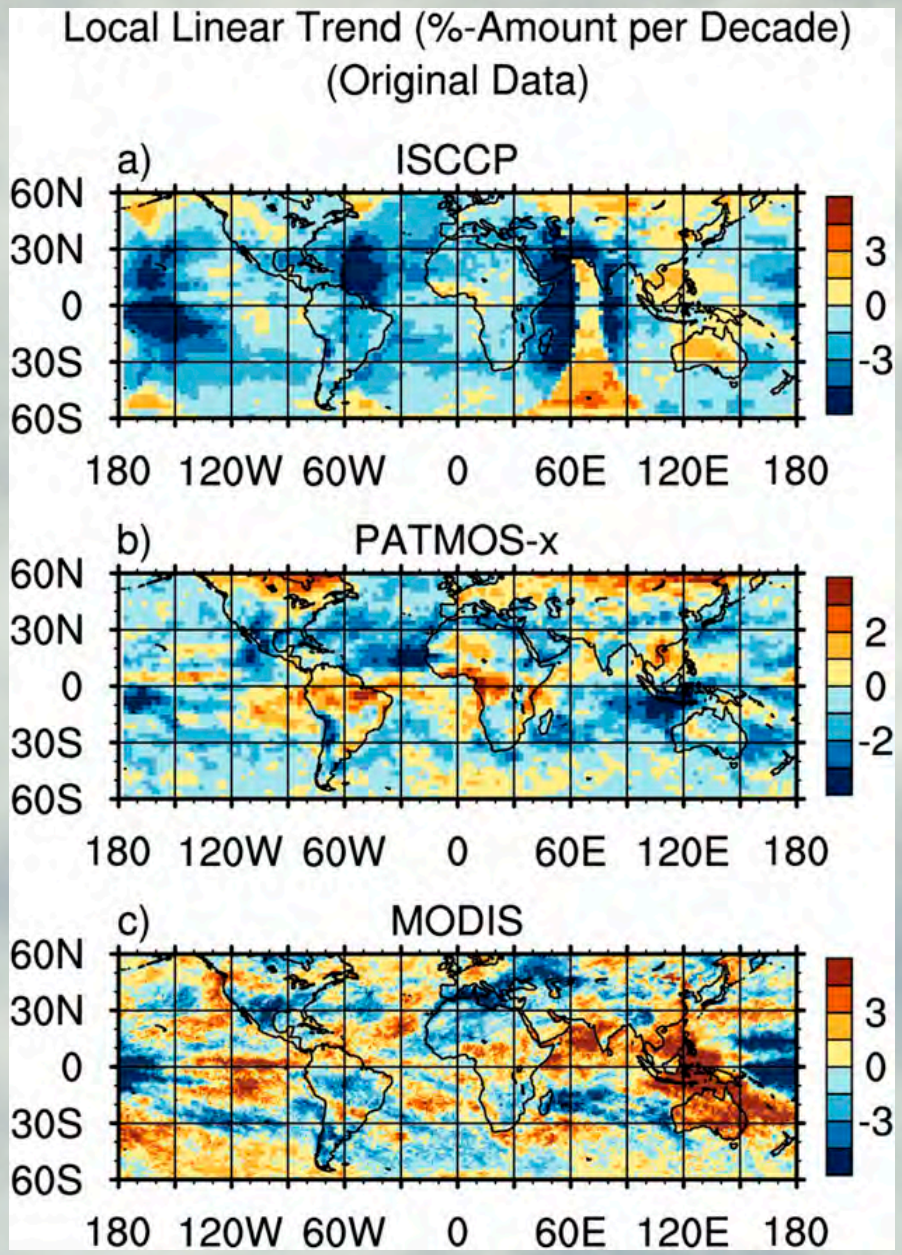


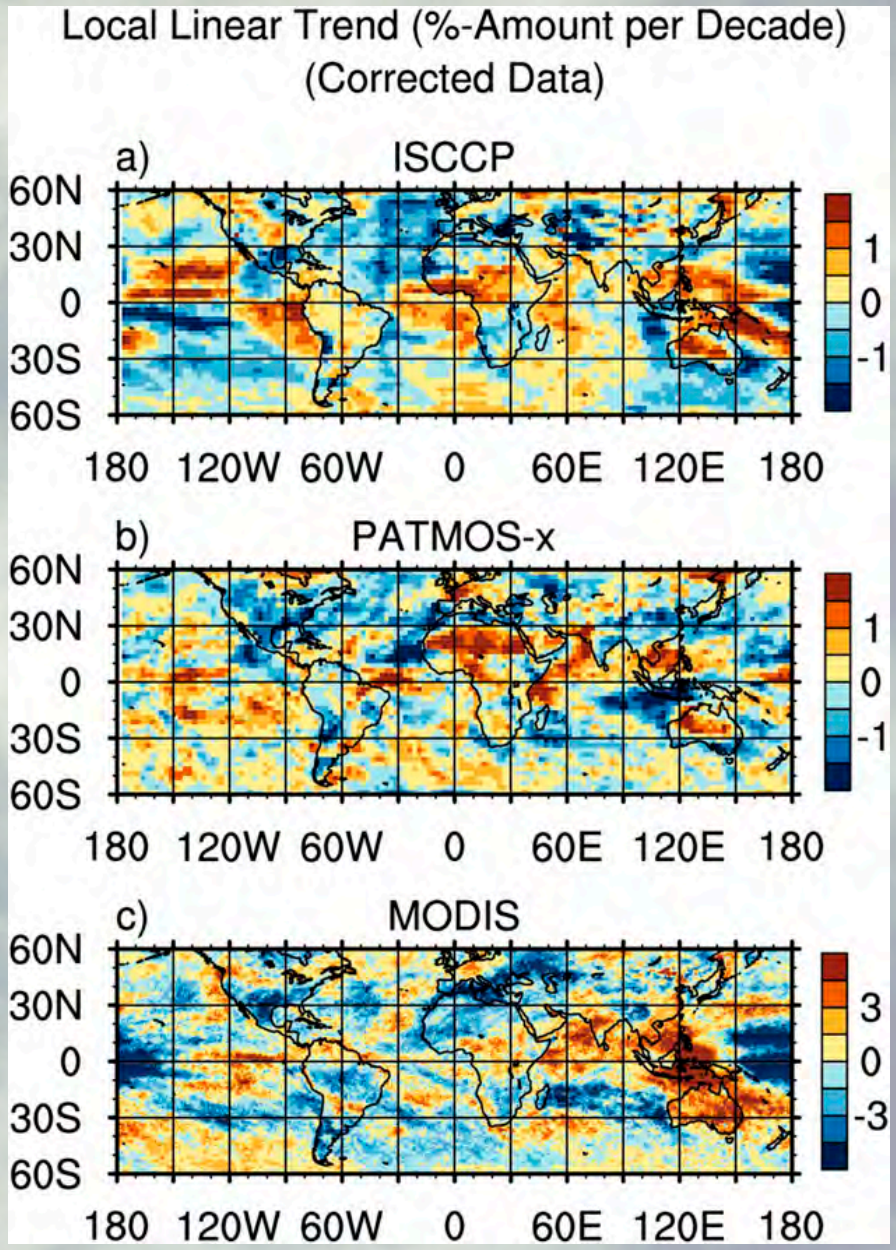


Staten et al., 2016, *J. Atmos. Ocean Tech.*, in review

State of the art cloud amount trends

Scan angle, solar zenith, and ECT artifacts

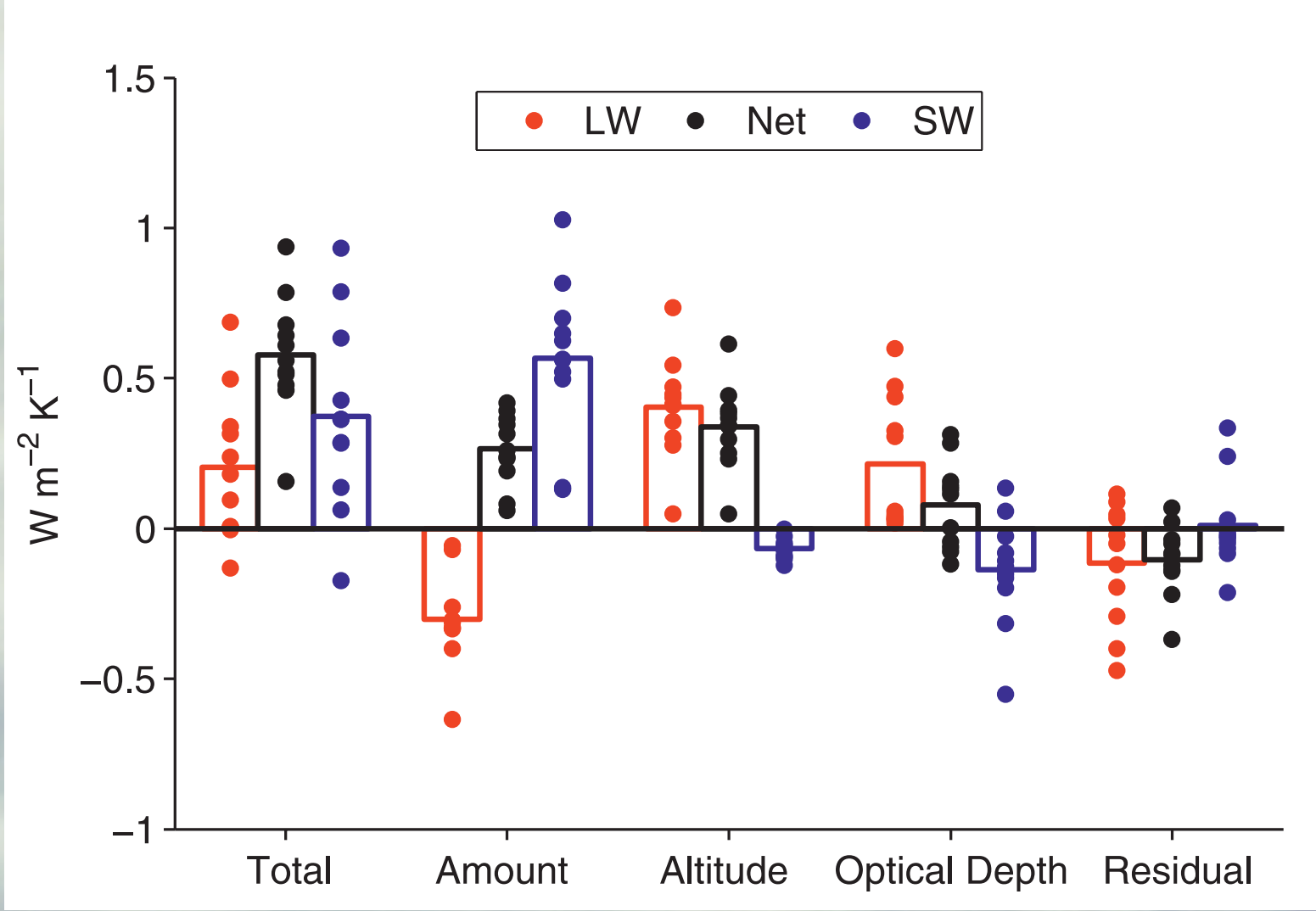




Norris and Evan, 2015, *J. Atmos. Ocean Tech.*

CMIP5 models show poor agreement in LW

Amount, altitude, optical depth have distinct feedbacks



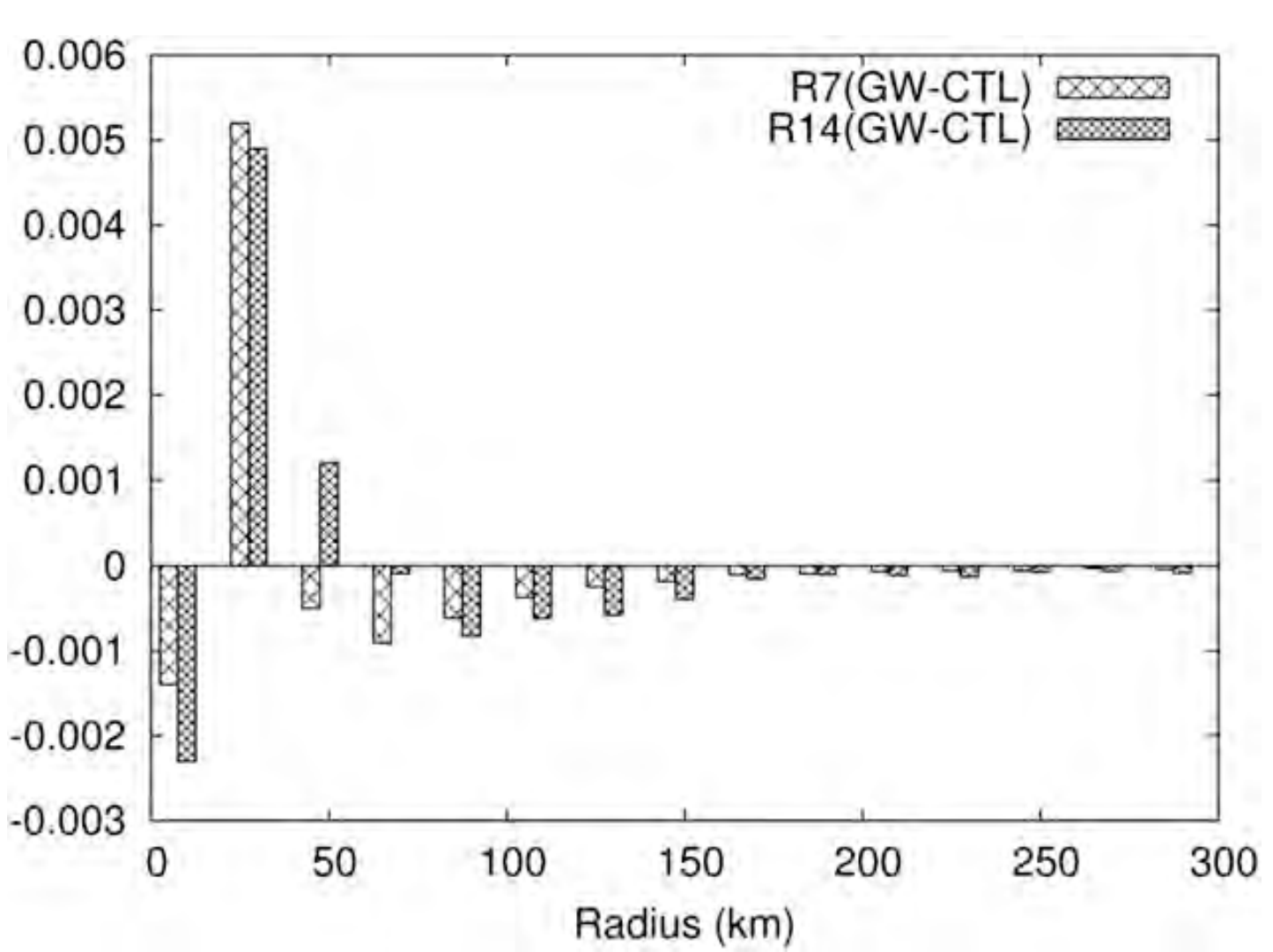
Zelinka and Hartmann, 2012, *J. Climate*

What HIRS/AVHRR bring to the table

- Cloud-type delineation of narrowband spectral T_b
  - Simultaneous observations of channels in CO_2-slicing bands, 8–12 µm window bands, 6.3 µm H_2O band (and elsewhere)
- Build up cloud-type composites of T_b spectra
  - Regional gridding by cloud type
  - Statistical moments (mean, variance, skewness, etc.)
- Difference moments between satellite intersects
  - Are means/variances larger than calibration uncertainties?
  - Show variable cloud type behavior – motivation to move beyond simplified cloud amount trend analyses
- Possible key role of monitoring variance of T_b
  - Variance characterizes cloud-type spatial/temporal variability

High ice cloud frequency versus size

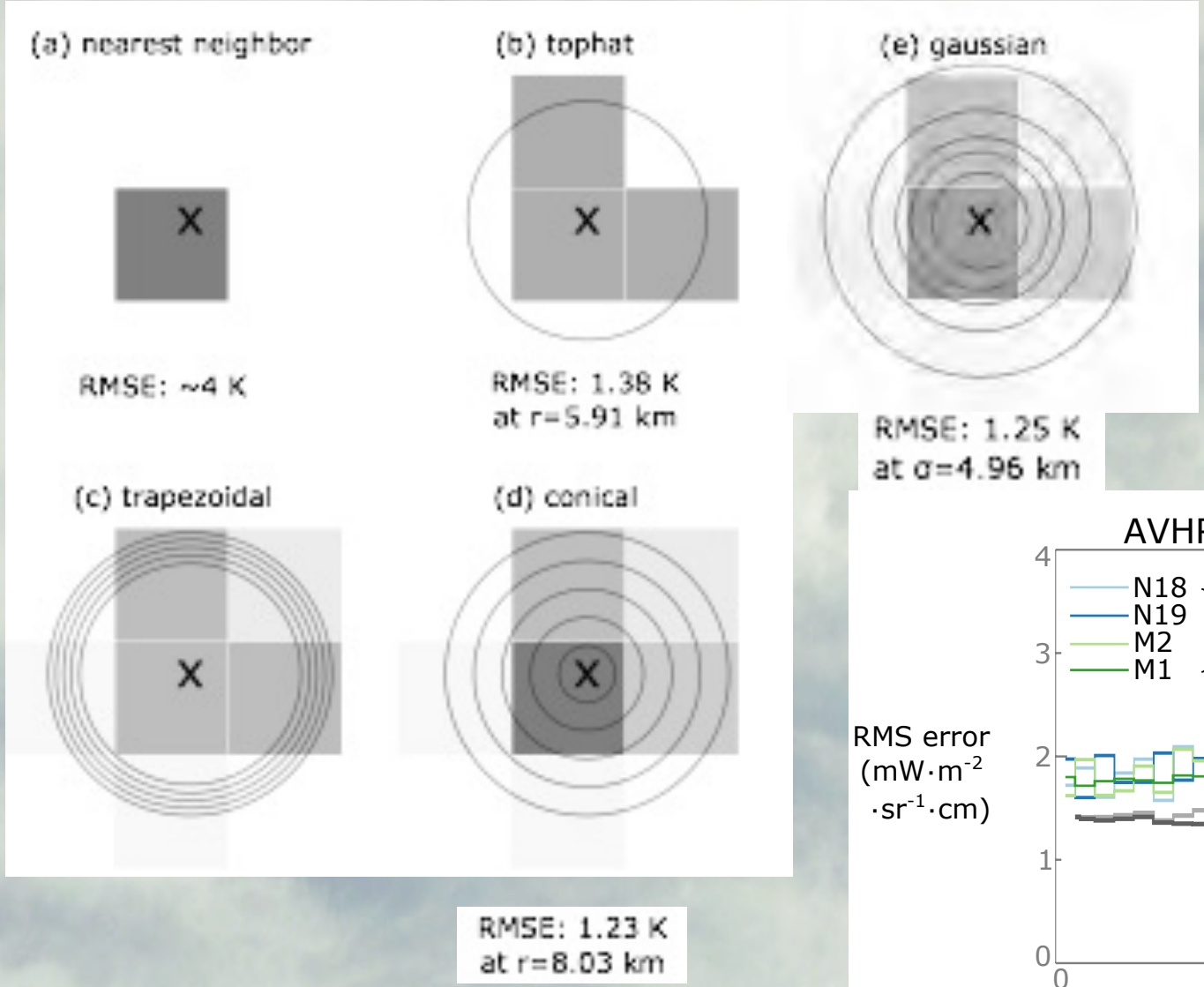
NICAM 7-km & 14-km runs (present-day & end 21st century)

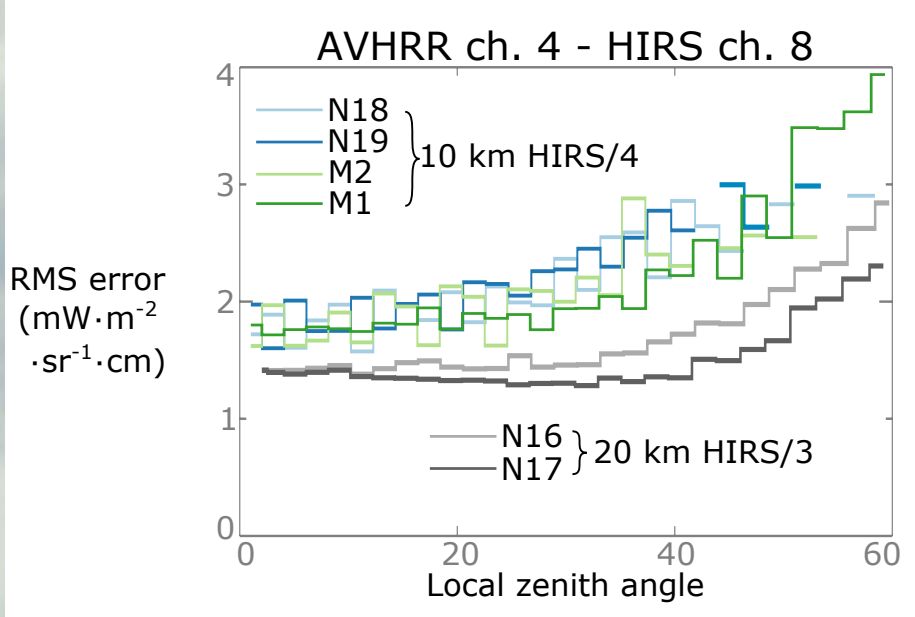


Noda et al., 2014, *J. Climate*

Optimal way to match HIRS and AVHRR

Conical point spread function "wins"



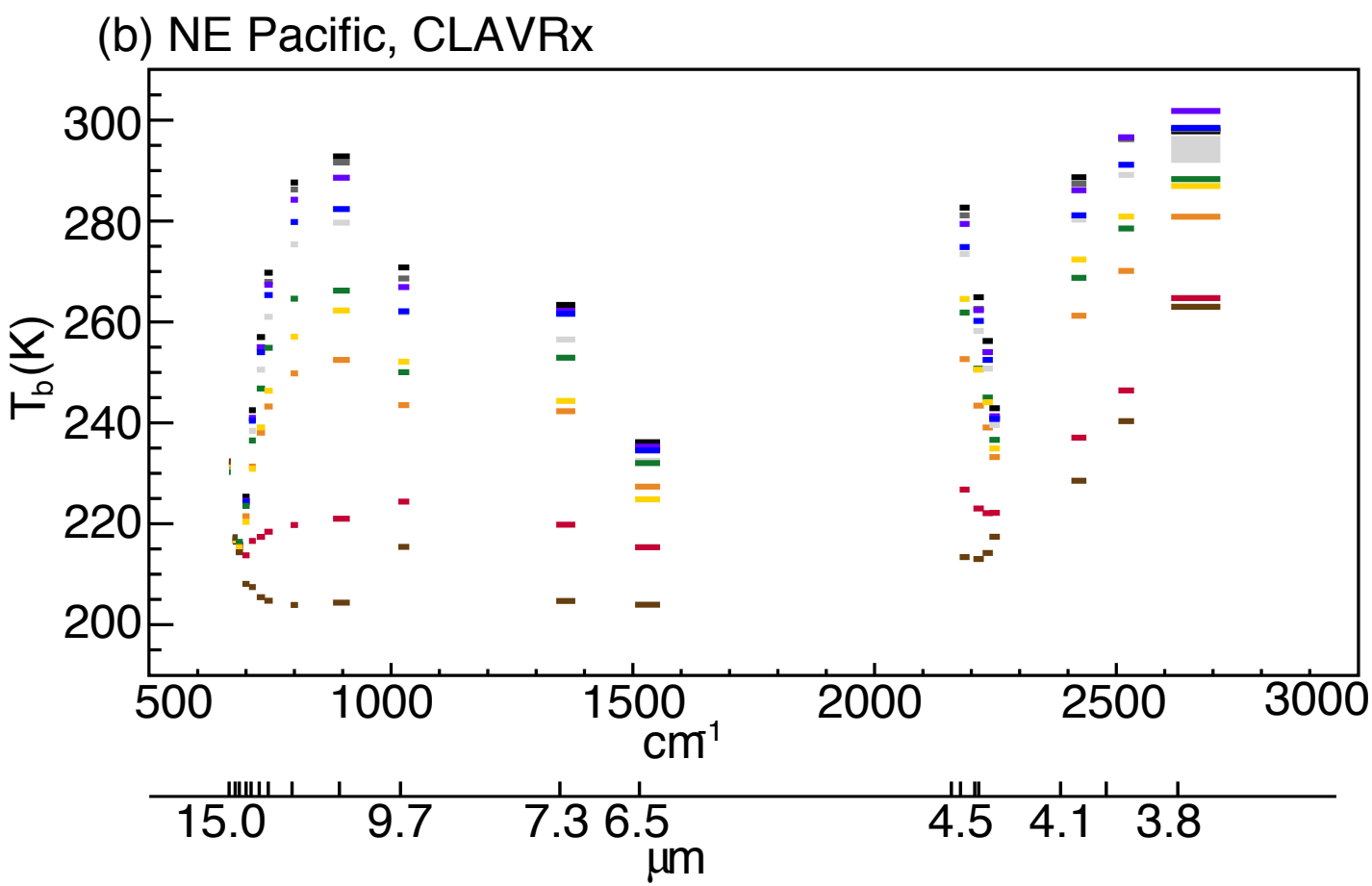


Staten et al., 2016, *J. Atmos. Ocean Tech.*, in review

The full T_b spectrum by cloud type

Realistic sorting of cold high clouds and warm low clouds

Thin cirrus and overlapping in between



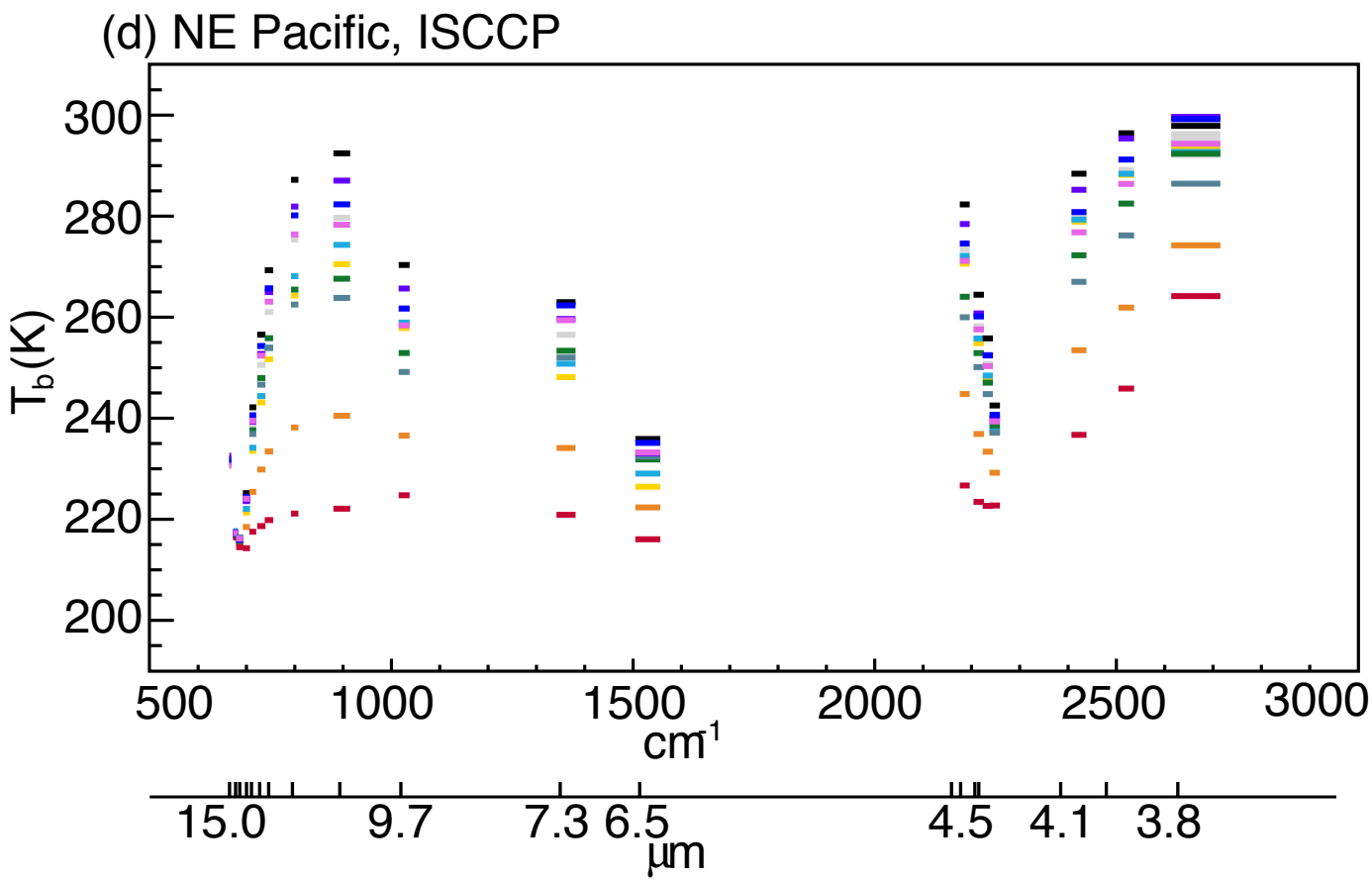
all	1434730	supercool water	16368
clear	171553	overlapping	34791
probably clear	70304	opaque ice	48499
near surface	29272	cirrus	92790
water	153752	overshooting	305

Staten et al., 2016, *J. Atmos. Ocean Tech.*, in review

The full T_b spectrum by cloud type

Realistic sorting of cold high clouds and warm low clouds

Thin cirrus and overlapping in between

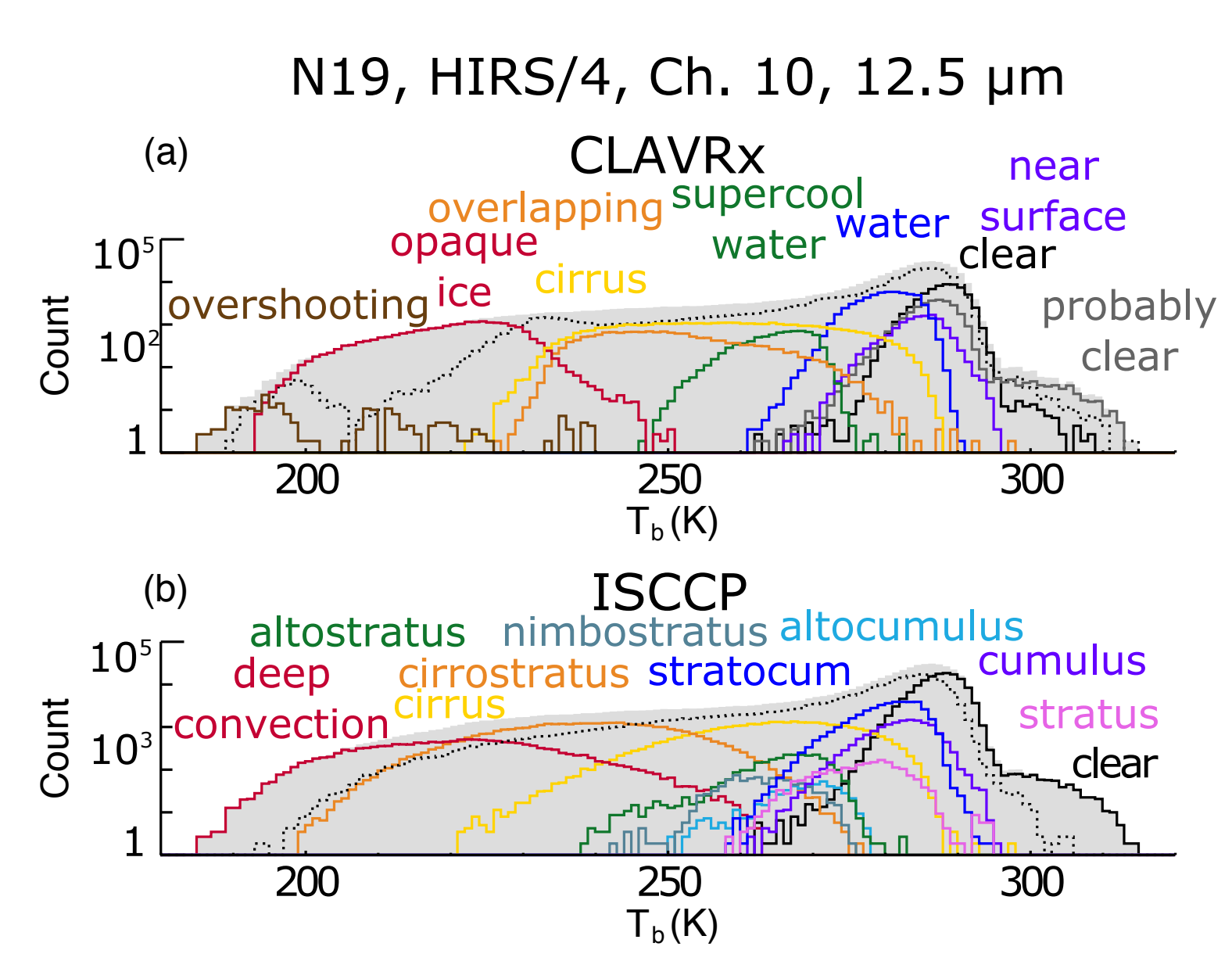


all	1434730	altostratus	5066
clear	392773	nimbostratus	1438
cirrus	75662	cumulus	32584
cirrostratus	84470	stratocumulus	100267
deep convection	30997	stratus	3416
altocumulus	797		

Staten et al., 2016, *J. Atmos. Ocean Tech.*, in review

HIRS 12.5µm T_b for two sets of cloud types

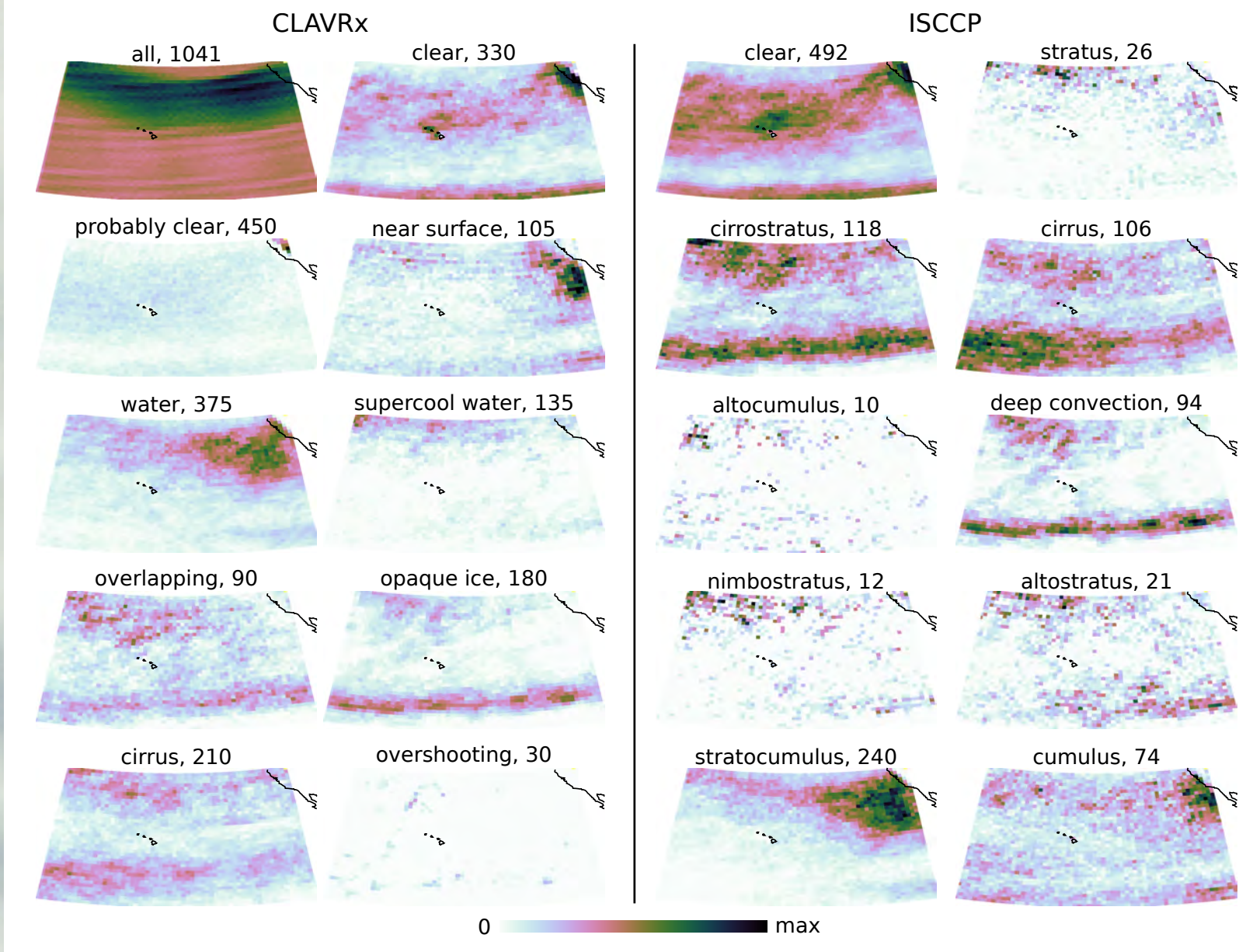
Somewhat more distinct cloud types with CLAVR-x



Staten et al., 2016, *J. Atmos. Ocean Tech.*, in review

Where are the clouds spatially distributed?

Focus on NE Pacific, clouds appear in right places and in right proportions



Staten et al., 2016, *J. Atmos. Ocean Tech.*, in review

The full T_b spectrum by cloud type

Mean T_b in tabular form (units in Kelvins)

(a) SOND 2009 N18 mean T_b

	CO_2							window		O_3	H_2O		N_2O/CO_2				near IR		
	15.0 µm	14.7 µm	14.5 µm	14.2 µm	14.0 µm	13.7 µm	13.3 µm	12.5 µm	11.1 µm	9.7 µm	7.3 µm	6.5 µm	4.6 µm	4.5 µm	4.5 µm	4.5 µm	4.1 µm	4.0 µm	3.8 µm
overshooting	232	217	214	208	207	205	204	204	204	215	204	204	213	213	214	217	228	240	262
cirrus	231	216	215	220	231	239	246	257	262	252	244	224	264	250	244	234	272	280	286
opaque ice	232	216	214	213	216	217	218	219	221	224	219	215	226	223	222	222	237	246	264
overlapping	231	216	215	221	231	238	243	249	252	243	242	227	252	243	239	233	261	270	280
supercool water	230	217	216	223	236	246	254	264	266	250	252	232	261	250	245	236	268	278	288
water	231	217	216	224	240	253	265	279	282	262	261	234	274	260	252	240	280	290	298
near surface	232	217	215	224	241	254	267	284	288	266	262	235	279	262	254	241	285	296	301
probably clear	232	217	215	224	240	254	267	286	291	268	261	235	280	262	253	240	287	296	297
clear	231	216	215	225	242	256	269	287	292	270	263	236	282	264	256	242	288	296	297
other	231	216	215	224	239	251	262	277	281	263	257	233	275	259	251	240	281	290	295
all	231	216	215	223	238	250	260	275	279	261	256	232	273	258	250	239	280	288	293

Staten et al., 2016, *J. Atmos. Ocean Tech.*, in review

The full T_b spectrum by cloud type

Standard deviation of T_b

(b) SOND 2009 N18 T_b standard deviation

	CO_2							window		O_3	H_2O		N_2O/CO_2				near IR		
	15.0 µm	14.7 µm	14.5 µm	14.2 µm	14.0 µm	13.7 µm	13.3 µm	12.5 µm	11.1 µm	9.7 µm	7.3 µm	6.5 µm	4.6 µm	4.5 µm	4.5 µm	4.5 µm	4.1 µm	4.0 µm	3.8 µm
overshooting	2.8	2.8	4.3	8.9	10.4	12.4	13.4	14.6	14.7	7.0	13.8	13.1	10.3	8.9	7.5	5.4	6.7	6.0	5.3
cirrus	3.1	2.3	2.0	2.7	5.2	7.6	9.6	12.6	13.8	10.5	7.1	3.7	10.8	8.5	7.2	4.9	10.8	11.1	8.7
opaque ice	2.9	2.5	2.6	4.1	5.2	6.5	7.3	8.2	8.3	4.5	7.3	5.8	7.1	5.4	4.4	3.0	6.2	6.6	6.4
overlapping	3.1	2.3	1.9	2.1	3.7	5.4	7.0	9.6	11.4	8.6	5.7	3.5	10.5	7.4	6.1	4.0	12.8	15.5	15.7
supercool water	3.4	2.5	2.2	2.2	3.0	3.4	3.6	4.5	4.6	4.1	3.7	4.8	3.9	3.7	3.5	3.5	4.1	5.6	7.4
water	2.9	2.2	1.8	2.2	3.3	3.7	3.4	3.6	3.7	4.5	5.1	5.0	3.4	3.9	3.9	3.8	3.9	4.7	6.0
near surface	2.9	2.1	1.7	2.4	3.7	4.2	3.7	3.4	3.9	6.2	5.0	4.9	4.6	5.1	4.9	4.4	5.5	6.0	6.5
probably clear	3.0	2.3	1.8	2.3	3.6	4.1	3.6	3.5	3.6	5.5	4.7	5.1	4.0	4.9	4.7	4.3	4.4	4.1	4.1
clear	3.0	2.1	1.7	2.0	3.1	3.4	3.0	2.8	3.2	5.0	4.2	4.5	3.6	4.2	4.0	3.7	4.3	5.1	5.8
other	2.9	2.2	1.9	2.9	5.8	8.6	10.9	14.5	15.2	10.9	9.4	6.1	11.3	8.9	7.6	5.3	10.9	11.0	8.9
all	3.0	2.2	1.9	3.5	7.0	10.5	13.4	17.6	18.5	12.7	11.6	6.9	14.0	10.9	9.1	6.1	13.3	13.4	10.5

Staten et al., 2016, *J. Atmos. Ocean Tech.*, in review

El Niño–La Niña mean of T_b by cloud type

2009–2008 for M2

(a) SOND 2009 – 2008 M2 T_b

	CO_2							window		O_3	H_2O		N_2O/CO_2				near IR		
	15.0 µm	14.7 µm	14.5 µm	14.2 µm	14.0 µm	13.7 µm	13.4 µm	12.5 µm	11.1 µm	9.7 µm	7.3 µm	6.5 µm	4.6 µm	4.5 µm	4.5 µm	4.5 µm	4.1 µm	4.0 µm	3.8 µm
overshooting	1.0	0.4	0.3	0.2	0.2	0.1	0.1	-0.0	-0.1	0.4	-0.1	0.1	0.4	0.7	0.9	0.8	0.4	0.3	0.1
cirrus	0.1	-0.6	-0.5	0.2	0.6	0.8	0.9	1.0	1.4	2.0	0.7	0.5	1.5	1.5	1.2	1.1	1.8	1.9	1.4
opaque ice	0.2	-0.7	-0.9	-0.9	-1.0	-1.2	-1.4	-1.5	-1.5	-0.5	-1.3	-1.1	-0.8	-0.5	-0.3	-0.1	-0.5	-0.5	-0.5
overlapping	-0.2	-0.7	-0.7	-0.1	0.2	0.3	0.3	0.4	0.5	0.9	0.3	0.0	0.8	0.8	0.7	0.6	0.9	0.7	0.3
supercool water	-1.0	-0.5	-0.3	-0.1	-0.1	-0.0	0.1	0.2	0.1	-0.0	0.1	0.2	-0.0	-0.1	-0.2	-0.2	-0.3	-0.2	-0.2
water	-0.6	-0.5	-0.4	0.0	-0.0	0.0	-0.0	0.0	0.0	0.3	0.2	0.3	0.1	0.1	0.1	0.1	0.0	-0.2	-0.4
near surface	-0.4	-0.7	-0.5	0.1	0.2	0.1	0.0	0.2	0.7	1.4	-0.1	0.3	0.7	0.6	0.5	0.5	1.0	0.7	0.1
probably clear	-0.4	-0.4	-0.3	0.2	0.2	0.2	0.1	0.2	0.3	0.5	0.4	0.7	0.2	0.3	0.3	0.3	0.4	0.3	0.2
clear	-0.3	-0.6	-0.4	0.2	0.3	0.3	0.2	0.3	0.5	1.0	0.2	0.5	0.4	0.4	0.4	0.4	0.5	0.4	0.3
other	-0.3	-0.5	-0.4	0.1	-0.1	-0.2	-0.4	-0.7	-0.6	0.1	-0.3	0.2	-0.2	-0.0	0.1	0.2	-0.1	-0.1	-0.1
all	-0.3	-0.5	-0.4	-0.0	-0.2	-0.4	-0.7	-1.0	-0.8	0.0	-0.5	0.1	-0.4	-0.2	-0.0	0.1	-0.2	-0.3	-0.3

Staten et al., 2016, *J. Atmos. Ocean Tech.*, in review

El Niño–La Niña standard deviation of T_b

2009–2008 for M2

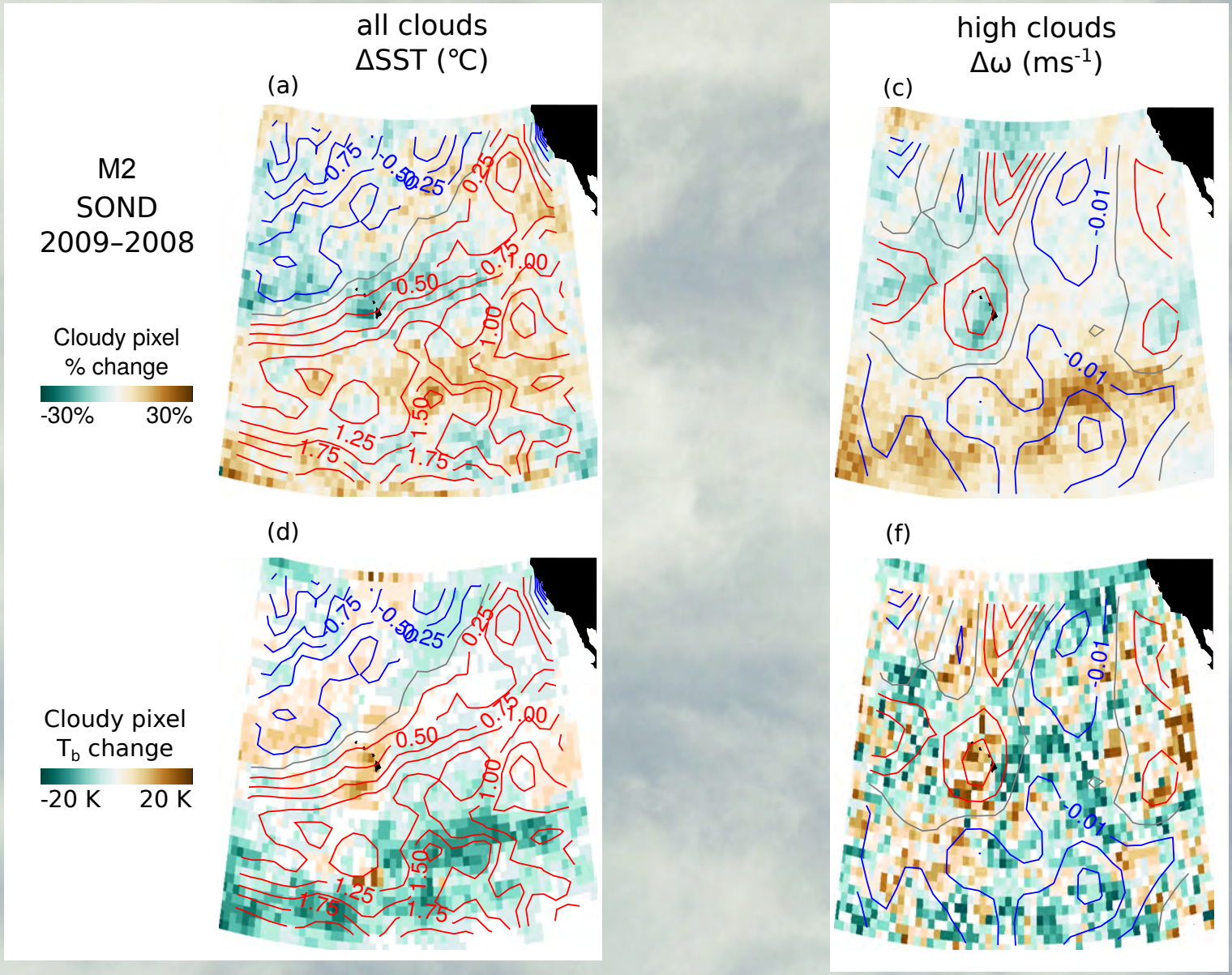
(b) SOND 2009 – 2008 M2 T_b standard deviation

	CO_2							window		O_3	H_2O		N_2O/CO_2				near IR		
	15.0 µm	14.7 µm	14.5 µm	14.2 µm	14.0 µm	13.7 µm	13.4 µm	12.5 µm	11.1 µm	9.7 µm	7.3 µm	6.5 µm	4.6 µm	4.5 µm	4.5 µm	4.5 µm	4.1 µm	4.0 µm	3.8 µm
overshooting	-0.6	0.2	1.0	1.9	2.2	2.6	2.7	2.9	2.9	1.6	2.6	2.6	1.7	1.7	1.4	1.1	0.0	-0.8	-1.0
cirrus	0.1	0.4	0.5	0.3	0.4	0.4	0.4	0.4	0.5	0.8	0.1	0.2	0.5	0.4	0.3	0.3	0.5	0.4	0.1
opaque ice	-0.1	0.5	0.6	0.8	0.8	0.9	1.0	1.0	1.0	0.6	1.0	0.9	0.7	0.6	0.5	0.4	0.2	0.0	-0.2
overlapping	0.3	0.4	0.4	0.2	0.2	0.3	0.4	0.5	0.5	0.5	0.3	0.2	0.5	0.4	0.3	0.3	0.3	0.0	-0.3
supercool water	-0.0	0.5	0.4	0.2	-0.0	-0.1	-0.2	-0.1	-0.1	-0.1	-0.0	0.3	-0.1	-0.1	0.0	0.1	-0.2	-0.1	-0.2
water	0.1	0.3	0.3	0.1	0.1	0.2	0.3	0.4	0.3	0.4	0.2	-0.1	0.4	0.3	0.2	0.1	0.4	0.1	-0.3
near surface	0.2	0.4	0.4	0.1	0.2	0.2	0.3	0.4	0.2	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.3	0.5	0.5
probably clear	0.1	0.3	0.4	0.1	0.2	0.3	0.3	0.3	0.2	0.6	0.2	0.3	0.4	0.4	0.3	0.2	0.5	0.4	0.3
clear	0.3	0.3	0.3	0.1	0.2	0.2	0.3	0.4	0.4	0.7	0.1	0.3	0.4	0.3	0.2	0.2	0.5	0.3	0.1
other	0.1	0.4	0.4	0.2	0.3	0.4	0.5	0.7	0.7	0.6	0.5	0.3	0.5	0.4	0.3	0.2	0.5	0.5	0.3
all	0.1	0.4	0.4	0.4	0.6	0.7	0.9	1.2	1.2	0.9	0.8	0.5	0.9	0.7	0.4	0.3	0.9	0.8	0.5

Staten et al., 2016, *J. Atmos. Ocean Tech.*, in review

SST/Δω changes connected to cloud fraction/T_b

For same 2009–2008 ENSO changes using M2



Staten et al., 2016, *J. Atmos. Ocean Tech.*, in review

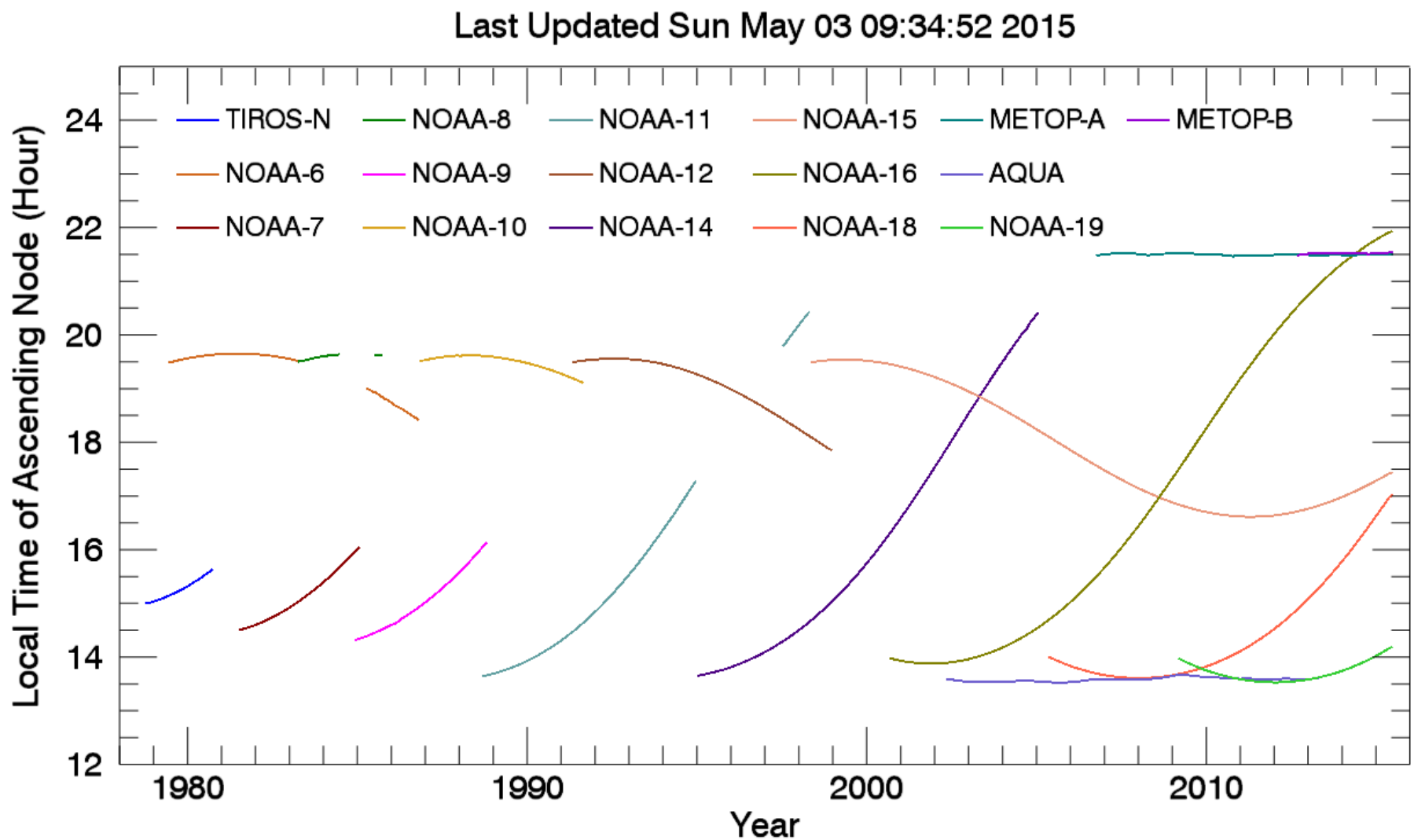
What have we learned?

- "Straightforward" combination of HIRS and AVHRR
  - Relative sorting of T_b spectra consistent with cloud types
  - Spatial distributions consistent with known climatology
- Further insights into data record with non-SNO coincidences
  - Explored HIRS sensor spatial resolution, same instrument configurations, diurnal variability, ENSO variations
  - Close correspondence of cloud-type cloud amount/T_b to model reanalysis of vertical velocity and SST
- Inter-satellite differences of standard deviations of T_b at times larger than mean
  - Cloud-type, process-based changes in T_b spectrum beyond simple mean differences
- Works backwards to establish useful observational benchmark

Backup Slides

Polar orbiting satellite drift

The HIRS/AVHRR record we show is not corrected for drift



Diurnal variability – standard deviation of T_b

Big changes in water vapor? Overlapping clouds? SRF differences?

MAM 2014 M1 – N16 T_b standard deviation

	CO_2							window		O_3	H_2O		N_2O/CO_2				near IR		
	15.0 µm	14.7 µm	14.5 µm	14.2 µm	14.0 µm	13.7 µm	13.3 µm	12.5 µm	11.1 µm	9.7 µm	7.3 µm	6.5 µm	4.6 µm	4.5 µm	4.5 µm	4.5 µm	4.1 µm	4.0 µm	3.8 µm
overshooting	-5.5	-2.2	-1.6	-0.5	-0.4	-0.1	-0.6	-0.3	-0.2	-0.5	-1.1	-4.0	-1.1	-1.1	-1.2	-0.8	-1.7	-2.0	-1.3
cirrus	-7.0	-2.0	-1.6	-0.2	0.5	1.2	1.0	1.4	1.4	1.0	0.5	-5.2	0.4	0.3	0.3	0.4	0.6	0.7	1.8
opaque ice	-6.9	-1.9	-1.3	-0.2	-0.0	0.2	0.1	0.2	0.2	0.2	-0.8	-6.9	0.3	0.0	-0.0	0.1	0.3	0.2	0.2
overlapping	-6.6	-1.8	-1.5	-0.8	-0.9	-1.1	-1.9	-3.3	-4.8	-3.9	-1.2	-4.8	-4.5	-3.1	-2.1	-1.5	-4.4	-4.8	-3.1
supercool water	-6.4	-1.6	-1.3	-0.8	-0.4	-0.3	-0.3	-0.2	-0.1	0.2	-0.5	-3.5	0.1	0.0	-0.0	-0.0	0.7	0.5	0.7
water	-6.9	-1.9	-1.6	-0.7	-0.3	-0.2	0.1	0.2	0.2	0.4	-0.2	-3.0	0.3	0.1	-0.1	-0.1	0.2	0.2	0.1
near surface	-6.8	-1.7	-1.4	-0.5	-0.1	0.0	0.0	-0.1	0.3	1.2	-0.6	-2.6	0.7	0.6	0.4	0.3	0.5	-0.3	-0.5
probably clear	-6.8	-1.9	-1.5	-0.8	-0.6	-0.5	-0.5	-1.3	-1.0	0.5	-0.3	-2.7	-0.4	-0.4	-0.5	-0.5	-0.4	-0.5	-0.1
clear	-7.0	-2.0	-1.7	-0.6	-0.2	-0.1	0.1	0.1	0.1	0.1	-0.1	-2.3	0.1	0.1	-0.0	-0.1	0.0	-0.2	-0.3
other	-6.9	-1.9	-1.5	-0.5	-0.6	-0.3	-0.8	-0.4	-0.2	-0.1	-0.4	-3.0	0.0	-0.2	-0.4	-0.3	0.2	0.3	0.4
all	-6.9	-1.9	-1.5	-0.3	-0.3	0.3	-0.1	0.6	0.6	0.3	0.1	-2.8	0.6	0.1	-0.2	-0.1	0.6	0.6	0.4

Staten et al., 2016, *J. Atmos. Ocean Tech.*, in review

Spatial resolution – mean of T_b

Scale dependence in particular cloud types ? Sampling limitations?

(a) SOND 2009 N19 – N18 mean T_b

	CO_2							window		O_3	H_2O		N_2O/CO_2				near IR		
	15.0 µm	14.7 µm	14.5 µm	14.2 µm	14.0 µm	13.7 µm	13.3 µm	12.5 µm	11.1 µm	9.7 µm	7.3 µm	6.5 µm	4.6 µm	4.5 µm	4.5 µm	4.5 µm	4.1 µm	4.0 µm	3.8 µm
overshooting	0.1	0.4	0.8	2.0	1.6	1.9	2.8	2.8	3.1	1.6	3.8	0.6	0.5	0.2	-1.6	-0.3	0.0	-0.0	-1.3
cirrus	0.0	-0.0	-0.1	-0.5	1.7	0.5	0.2	1.7	1.6	1.0	0.7	-0.1	3.3	-0.5	3.9	-0.3	1.3	1.3	0.9
opaque ice	-0.1	-0.1	-0.1	-0.1	0.2	-0.1	0.1	0.3	0.5	0.3	0.3	-0.4	0.5	-0.7	-0.7	-0.8	0.2	0.5	-0.2
overlapping	-0.3	-0.0	-0.1	-0.9	0.8	-0.7	-1.2	-1.0	-1.4	-1.2	-0.7	-0.6	-0.0	-2.0	1.2	-1.1	-1.6	-1.9	-2.1
supercool water	-0.4	-0.1	-0.2	-1.0	1.7	-0.1	-0.6	0.3	0.3	-0.0	0.0	-0.1	1.6	-1.1	2.8	-0.7	0.2	0.3	0.1
water	-0.2	-0.0	-0.2	-1.1	2.2	-0.2	-1.0	0.3	0.2	-0.0	-0.0	-0.1	2.2	-1.4	4.1	-0.7	0.2	0.3	0.2
near surface	-0.2	-0.1	-0.2	-1.2	2.2	-0.4	-1.5	0.1	-0.2	-0.2	-0.6	-0.4	2.5	-1.7	4.5	-0.8	0.1	0.0	-0.1
probably clear	-0.1	0.1	-0.1	-1.2	2.1	-0.5	-1.5	0.3	-0.1	-0.4	-0.1	-0.2	2.7	-2.1	4.6	-0.9	-0.0	-0.0	0.1
clear	-0.1	-0.1	-0.2	-1.1	2.4	-0.2	-1.3	0.4	-0.0	-0.1	-0.0	-0.1	2.8	-1.6	4.9	-0.6	0.2	0.0	0.1
other	-0.2	-0.1	-0.2	-1.0	2.0	-0.4	-1.2	0.1	-0.2	-0.3	-0.2	-0.3	2.2	-1.6	4.1	-0.7	-0.0	-0.1	-0.1
all	-0.2	-0.1	-0.2	-1.0	1.9	-0.5	-1.3	-0.1	-0.4	-0.3	-0.3	-0.3	2.1	-1.7	3.9	-0.8	-0.1	-0.2	-0.2

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Spatial resolution – mean of T_b

Scale dependence in particular cloud types ? Sampling limitations?

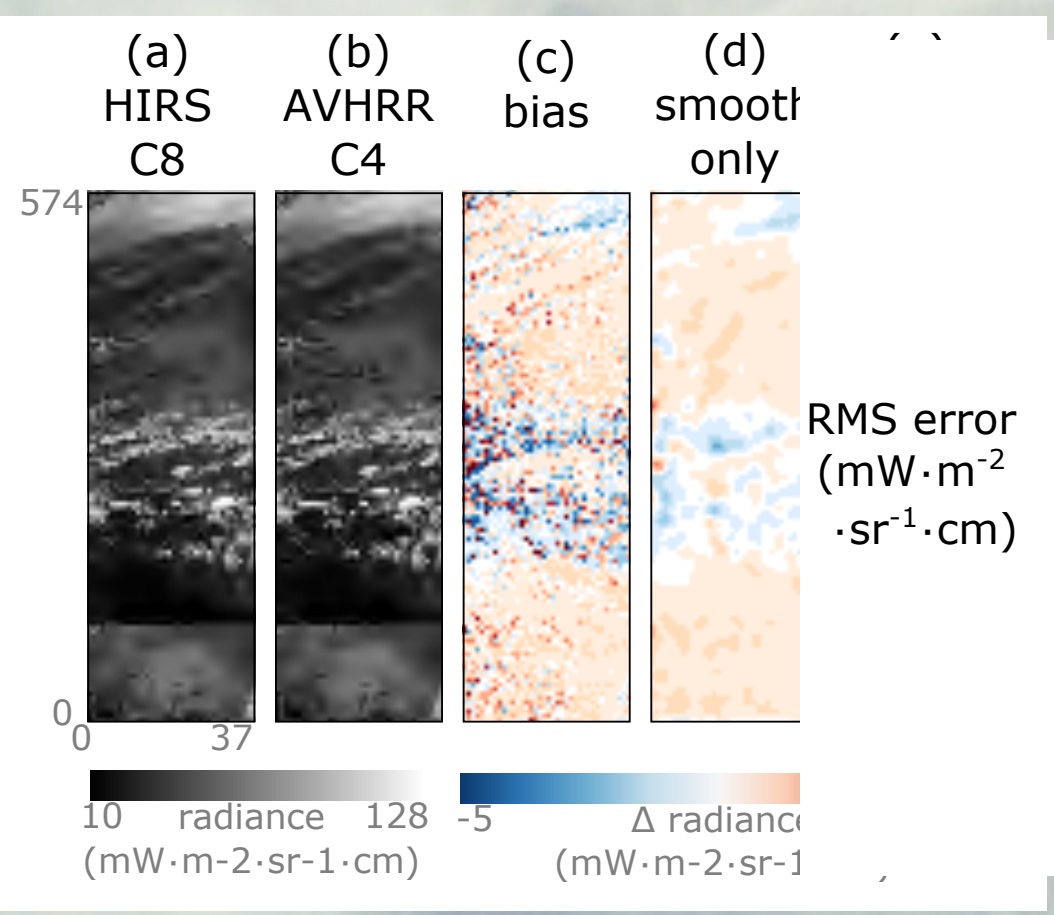
(b) SOND 2009 N19 – N18 T_b standard deviation

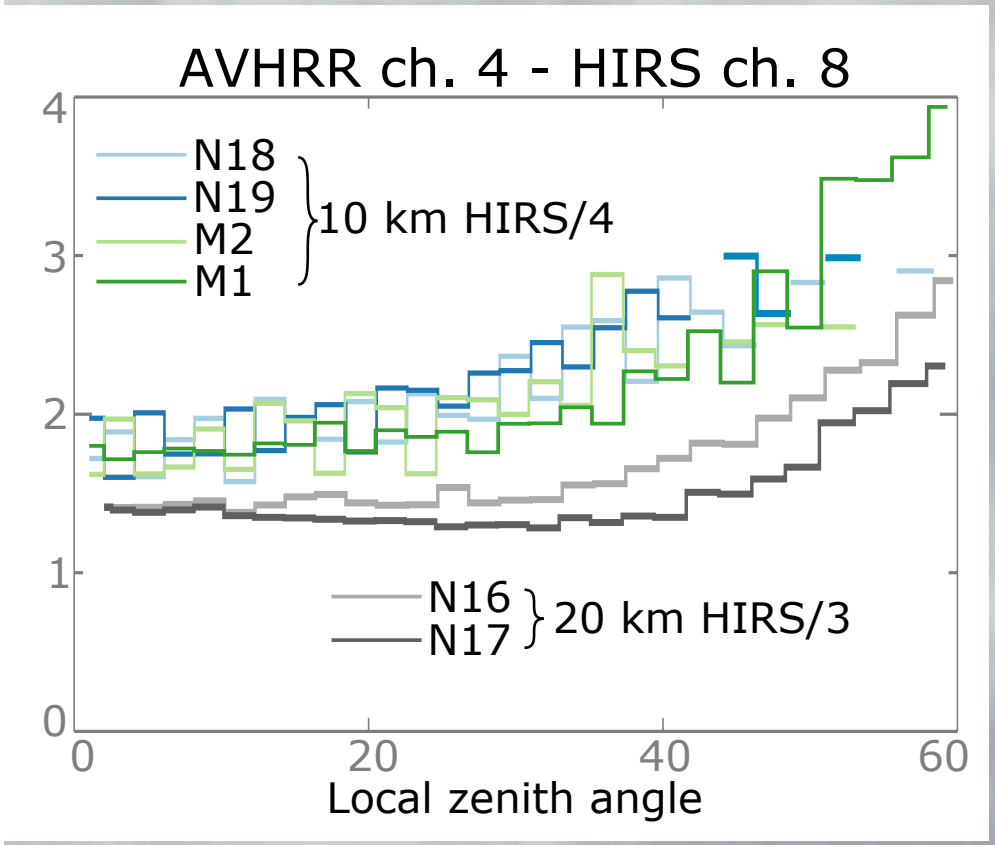
	CO_2							window		O_3	H_20		N_2O/CO_2				near IR		
	15.0 µm	14.7 µm	14.5 µm	14.2 µm	14.0 µm	13.7 µm	13.3 µm	12.5 µm	11.1 µm	9.7 µm	7.3 µm	6.5 µm	4.6 µm	4.5 µm	4.5 µm	4.5 µm	4.1 µm	4.0 µm	3.8 µm
overshooting	-0.2	-0.2	0.1	0.8	1.4	1.7	1.7	1.9	2.0	1.0	0.1	0.2	2.6	1.9	2.5	1.3	1.1	0.3	0.1
cirrus	-1.5	-0.2	-0.0	-0.2	0.5	0.1	-0.1	0.1	-0.0	-0.1	-0.0	-1.0	0.2	-0.2	0.9	0.1	-0.3	-0.4	-0.2
opaque ice	-0.7	-0.1	0.0	-0.2	0.1	-0.1	-0.2	-0.2	-0.1	-0.1	-0.6	-1.3	0.4	0.0	0.8	0.2	0.3	0.4	0.2
overlapping	-1.2	-0.2	0.0	-0.3	0.0	-0.4	-0.7	-0.7	-1.0	-0.8	-0.4	-0.9	-0.4	-0.9	0.5	-0.2	-0.9	-1.0	-0.7
supercool water	-1.2	-0.2	-0.0	-0.2	-0.0	-0.1	-0.2	-0.1	-0.1	-0.1	-0.1	-0.2	0.0	-0.0	-0.1	0.0	-0.1	-0.1	-0.2
water	-1.0	-0.3	-0.1	-0.1	0.2	0.2	0.1	0.0	-0.1	0.0	0.0	-0.4	0.0	0.3	0.1	0.2	-0.1	-0.1	-0.1
near surface	-1.0	-0.3	-0.1	-0.2	0.2	0.1	0.0	-0.1	-0.1	0.2	-0.2	-0.5	0.2	0.3	0.2	0.2	0.2	0.3	0.3
probably clear	-1.5	-0.3	-0.1	-0.1	0.2	0.1	0.1	-0.0	-0.1	0.1	-0.1	-0.5	-0.0	0.3	0.2	0.2	-0.0	-0.1	-0.2
clear	-1.1	-0.3	-0.0	-0.2	0.1	0.1	0.1	0.1	0.0	0.1	-0.1	-0.6	0.1	0.2	0.2	0.2	0.0	-0.0	-0.1
other	-1.2	-0.3	-0.0	-0.2	0.6	0.1	-0.1	0.3	0.2	0.1	0.0	-0.4	0.6	0.0	1.1	0.2	0.1	0.1	0.1
all	-1.2	-0.3	-0.0	-0.2	0.7	0.2	-0.1	0.3	0.2	0.1	0.0	-0.3	0.8	0.0	1.4	0.2	0.2	0.1	0.2

Staten et al., 2016, *J. Atmos. Ocean Tech.*, in review

Optimal way to match HIRS and AVHRR

Conical point spread function "wins"





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