Upper tropospheric humidity measurements with operational microwave sounders

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Overview

- Why care about upper tropospheric humidity?
- Satellite data – opportunities
- Satellite data – challenges
- Summary and conclusions

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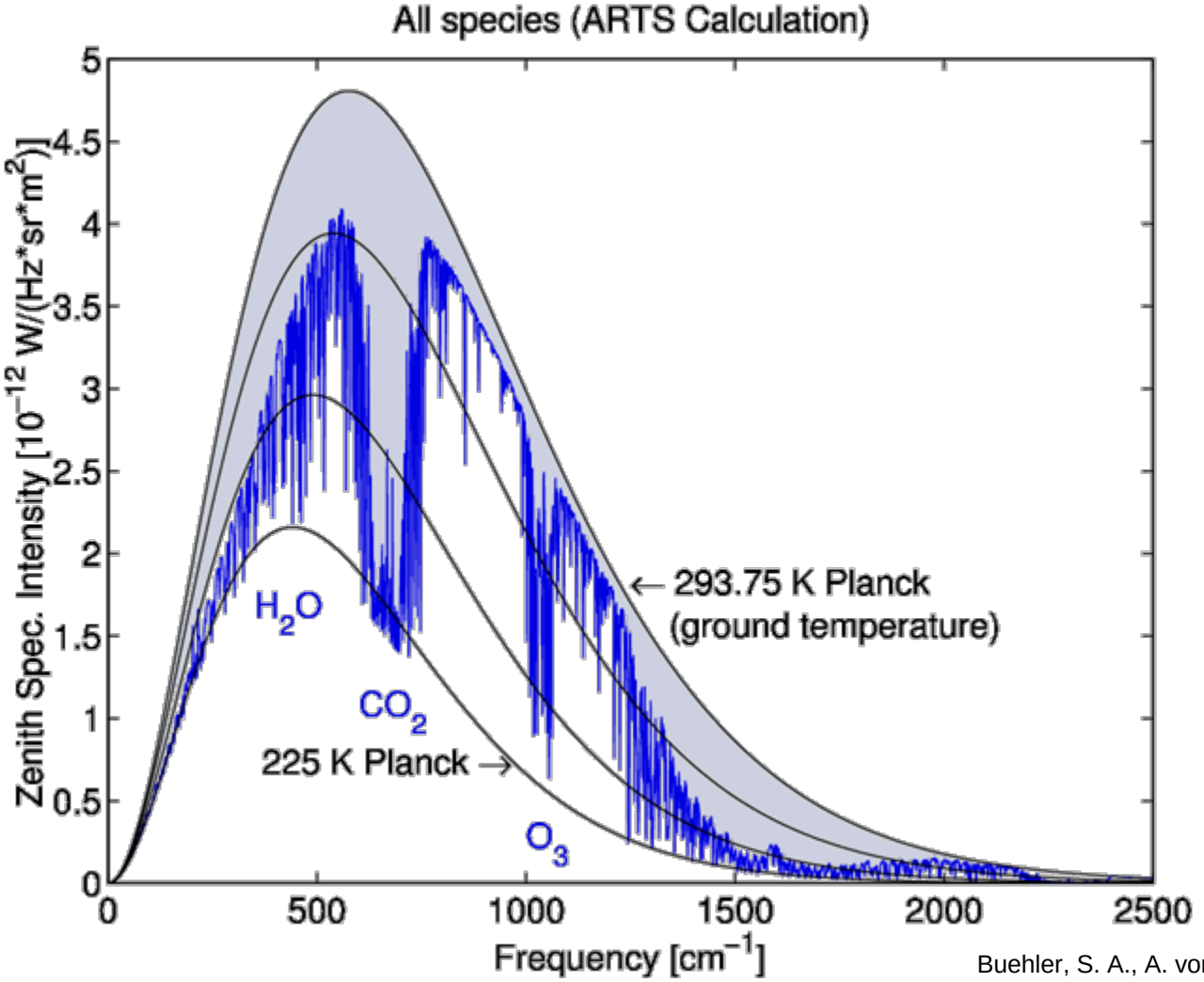
Clear-sky OLR spectrum



- Upper troposphere important for outgoing longwave radiation
- Ample opportunities for remote sensing

Buehler, S. A., A. von Engeln, E. Brocard, V. O. John, T. Kuhn and P. Eriksson (2006),
Recent developments in the line-by-line modeling of outgoing longwave radiation,
J. Quant. Spectrosc. Radiat. Transfer, *98*(3), 446–457,
doi:10.1016/j.jqsrt.2005.11.001.

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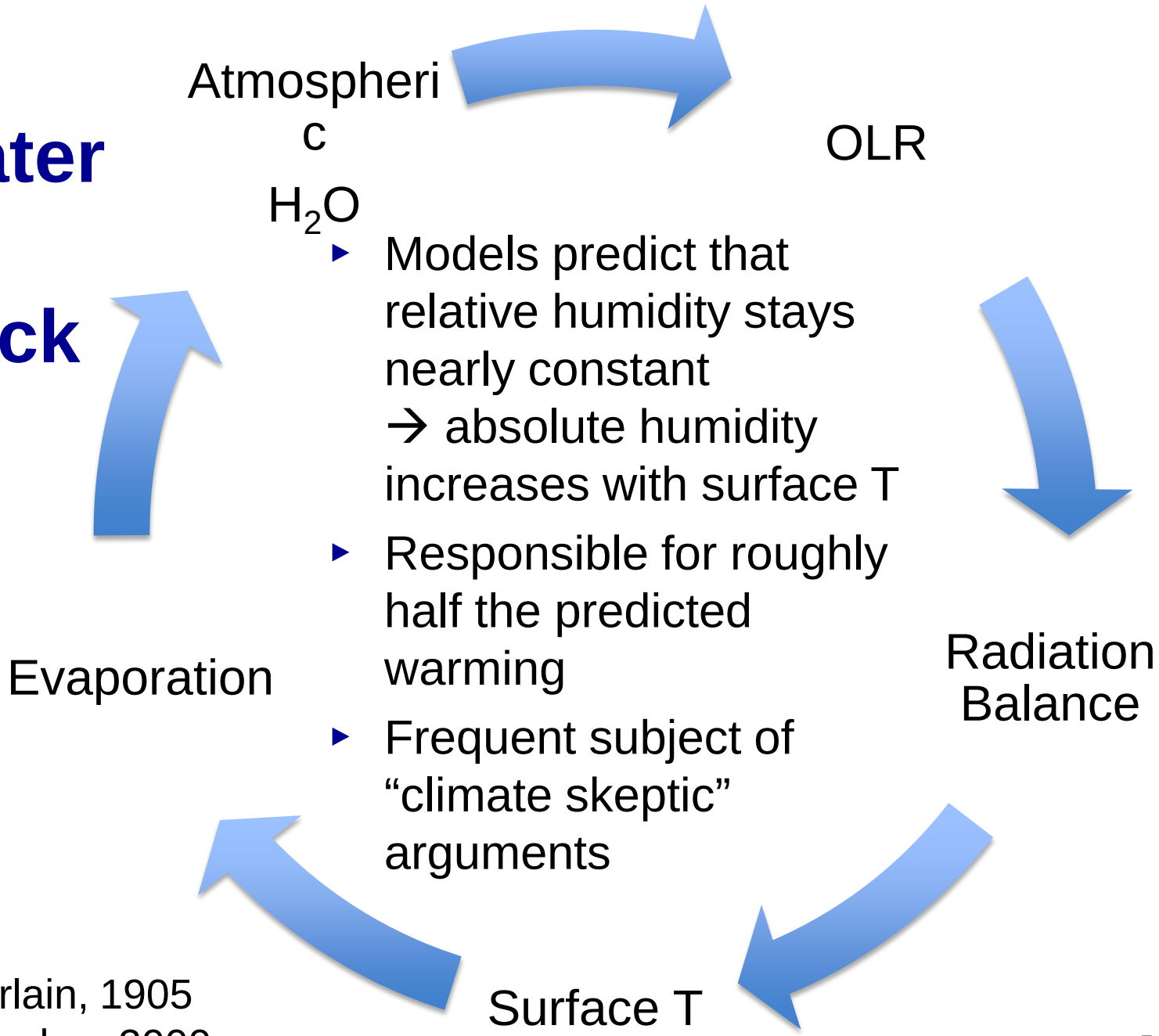
The water vapor feedback



- Models predict that relative humidity stays nearly constant
  → absolute humidity increases with surface T
- Responsible for roughly half the predicted warming
- Frequent subject of “climate skeptic” arguments

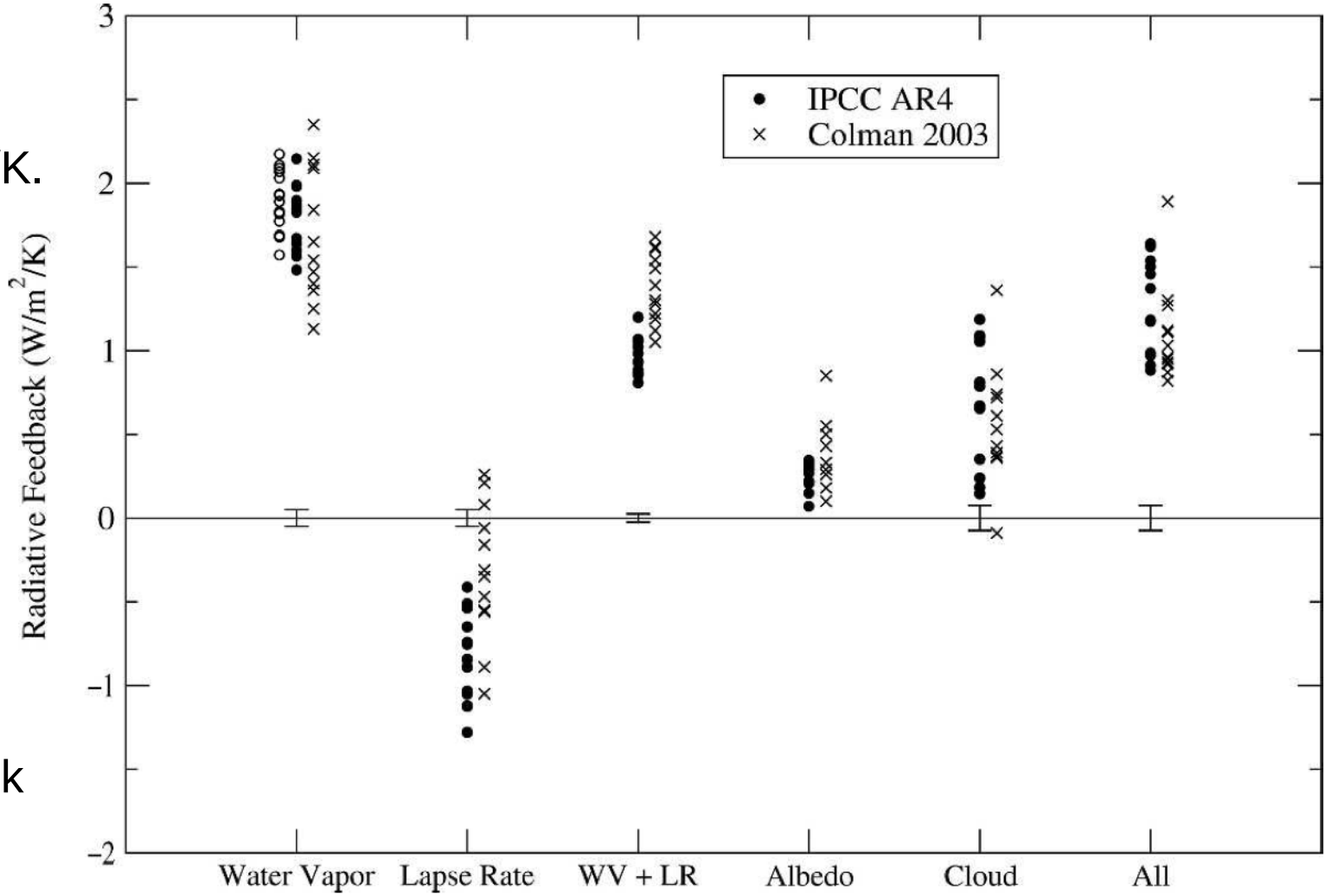
T.C. Chamberlain, 1905
z.B. Held & Soden, 2000

Water vapor and lapse rate feedback

Planck feedback ~ -3.2 W/m^2/K.

Models with large trop. warming also have large trop. moistening.

Combined H2O/lapse rate feedback still large



Soden, B. J. and I. M. Held (2006),
An assessment of climate feedbacks in coupled ocean-atmosphere models,
J. Climate, 19(14), 3354–3360.

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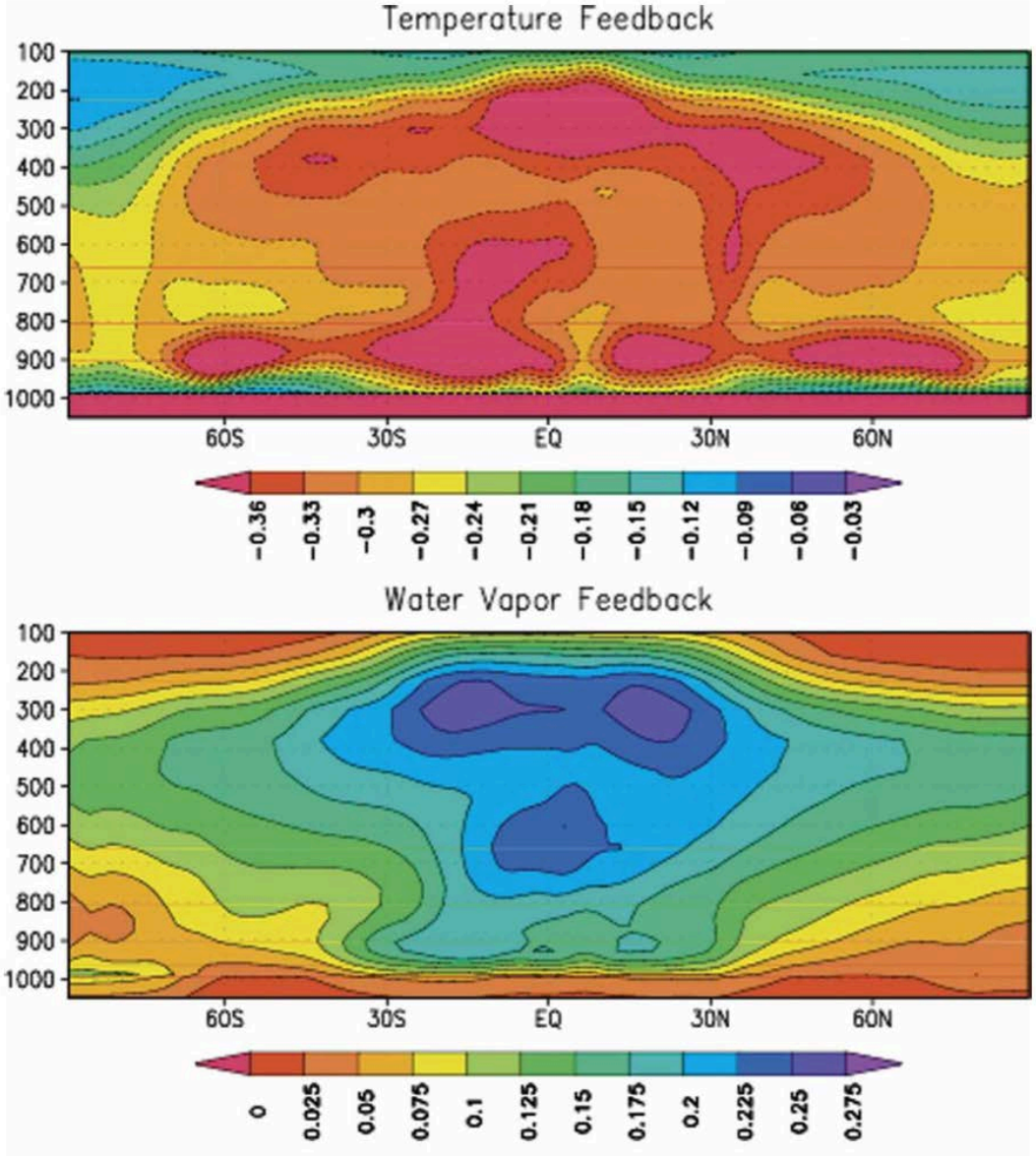
Kernel method for feedback calculation



$$\lambda_x = \frac{\partial R}{\partial x}\frac{\mathrm{dx}}{\mathrm{dT_s}}$$

λ_x : Feedback for H_2O, T, ...

R: Radiative flux at top of atmosphere

T_s : Surface temperature

Units:
W m^{-2} K^{-1} $(100\ mb)^{-1}$

Humidity changes in upper troposphere have strongest impact on radiation flux.

Soden, B. J. and I. M. Held (2006),
An assessment of climate feedbacks in coupled ocean-atmosphere models,
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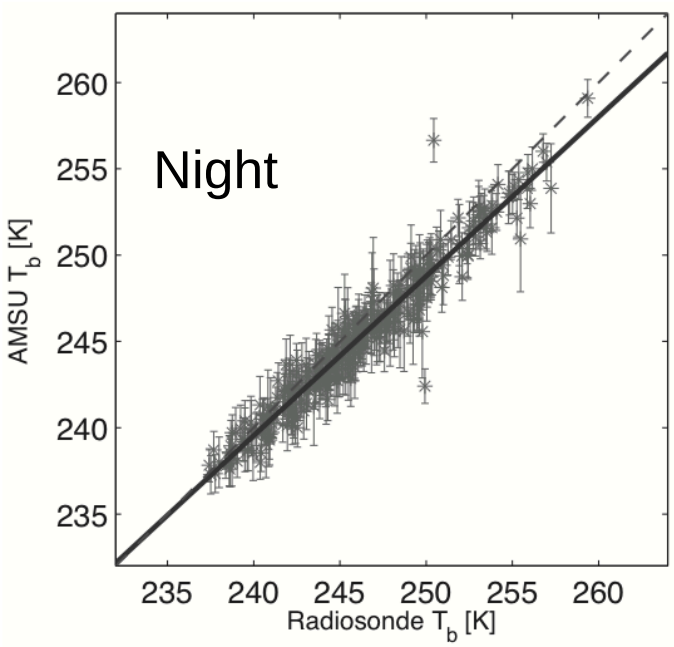
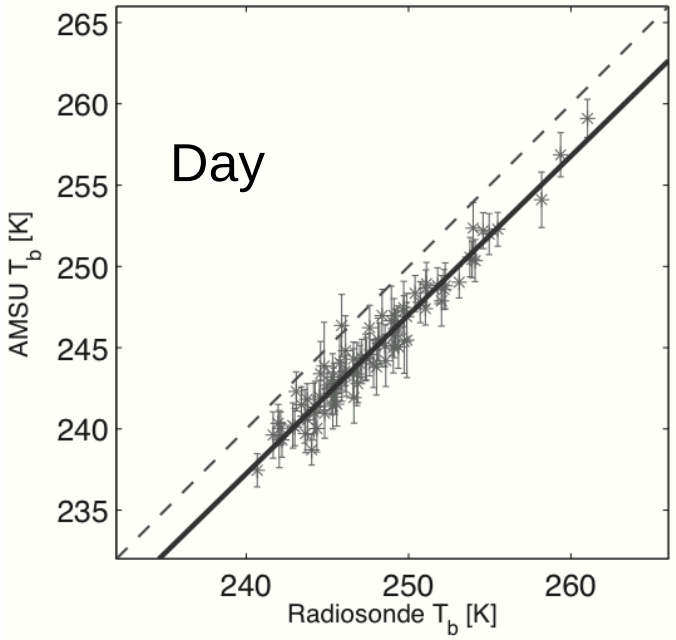
Satellite data more stable than radiosondes

Example: radiation bias





Radiosonde radiation bias, ARM Station TWP-C1

Moradi, I., S. A. Buehler, V. O. John, and S. Eliasson (2010), **Comparing upper tropospher humidity data from microwave satellite instruments and tropical radiosondes,** ***J. Geophys. Res., 115, D24310, doi:10.1029/2010JD013962.***

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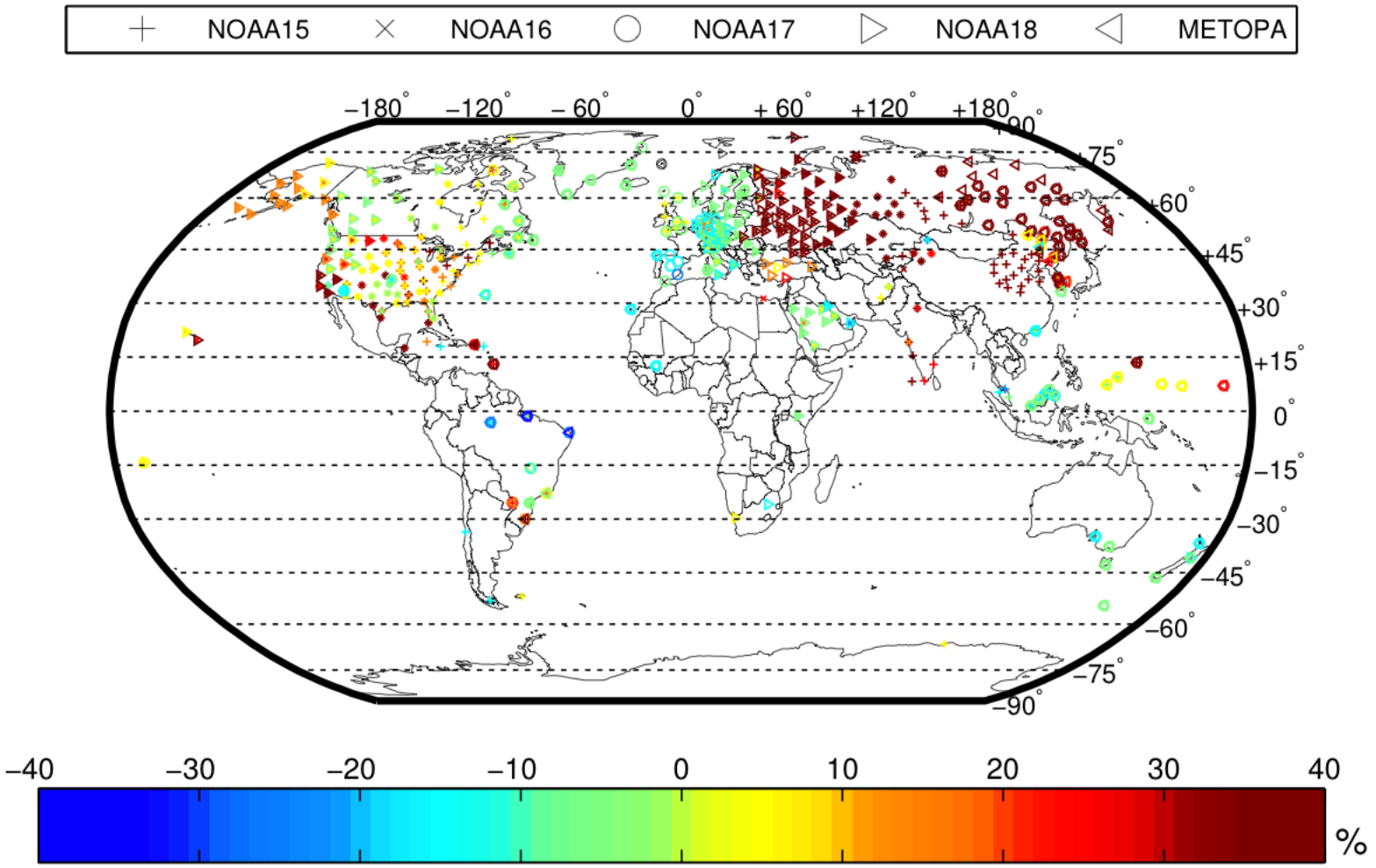
„Geopolitical“ radiosonde error



Moradi, I., S. A. Buehler, V. O. John, A. Reale, and R. R. Ferraro (2013), **Evaluating instrumental inhomogeneities in global radiosonde upper tropospheric humidity data using microwave satellite data**, *IEEE Geosci. Remote Sens.*, ***51***(6), 3615–3624, doi:10.1109/TGRS.2012.2220551.

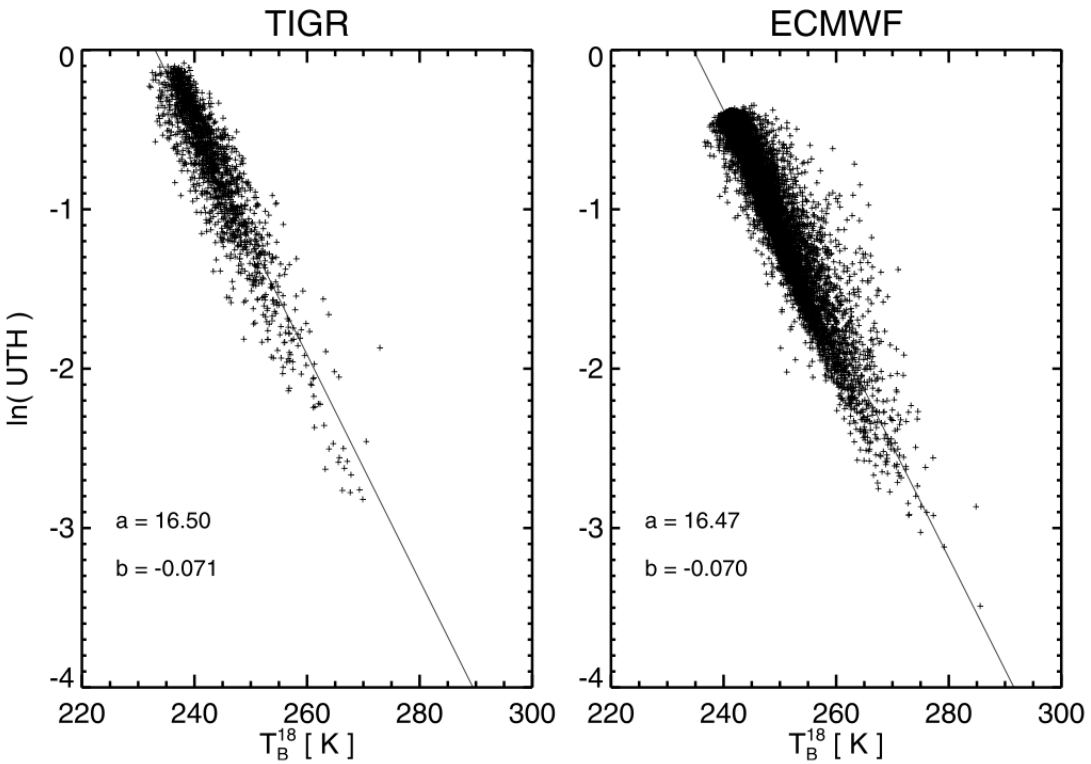
yellow-red = sonde too wet

green-blue = sonde too dry

UTH and Tb-scaling method

UTH = upper tropospheric humidity
= weighted mean relative humidity

Weighting depends on instrument/channel, broadly between 500-200 hPa



$$\ln(\mathrm{UTH}) = a + bT_b$$

UTH is more or less just a special unit for radiance, we sometimes also use radiance or brightness temperature directly.

Buehler, S. A. and V. O. John (2005),
A Simple Method to Relate Microwave Radiances to Upper Tropospheric Humidity,
J. Geophys. Res., *110*, D02110, doi:10.1029/2004JD005111.

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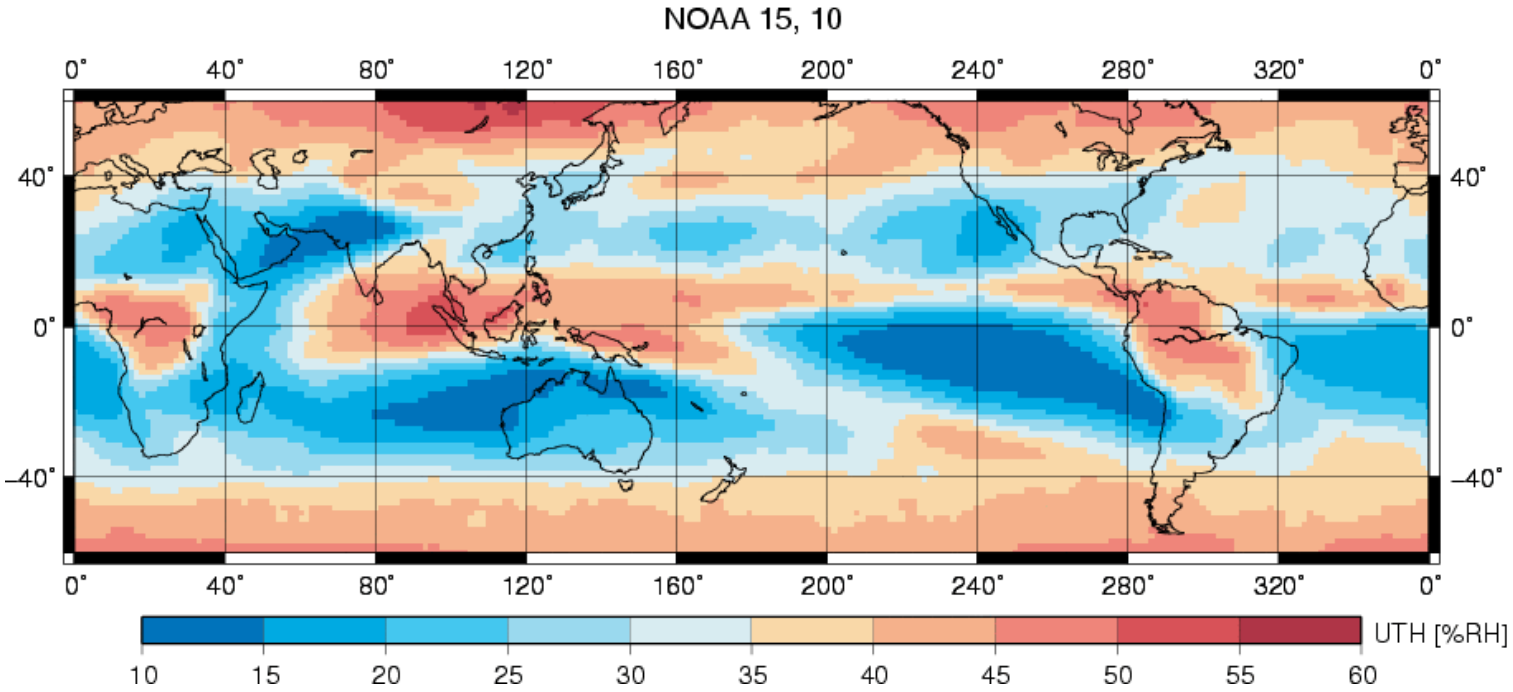
Upper tropospheric humidity climatology



Buehler, S. A., M. Kuvatov, V. O. John, M. Milz, B. J. Soden and J. Notholt (2008), **An Upper Tropospheric Humidity Data Set From Operational Satellite Microwave Data**, *J. Geophys. Res.*, *113*, D14110, doi:10.1029/2007JD009314.

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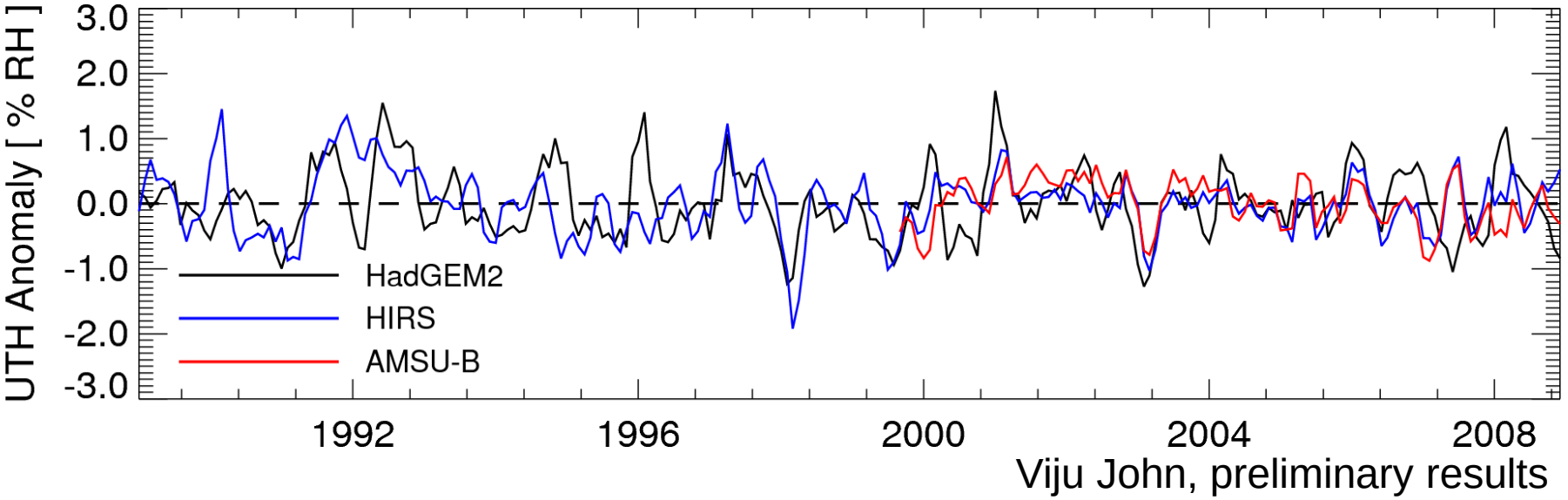
UTH time series



- De-seasonalized
- Tropical (30° S-30° N)
- Only subsidence regions
- 3 month running mean filter

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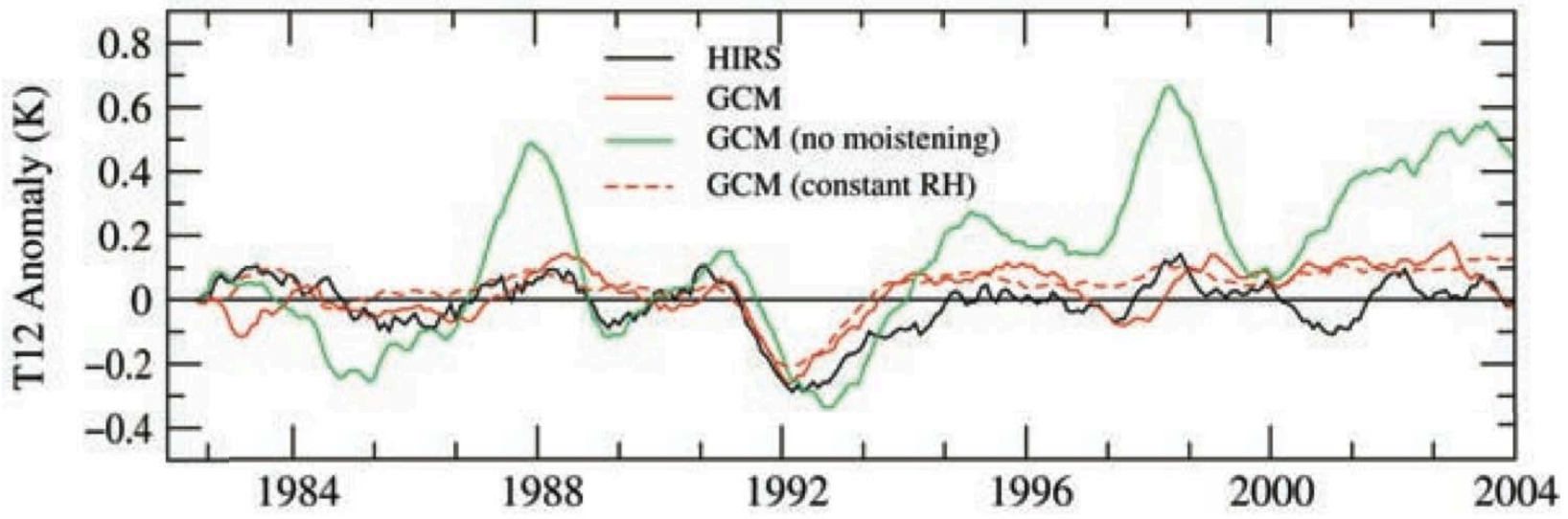
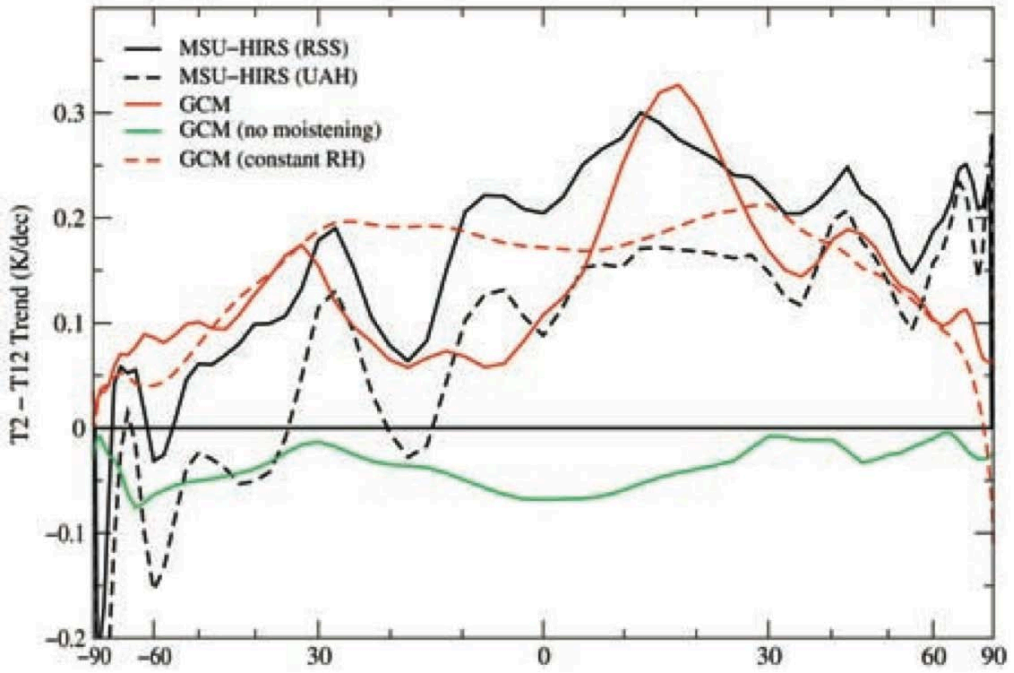
The global picture – HIRS, MSU, and GCM



Soden, B. J., D. J. Jackson, V. Ramaswamy, M. D. Schwarzkopf, and X. Huang (2005),
The Radiative Signature of Upper Tropospheric Moistening,
Science, 310(5749), 841–844,
doi:10.1126/science.1115602.

Viewed globally, UTH closely follows constant RH assumption in both models and observations.

But viewed latitudinally (or regionally), there are trend pattern deviations from the constant RH behavior, associated with changes in dynamics.



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Satellite data opportunities

- Benchmark for global model trend
- Better understand regional and decadal patterns of change
  - Are there changes in ENSO characteristics? (Has been proposed as one explanation of recent warming hiatus)
  - Are there climatological trends in the Hadley and Walker circulation patterns?
- Better understand diurnal cycles
- Consolidate GCM humidity mean states

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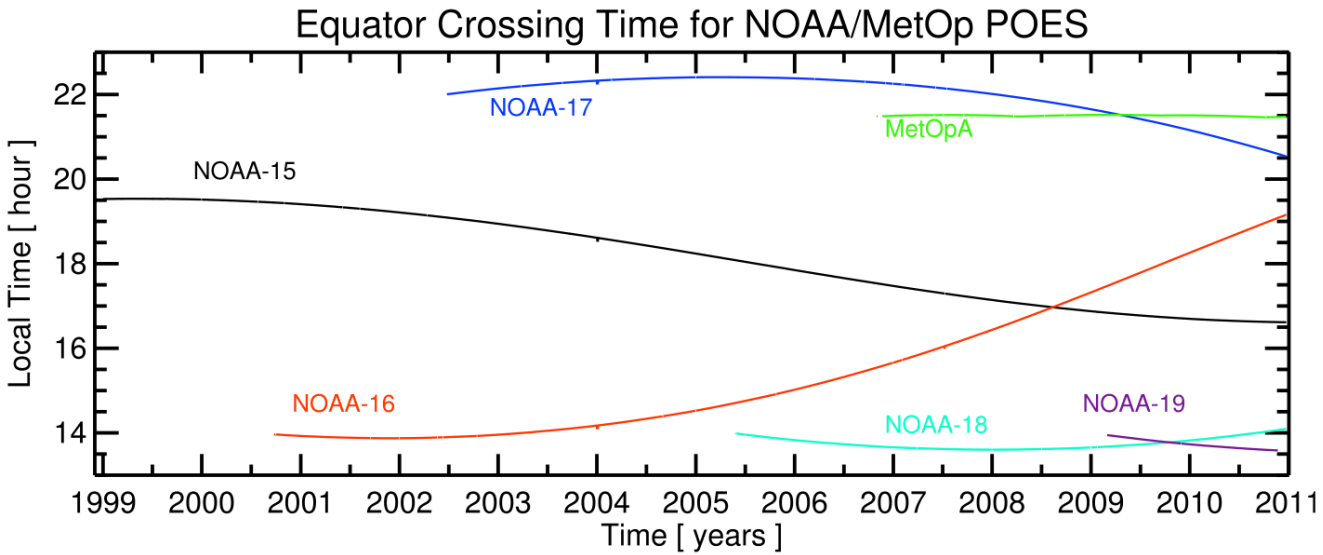
Main challenges

- Instrument bias
  (instrument offsets, scan biases)
- Orbit drift (measurement local time changes)
  (can lead to aliasing in time series)
- Clouds
  (make microwave and IR data different)



John, V. O., G. Holl, S. A. Buehler, B. Candy, R. W. Saunders, and D. E. Parker (2012), **Understanding inter-satellite biases of microwave humidity sounders using global simultaneous nadir overpasses**, *J. Geophys. Res.*, ***117***(D2), D02305, doi:10.1029/2011JD016349.

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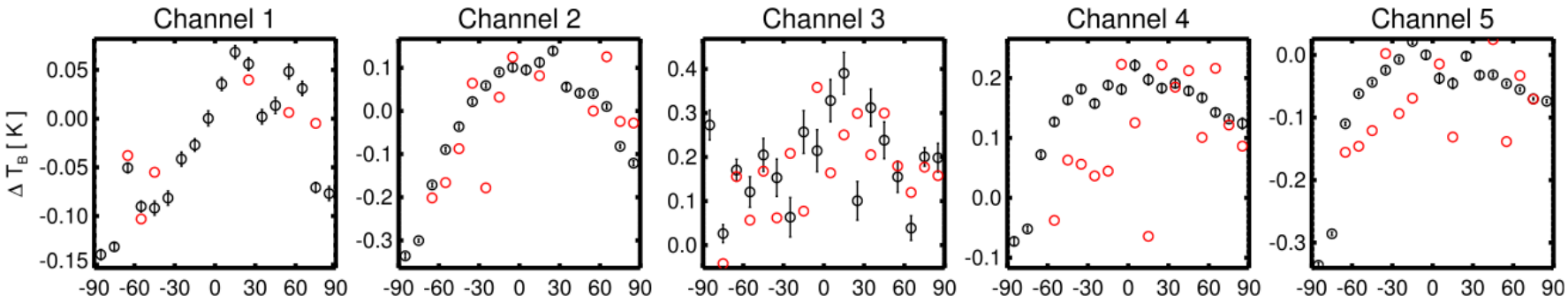
Simultaneous nadir overpasses (SNOs)

- Simultaneous nadir overpasses (SNOs) typically occur only at high latitudes, but when orbits meet due to drift they occur globally.
- Shown below: NOAA-19–NOAA-18 during September 2009-09.
- Black: SNOs, red: Estimate from zonal mean data.
- A large part of the latitude dependence really is scene radiance dependence.



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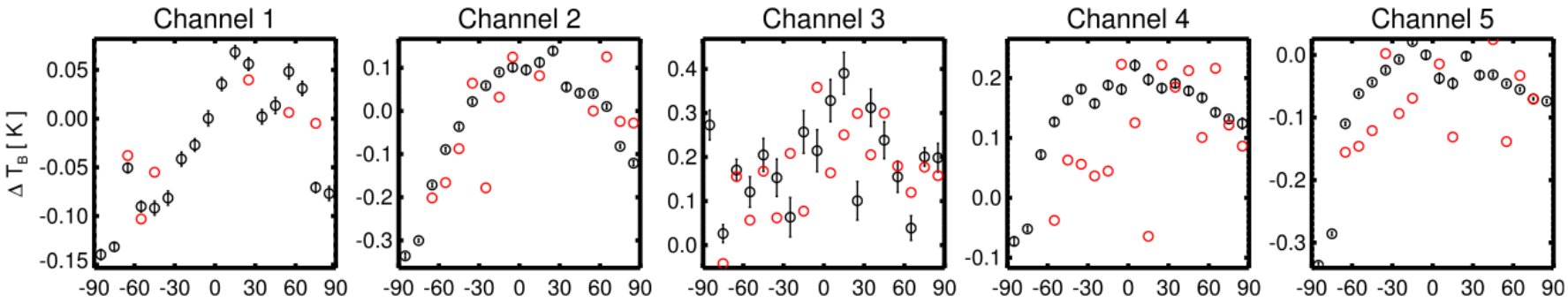
Simultaneous nadir overpasses (SNOs)

- Since normal SNOs occur only at high latitudes, biases derived from them will not be representative for the global data.



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Scan biases

- Microwave humidity sounders are cross track scanners
- Unfortunately suffer from scan dependent biases, partly due to radio interference problems, especially on NOAA-15
- Studies:
  - John, V. O., G. Holl, N. Atkinson, and S. A. Buehler (2013), **Monitoring scan asymmetry of microwave humidity sounding channels using simultaneous all angle collocations (SAACs)**, *J. Geophys. Res.*, ***118***, 1536–1545, doi:10.1002/jgrd.50154.
  - Buehler, S. A., M. Kuvatov, and V. O. John (2005), **Scan asymmetries in AMSU-B data**, *Geophys. Res. Lett.*, ***32***, L24810, doi:10.1029/2005GL024747.

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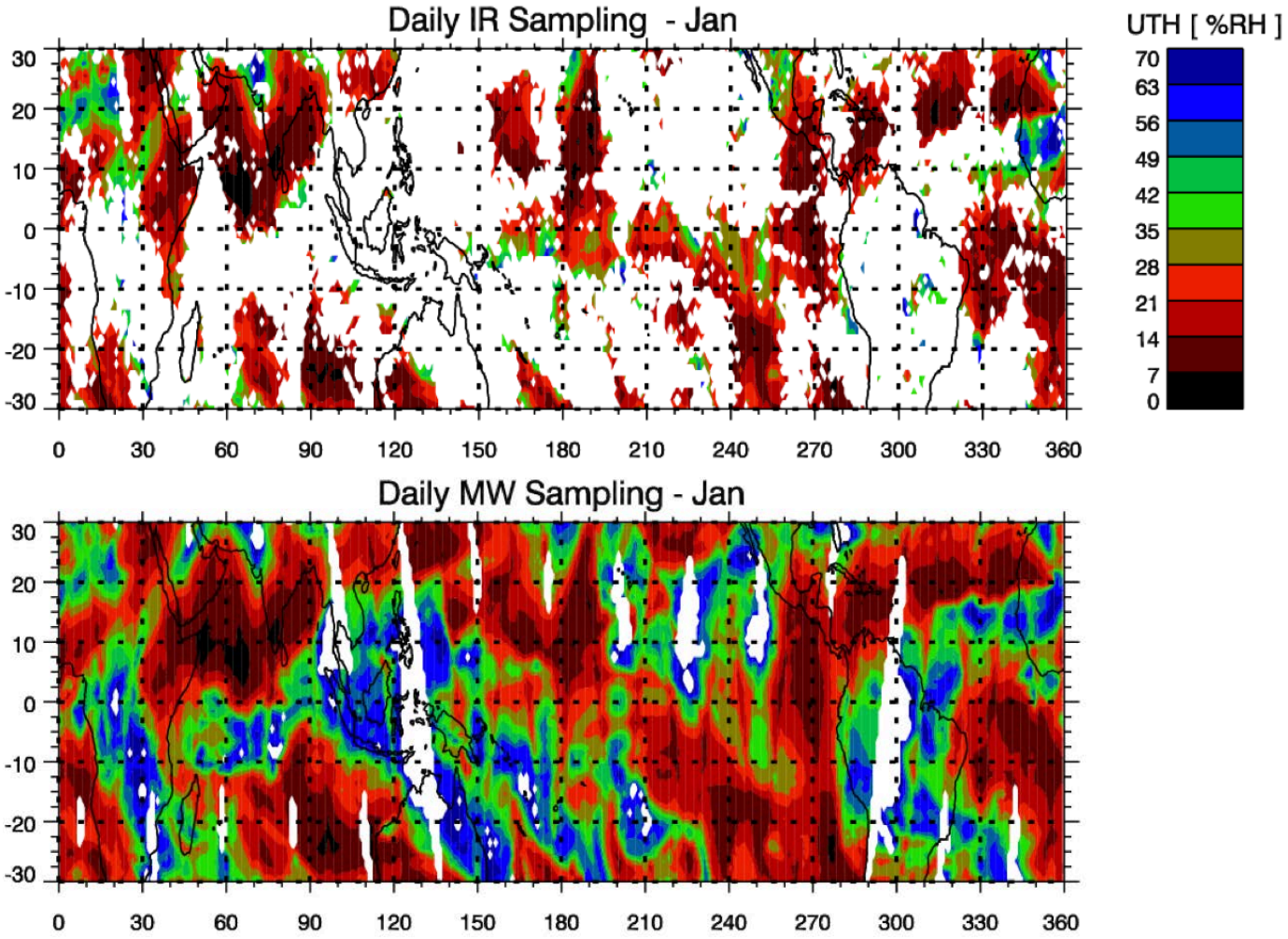
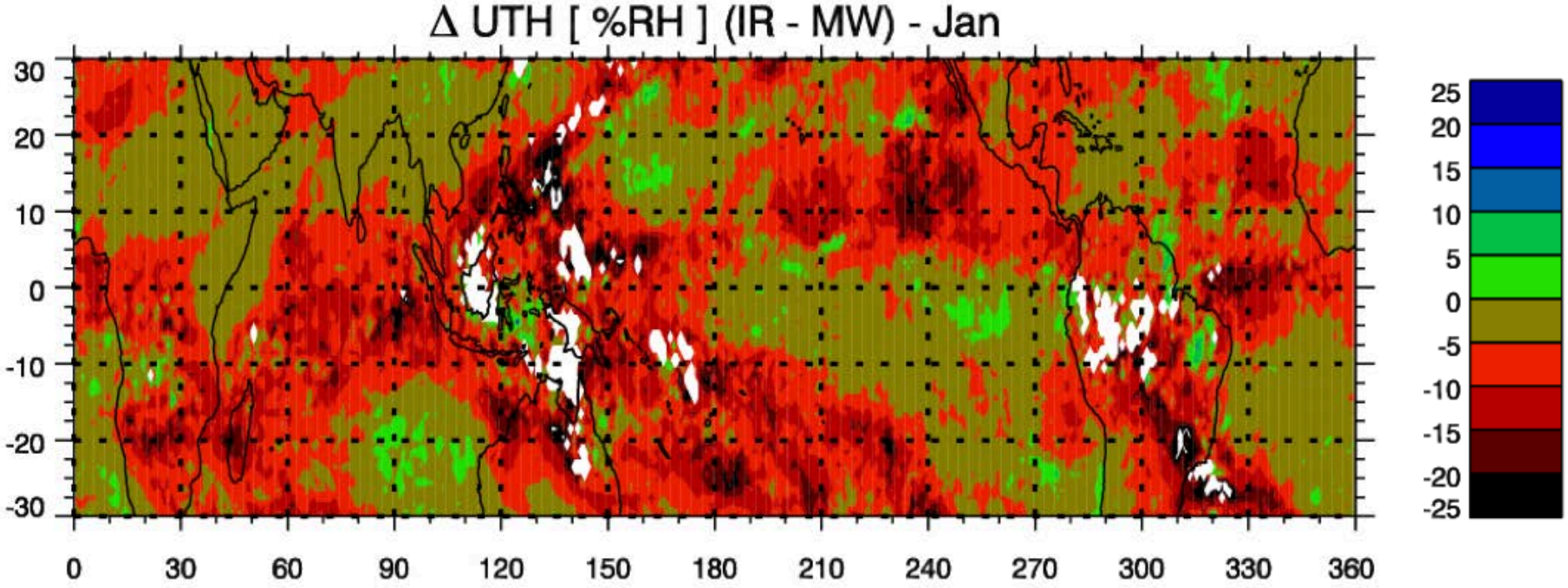
Clouds



John, V. O., G. Holl, R. P. Allan, S. A. Buehler, D. E. Parker, and B. J. Soden (2011), **Clear-sky biases in satellite infra-red estimates of upper tropospheric humidity and its trends**, *J. Geophys. Res.*, ***116***, D14108, doi:10.1029/2010JD015355.

IR dry bias compared to MW



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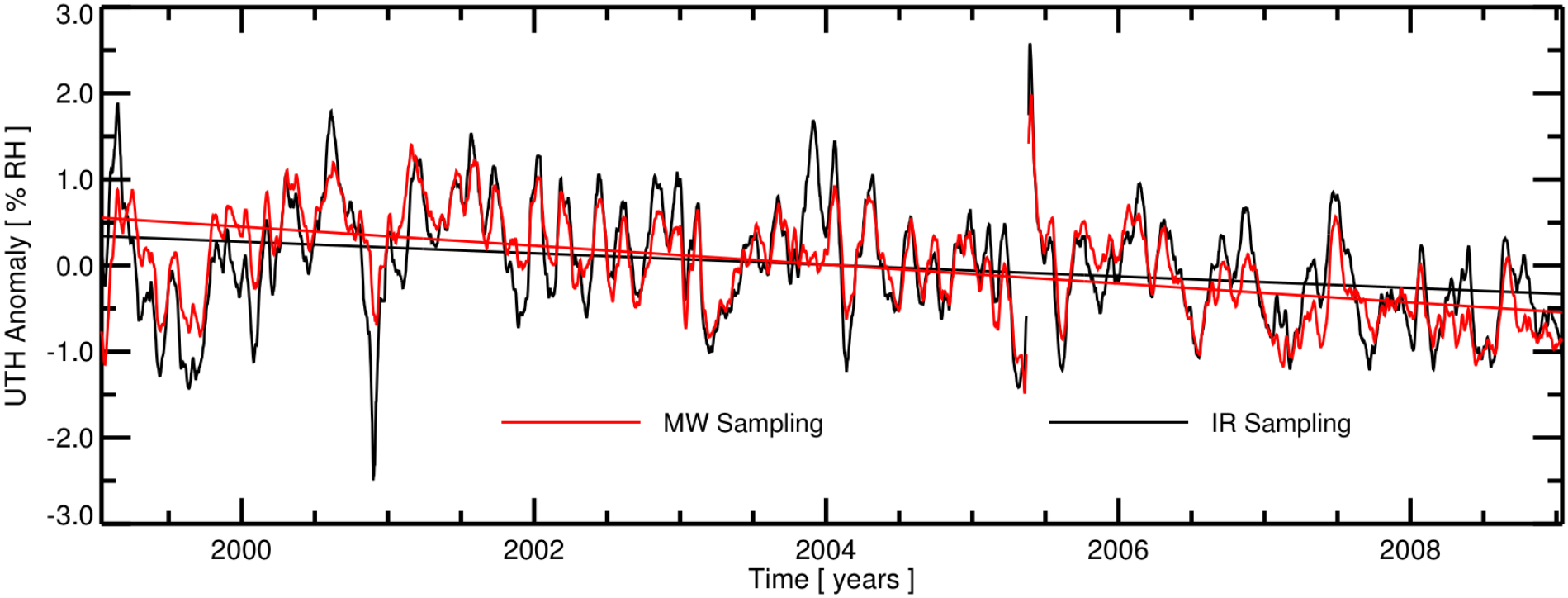
Impact on timeseries



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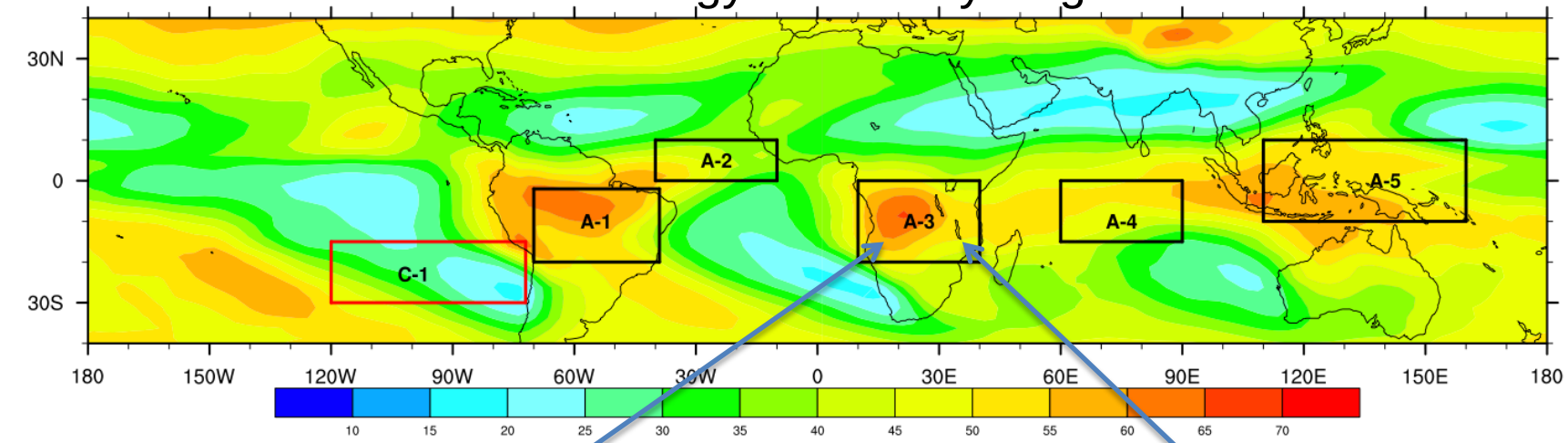
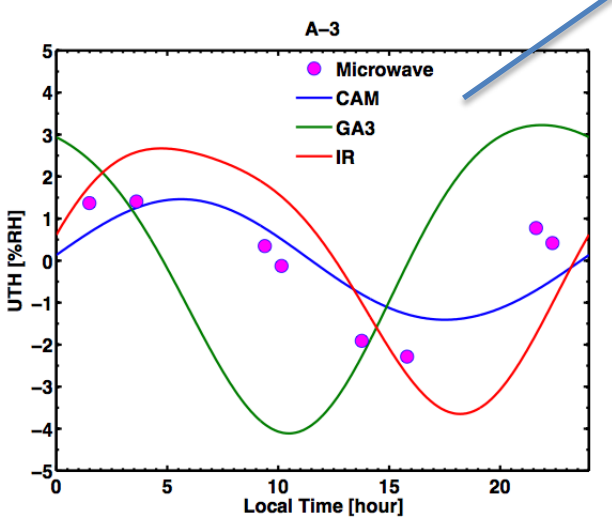
Cloud Impact on diurnal cycle

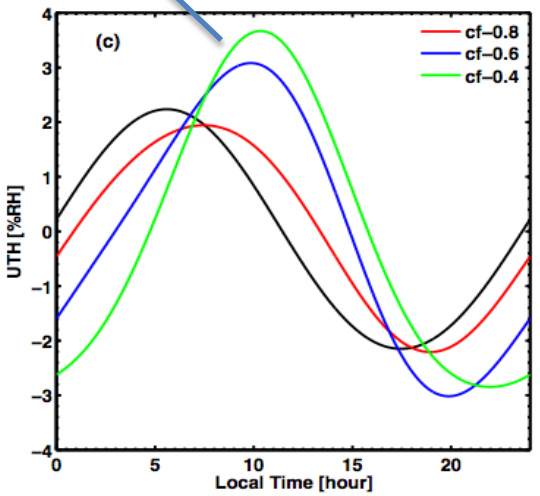
UTH Climatology with Study Regions





Left: Observed and modeled diurnal cycles.

Right: Diurnal cycle from CAM5 climate model as is (black), and with different cloud fraction thresholds, simulating IR data.



Kottayil et al., under review JGR

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Summary and conclusions

- UTH very important for climate research
- Still a lot of technical work to do for microwave humidity satellite data homogenization
- Goal, derive FCDR = consistent low level data record of all historic missions
- Disentangling instrumental problems and orbit drift is a tough but crucial challenge

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Poster advertisements

- A new microwave radiance fundamental climate data record for upper tropospheric humidity by John et al.
- Initial assessment of SSM/T-2 radiances by Chung et al.