MOZAIC-UTH

Routine Aircraft Measurements of Water Vapor in a Global Observing System: The Link Between Surface and Space

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MOZAIC:Measurement of Ozone and Water Vapor by Airbus In-Service Aircraft

Passenger Aircraft as Observation Platform for Atmospheric Research

- Five Passenger A340-aircraft, operated by 3 European Airlines on scheduled flights
- Quasi continuous sampling between 0 and 12 km altitude
- 2,000 Flights per year; 250,000 hours of O_3 and H_2O data since August 1994
- CO and NO_Y since 2001

Importance of Water Vapor in Climate and Future Changes

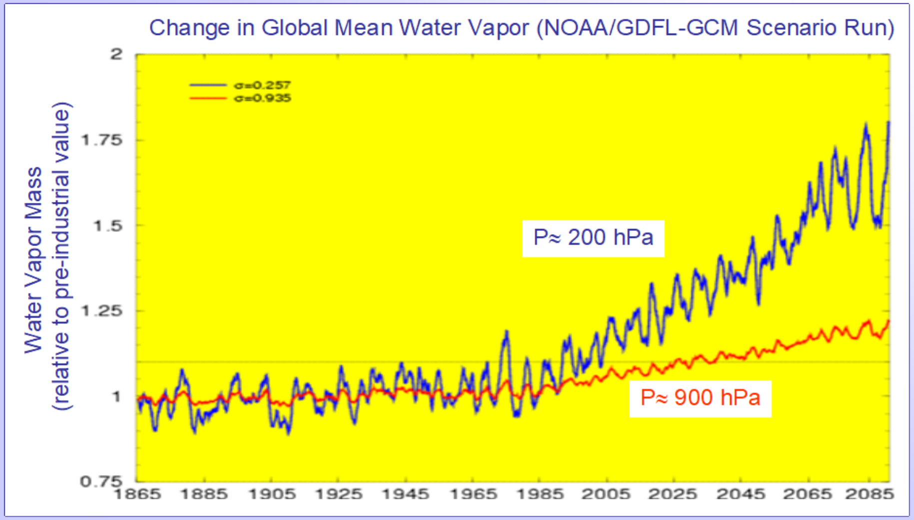
Water Vapor Plays Key Role in Climate and Future Changes

- Engine of atmospheric dynamics
- Most prominent greenhouse gas
- Strong interaction with clouds & aerosols

IPCC-Reports 1990‘s and 2001:

Doubling CO_2-concentration ⇒ 2-5°C Temperature increase

- ➢ 1/3-part: direct via CO_2
- ➢ 2/3-part: via positive feedback of H_2O (vapor+clouds)

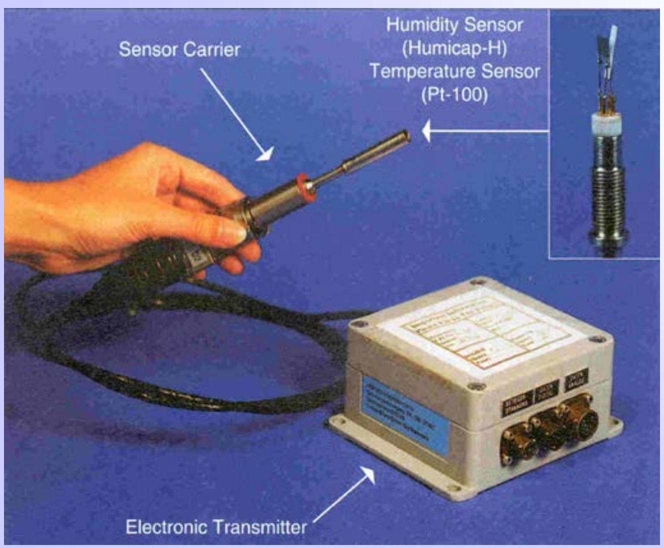


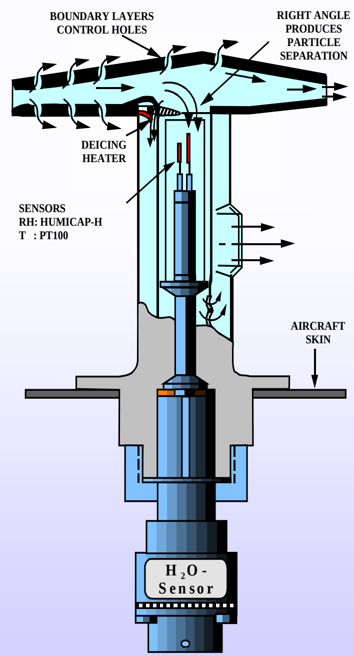
Crucial in climate research:

- Processes govern UTH
- Feedback of H_2O in UT

Urgent need for
accurate climatologies of UTH
with global coverage

MOZAIC: Humidity Sampling





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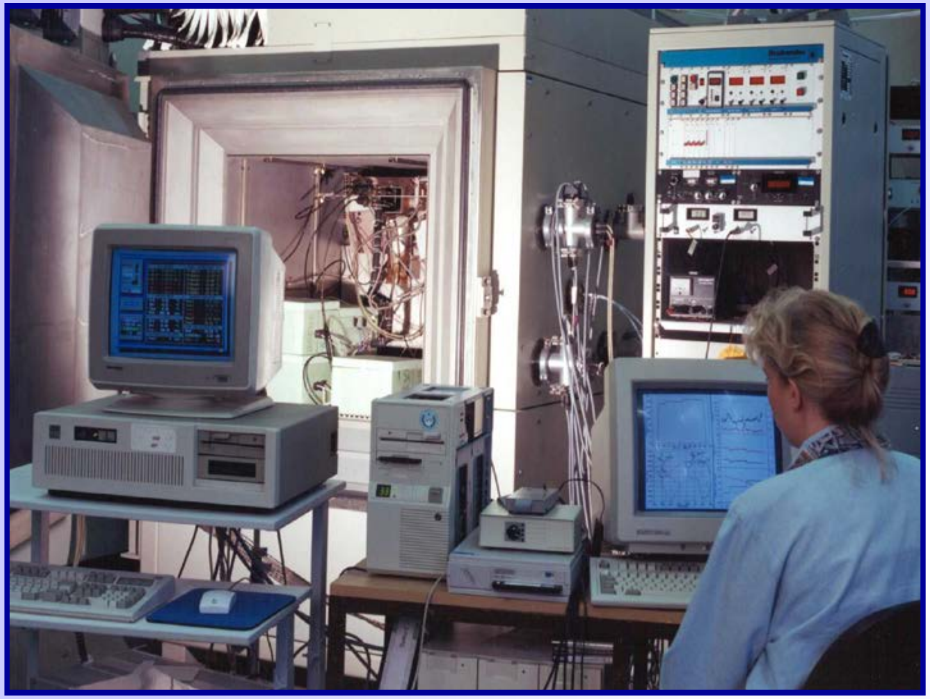
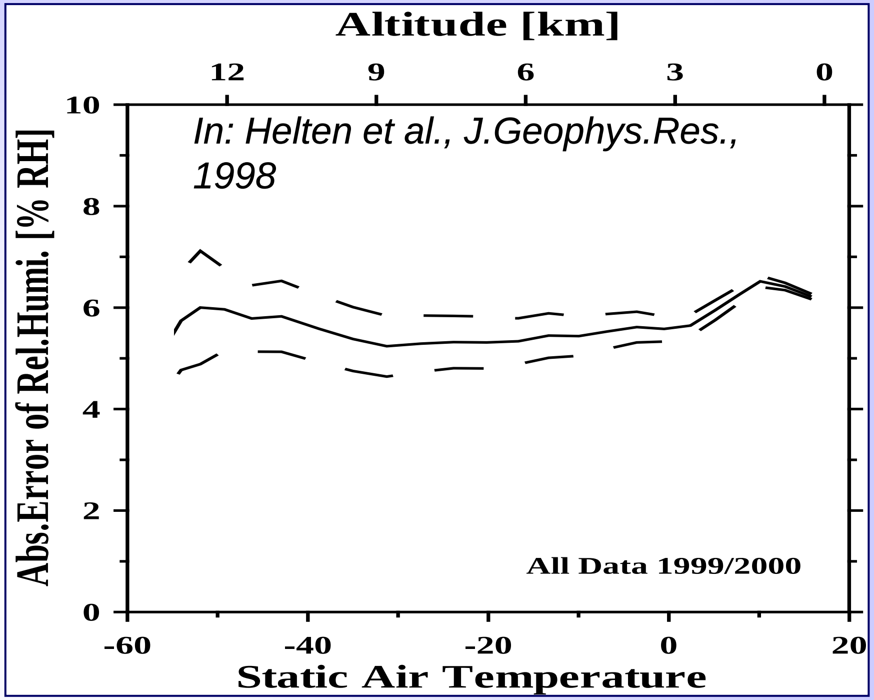
MOZAIC-Humidity Device: Pre-&Post Flight Calibration



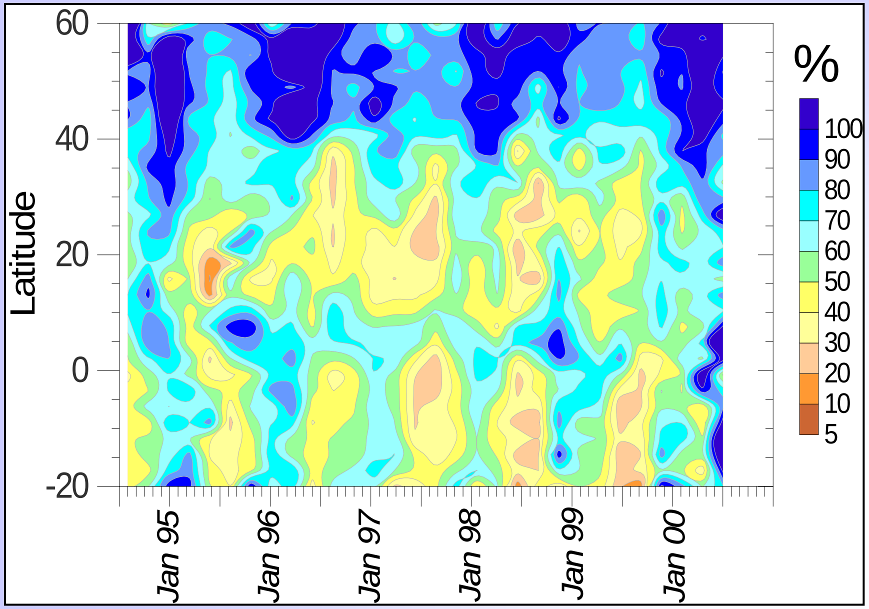


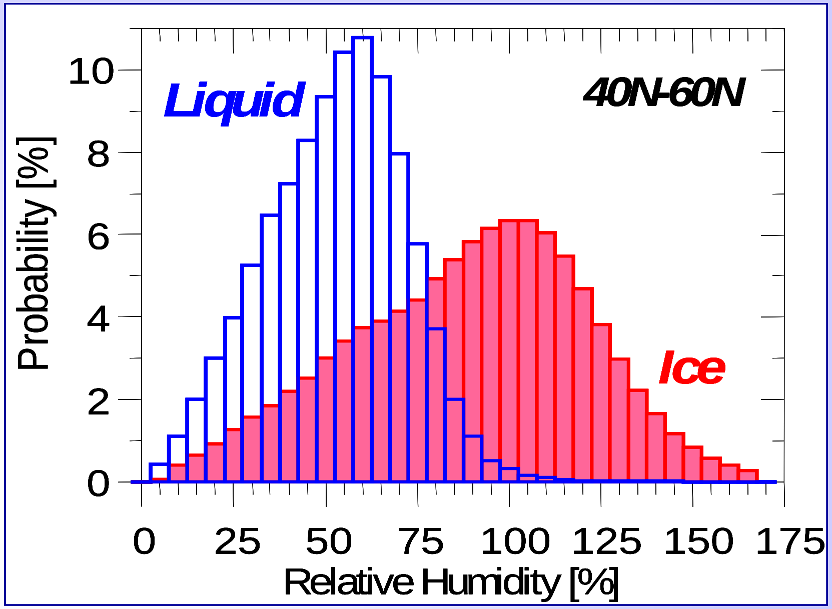
- Regular calibration (every 500 flight hours)
- In environmental simulation chamber
- Against Lyman(α)-fluorescence hygrometer
- Under realistic flight conditions of humidity, temperature and pressure

- Evaluation of two year record of pre- and post-flight calibrations
- Results agree well with in-flight intercomparisons

  [Helten et al. Geophys.Res.1998, 1999]

MOZAIC Relative Humidity in Upper Troposphere (UT) over Atlantic





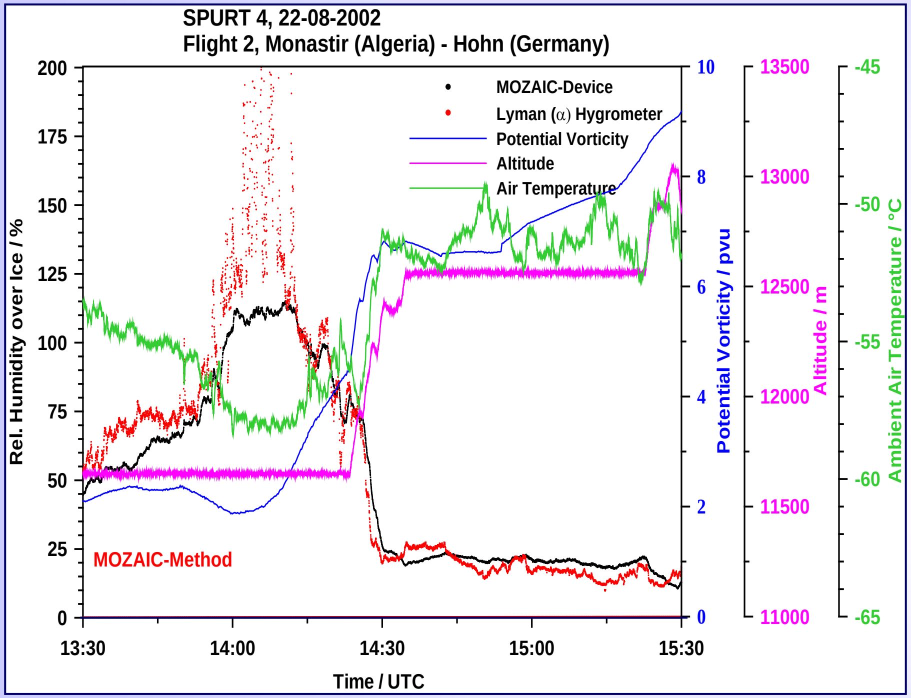
- MOZAIC provided the first climatology of humidity in the UT
- Large variability in time and space

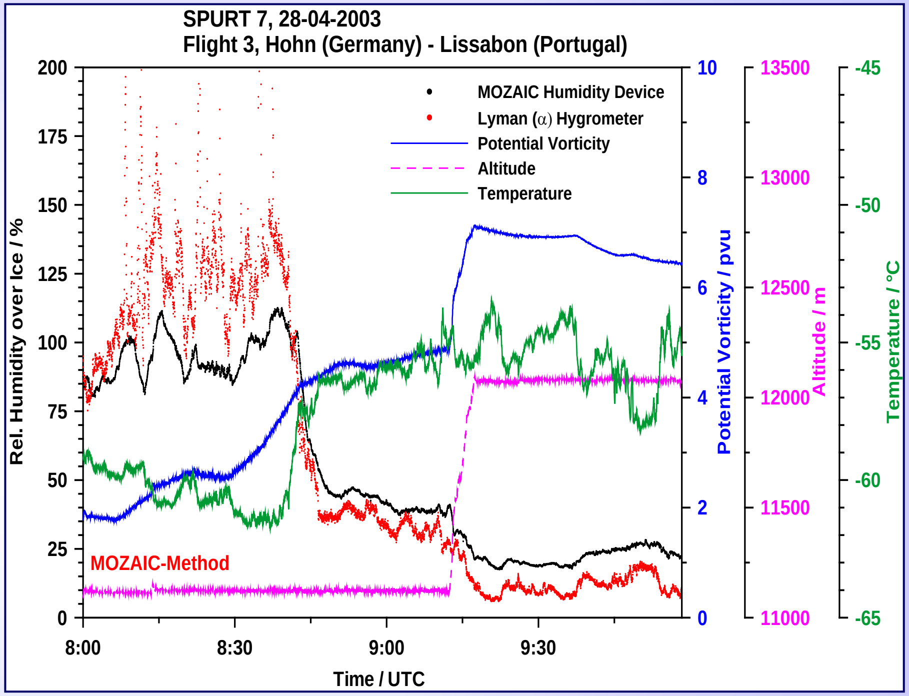
- More than 30% of UTH-data are Ice Super Saturated (ISS)
- But less than 0.5-1% of data are Saturated to Liquid

➢ Long Term Changes ??

➢ Control of Humidity in UT??

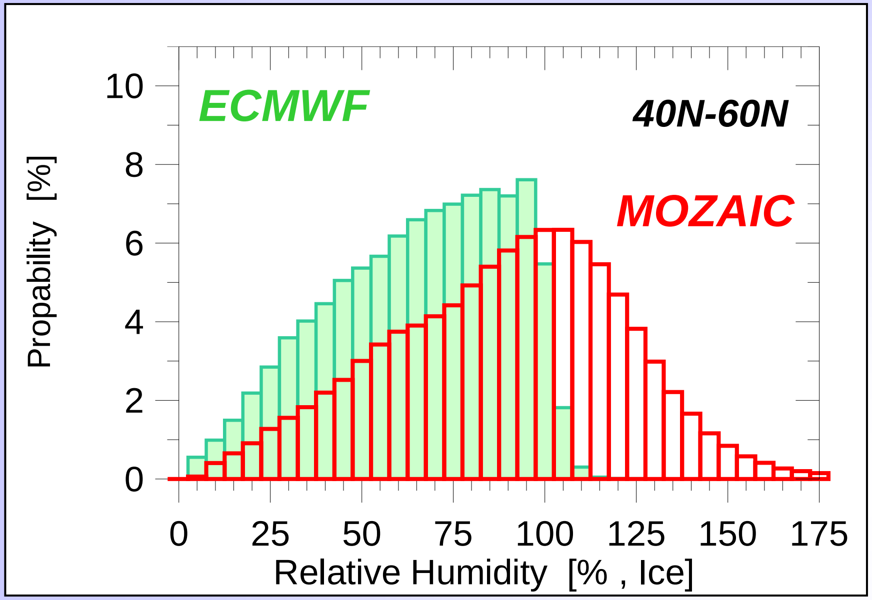
Performance MOZAIC Humidity Device in Clouds
Evaporation of Ice Crystals ???????

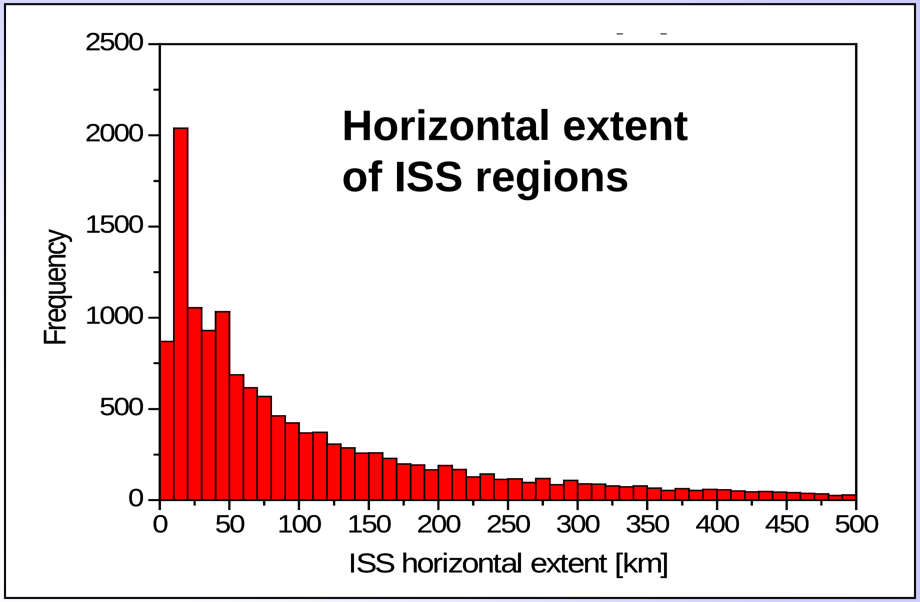




- Clouds are clearly detected as „RHI-burst“ to 200% by the Lyman (α)-Total H_2O
- In clouds the MOZAIC-Humidity Device not exceeding 100% RHI

MOZAIC: Ice Super Saturation (ISS) in the UT





- 30% of the UT shows ice super saturation (ISS)
- Global models do not reproduce ISS
- ISS relates with sub-visible cirrus

- Small scale phenomenon (ΔX < 200 km, ΔZ < 1-2 km)
- Difficult to see by satellites
- Importance:
  contrail & cirrus formation;
  radiative balance; OH formation

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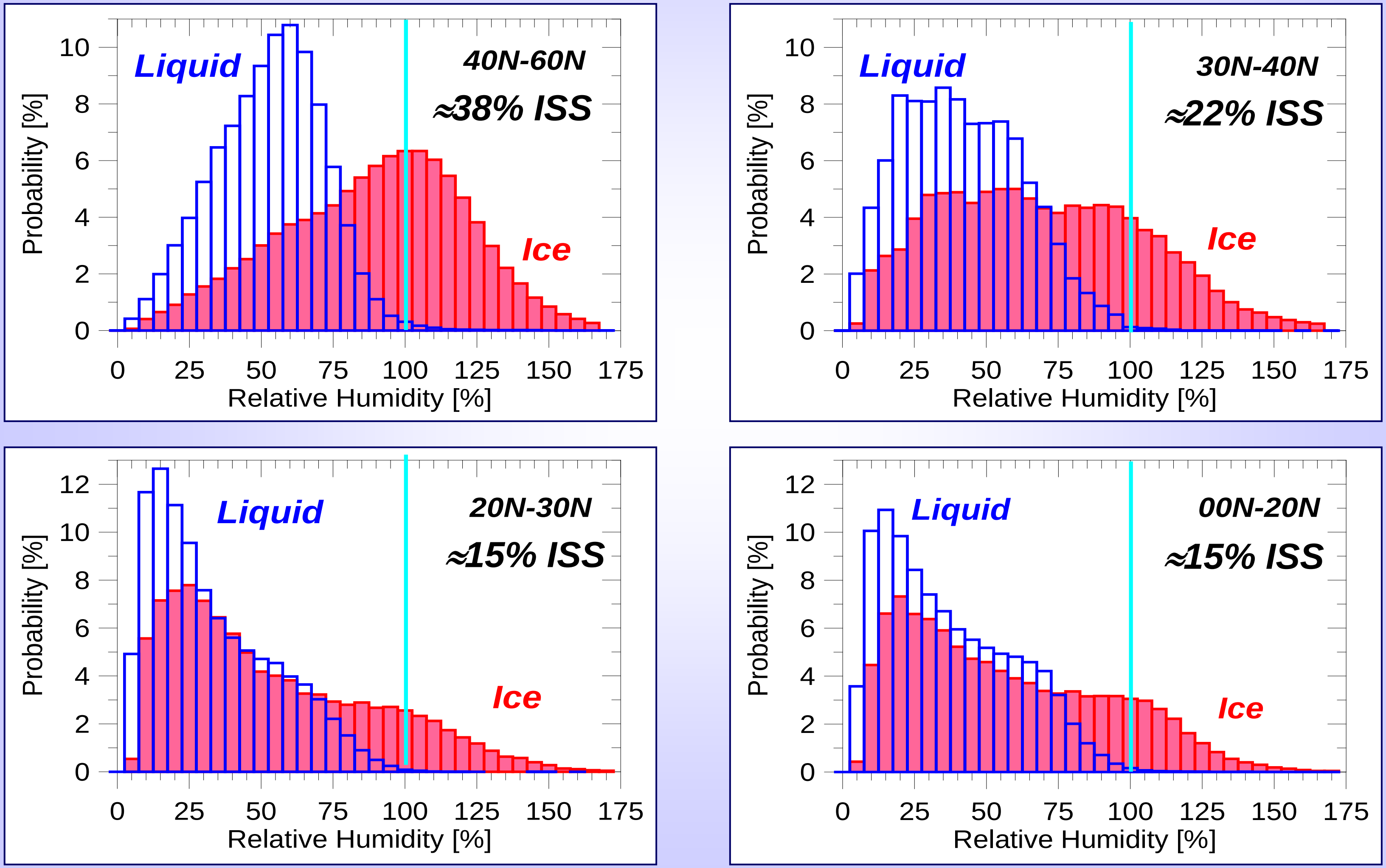
MOZAIC: Distribution Relative Humidity in UT over Atlantic

Z = 9-12 km, PV ≤ 2.0pvu, 10^oW-70^oW, Aug 1994 - June 2000



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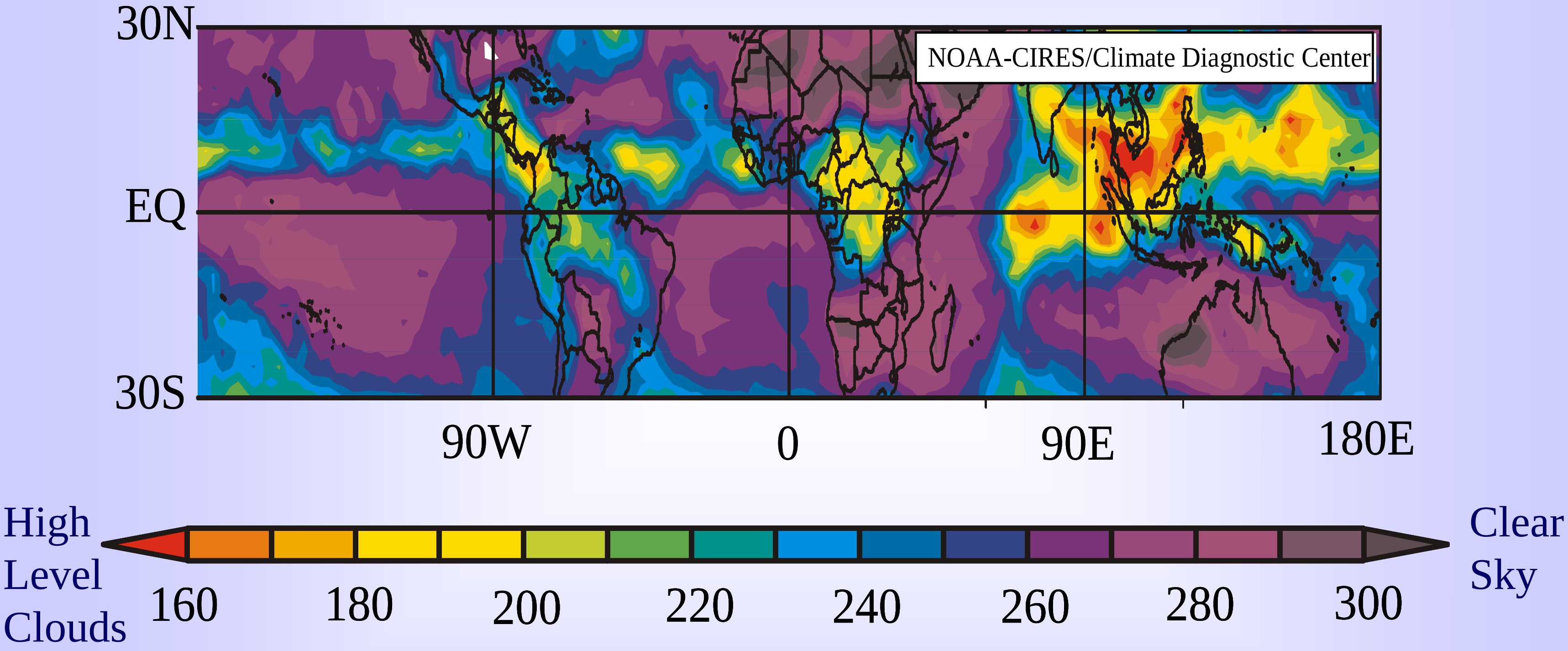
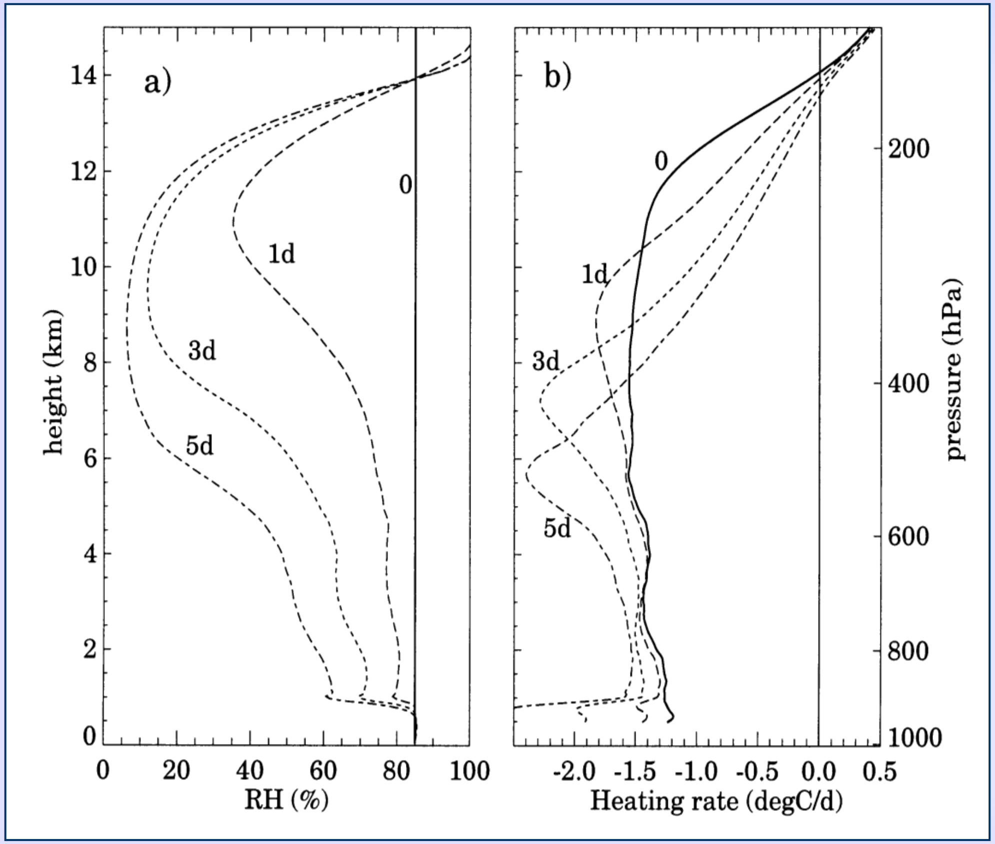
How Dry Are The Tropics ?
Global Distribution of OLR (Outgoing Longwave Radiation)

OLR (W/m2) Composite Mean 9/26-88 to 9/30/88



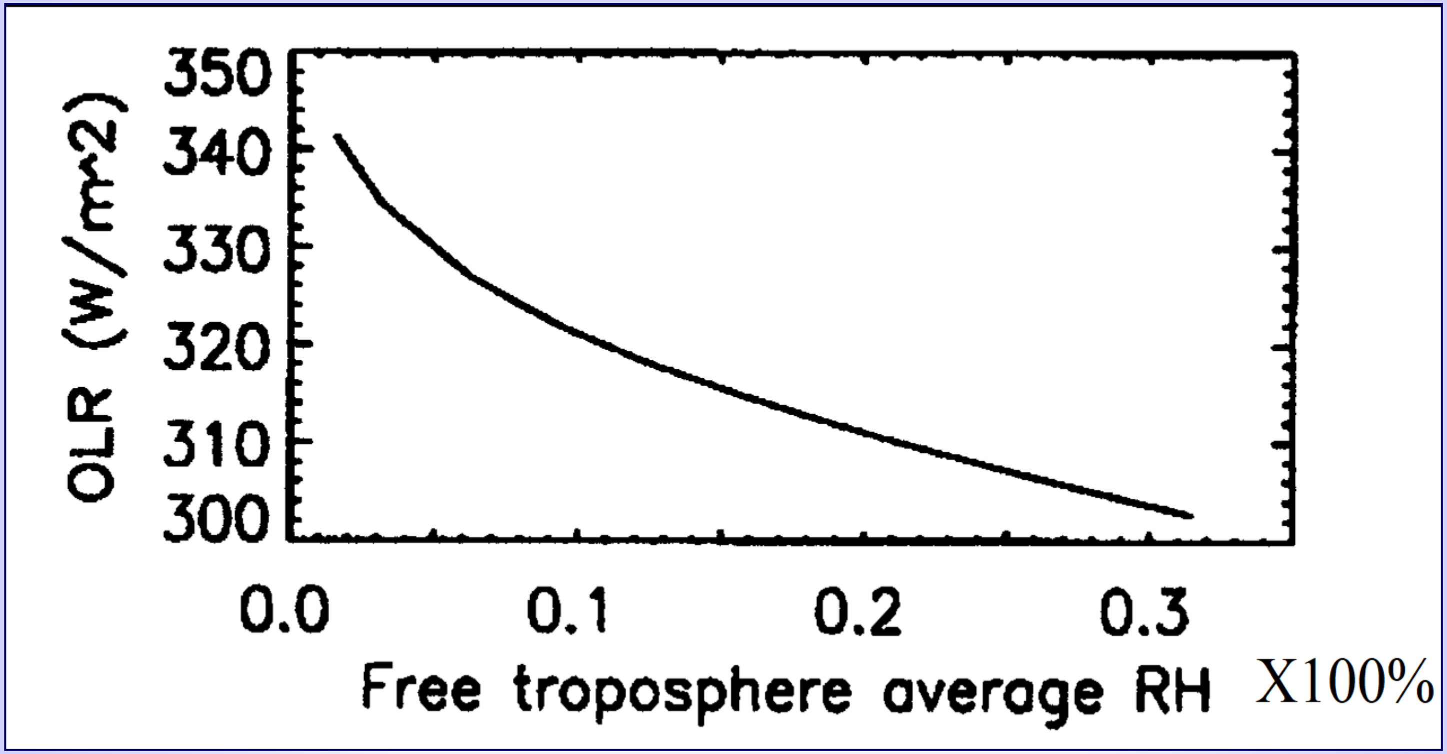
o Less than 1/3 of the Tropics is in active convection
o More than 2/3 is subject to subsidence

How fast can saturated Tropics getting dry under clear sky conditions??



Evolution of vertical relative humidity profile under cloudless conditions and subject to diabatic subsidence (left diagram), and corresponding evolution of the radiative cooling profile (right diagram). Source: Mapes et al., Quart. J. Roy. Met.Soc., 2002

High Sensitivity of OLR at Low Humidities



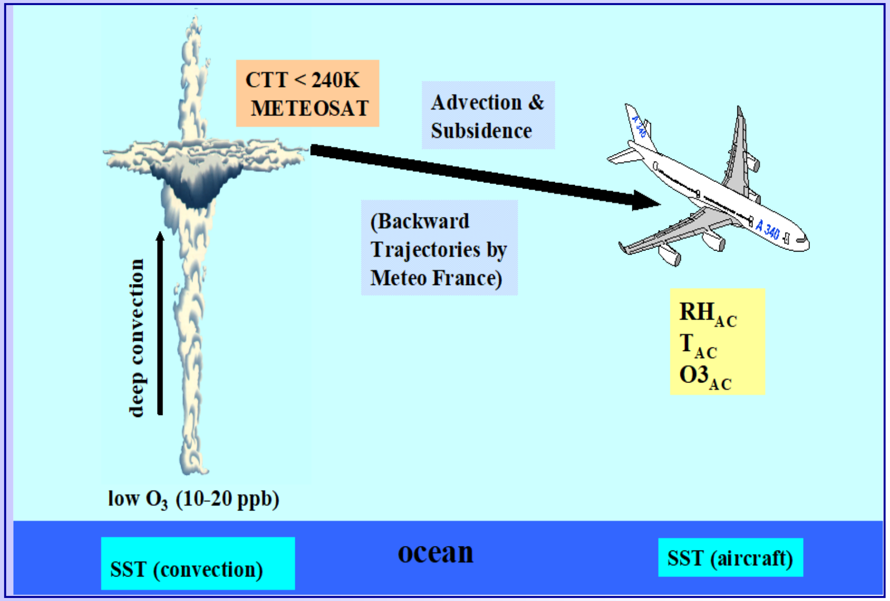
OLR calculated as function of RH (over vertical column: 800-100 hPa)

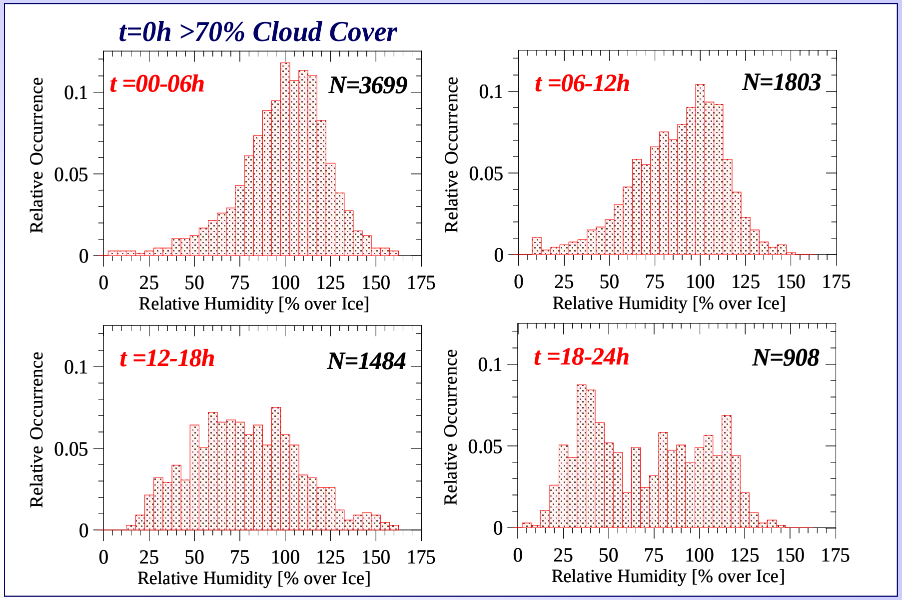
>>>>>> Δ OLR / Δ RH = 0.7 W/m2 per percentage RH (Note: CO_2 x2 = 4 W/m2)

Source:

Spencer, R.W., and W.D. Braswell, How dry is the tropical free troposphere? Implications for global warming theory, *Bull. Am. Meteorol. Soc.*, *78*, 1097-1106, **1997**.

MOZAIC: UTH in outflow of Cb-Convection

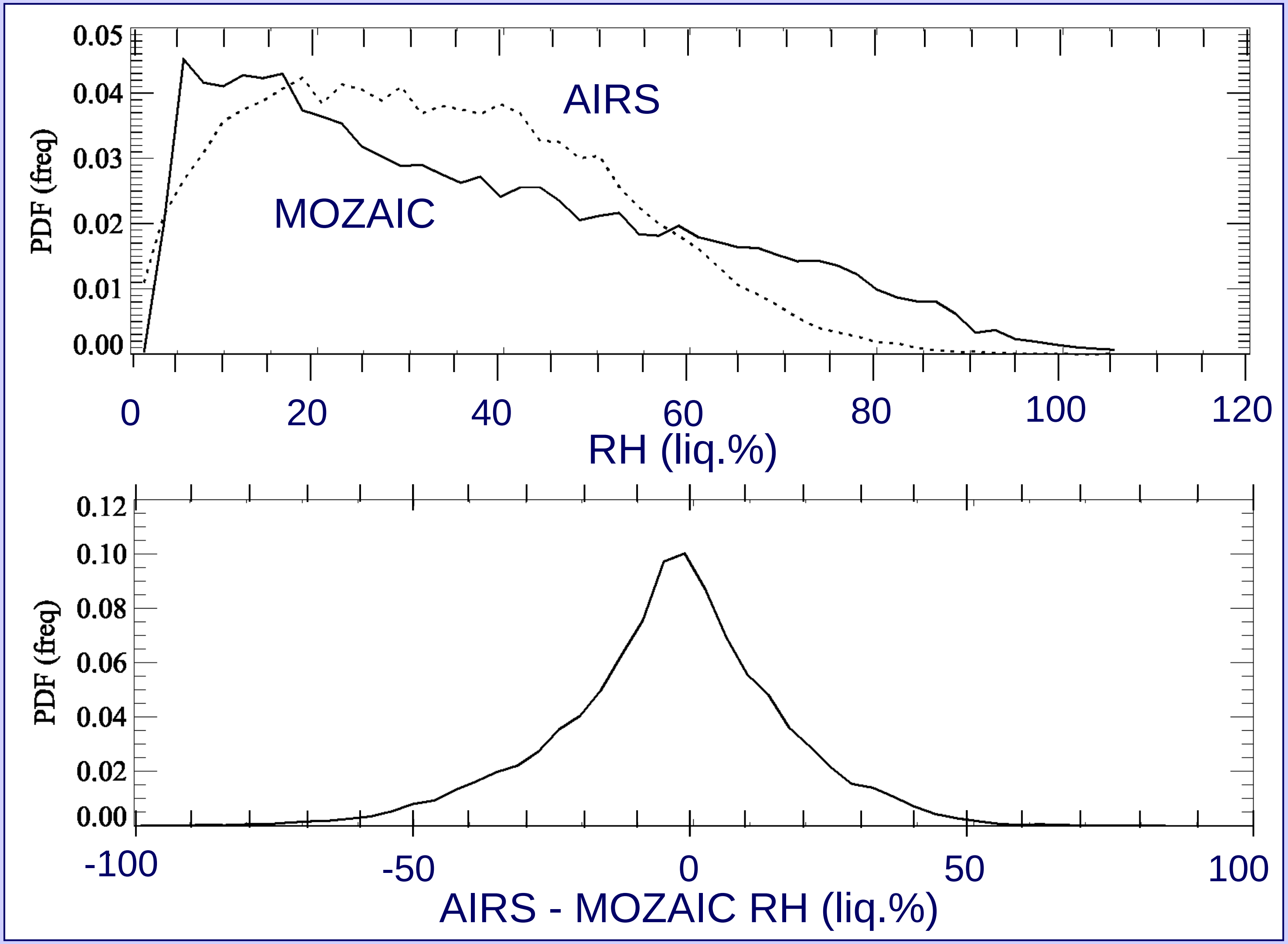


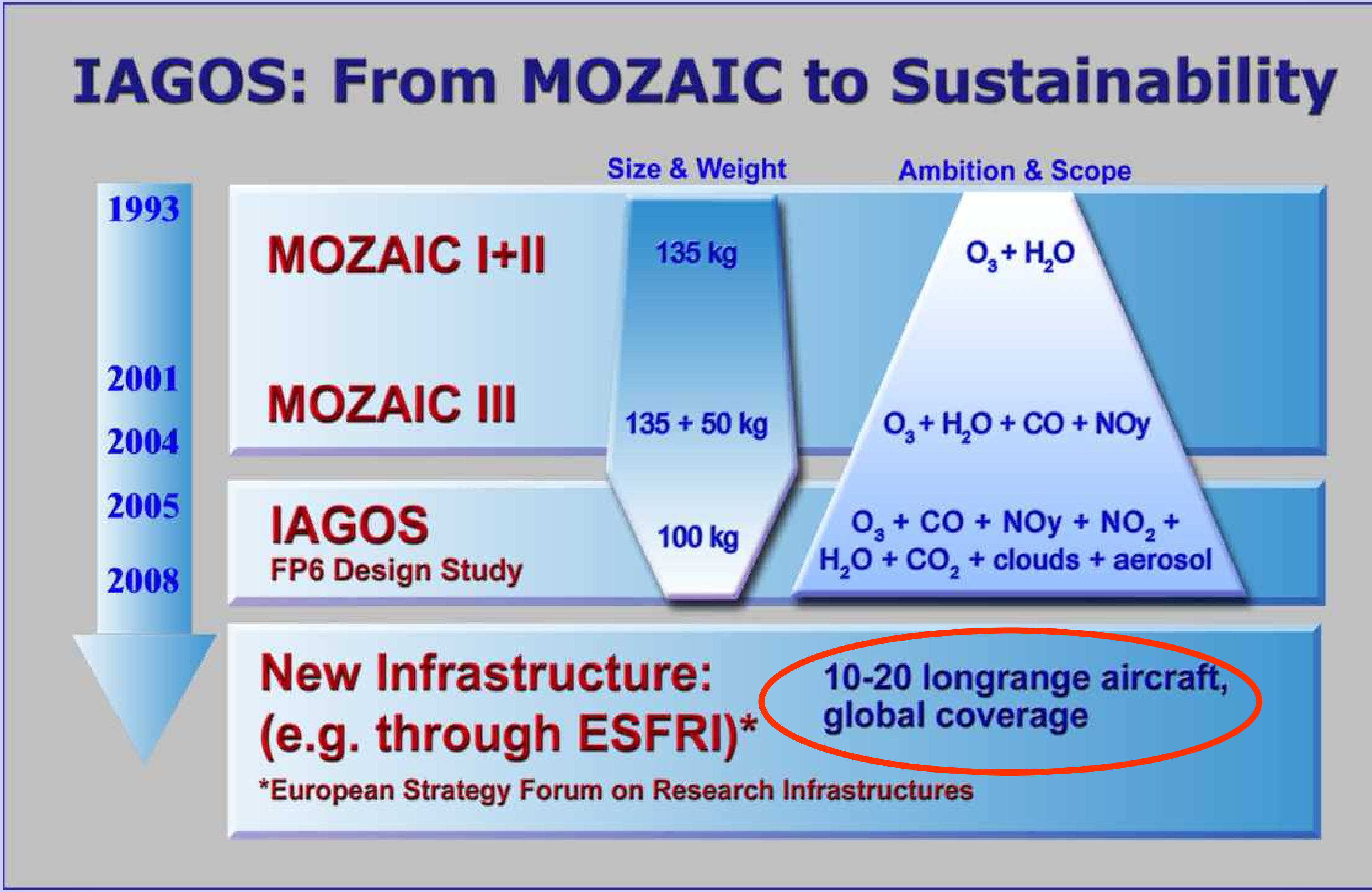


- Near cloud: PDF of RHI is uni-modal: > 60% ice super saturated (ISS)
- Cb-Outflow: Development of bi-modal PDF of RHI
  - Dry branch: Fast drying within one day from 70-90% RHI down to 40-50% RHI :: Clear sky subsidence
  - Wet branch: ISS remains (slope PDF of 100-150% RHI still same even after 2 days downwards of flow: Uplifting ???

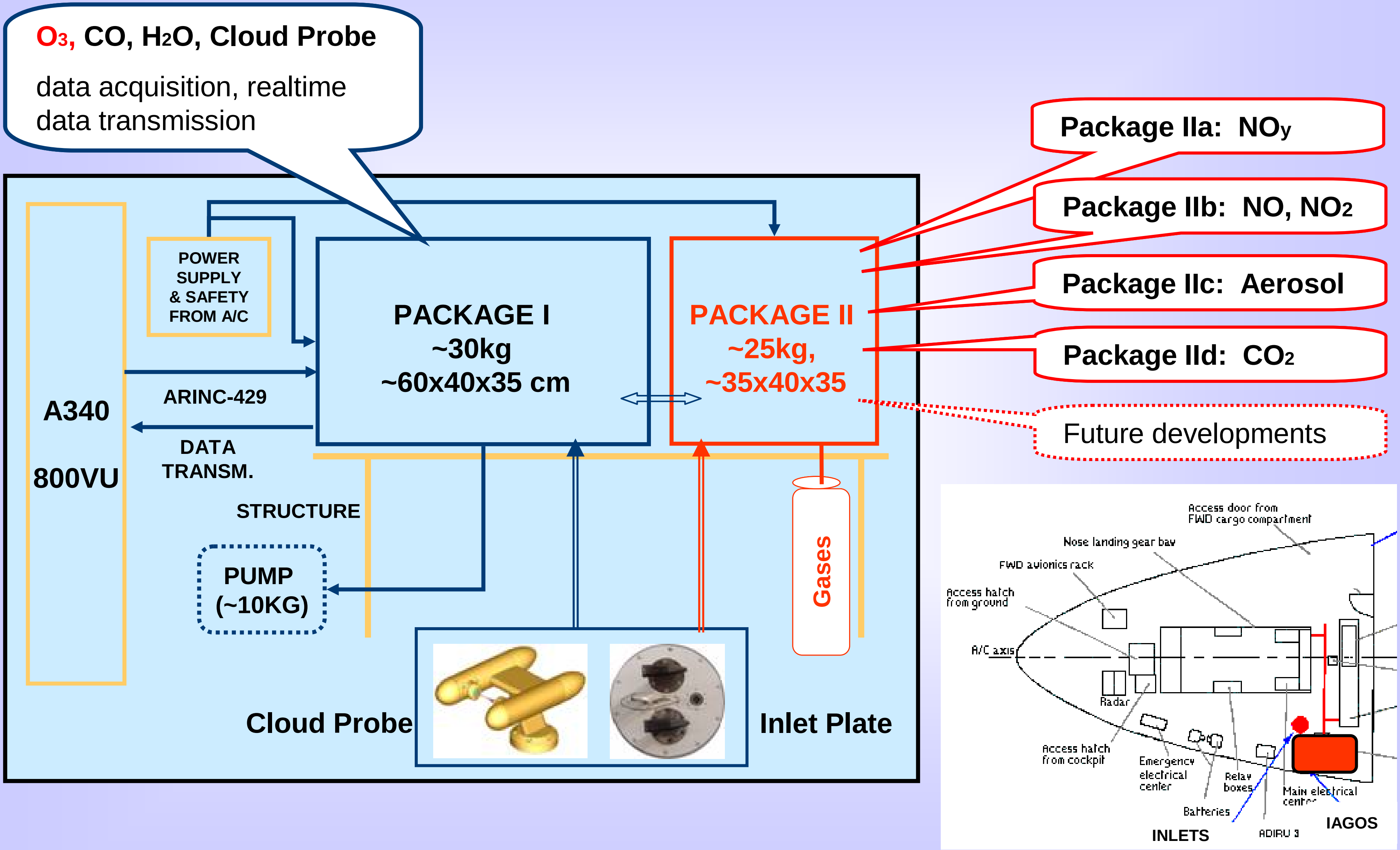
MOZAIC- UTH: Comparison with AIRS-Satellite over 2003

(Work by Co PI: Andrew Gettelman, NCAR, Boulder, USA)




IAGOS: From MOZAIC to Sustainability
Size & Weight
Ambition & Scope
1993
2001
2004
2005
2008
MOZAIC I+II
135 kg
$O_3 + H_2O$
MOZAIC III
135 + 50 kg
$O_3 + H_2O + CO + NOy$
IAGOS
FP6 Design Study
100 kg
$O_3 + CO + NOy + NO_2 +$
$H_2O + CO_2$ + clouds + aerosol
New Infrastructure:
(e.g. through ESFRI)*
10-20 longrange aircraft,
global coverage
*European Strategy Forum on Research Infrastructures

Technical Concept IAGOS



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Time Table for IAGOS-ERI

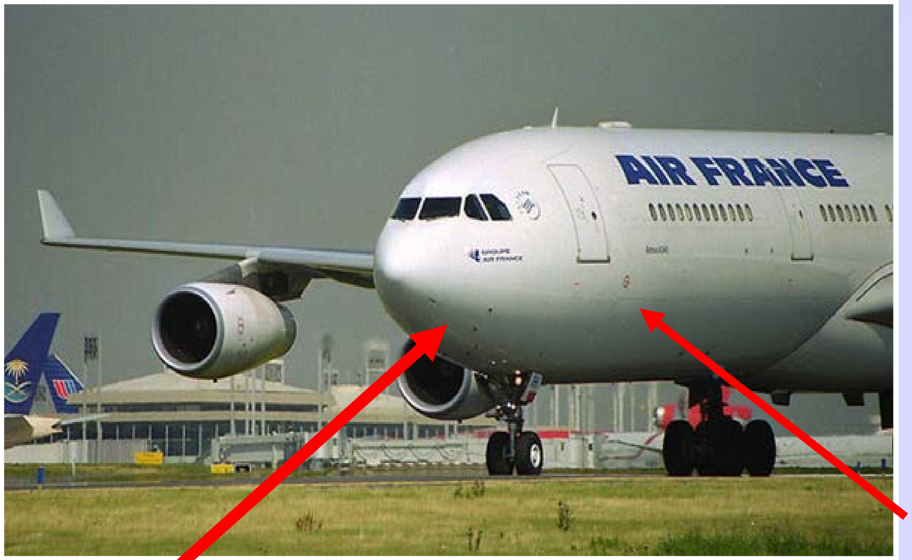
- 4/2008 IAGOS Design Study completed,
  - Prototypes available,
  - Partner airlines committed
- 2008 First aircraft equipped and commissioned: O_3, CO, H_2O, CDP, NO_y
- 2009 Certification for CO_2 and aerosol
- 2016 20 aircraft equipped and commissioned
- 2028 20 years of data available
  ~ 150 000 flights

http://www.fz-juelich.de/icg/icg-ii/iagos

Coordinator: Dr. Andreas Volz-Thomas
E-mail: A.Volz-Thomas@fz-juelich.de

Extra Material

MOZAIC: Automated Instruments to sample O_3, H_2O, CO & NO_Y



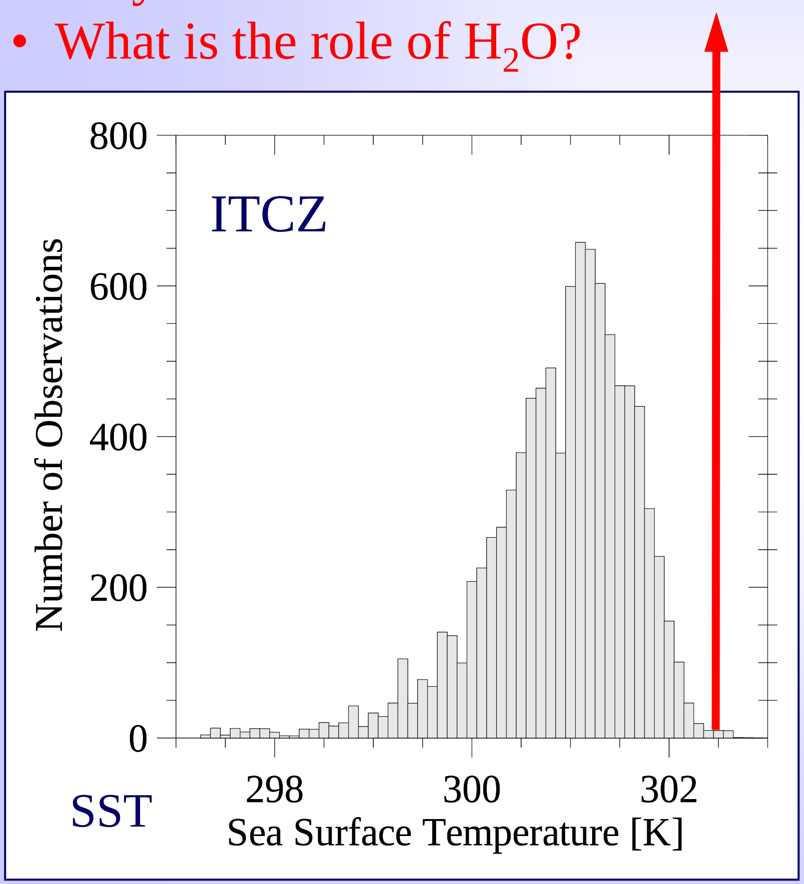
Instrumentation in Avionic Bay
below the cockpit
O3/CO/H2O/NOy/DAS

Inlet tubes
On the
Aircraft
Fuselage

„Upper Tropopsheric Humidity (UTH) and its Control“

Example of a dilemma in climate research:

- Why SST does not exceed 302.5K ?
- What is the role of H_2O?



- **Hydrological Cycle:**
  - ✸Source : Evaporation at surface
  - ✸Sink: Rain/Snow
- **UTH-Balance:**
  - ❄Source: Moist convection
  - ❄Removal: Subsidence
    Sedimentation of ice crystals
    Injection (gas+ice) into LS
- **<u>Key Open Questions in Control UTH:</u>**
  - ❄ Thermodynamic: Clausius-Clapeyron (T)
  - ❄ Dynamic: Atmospheric Motions
    Radiative Interaction of H_2O (Vapor & Clouds)

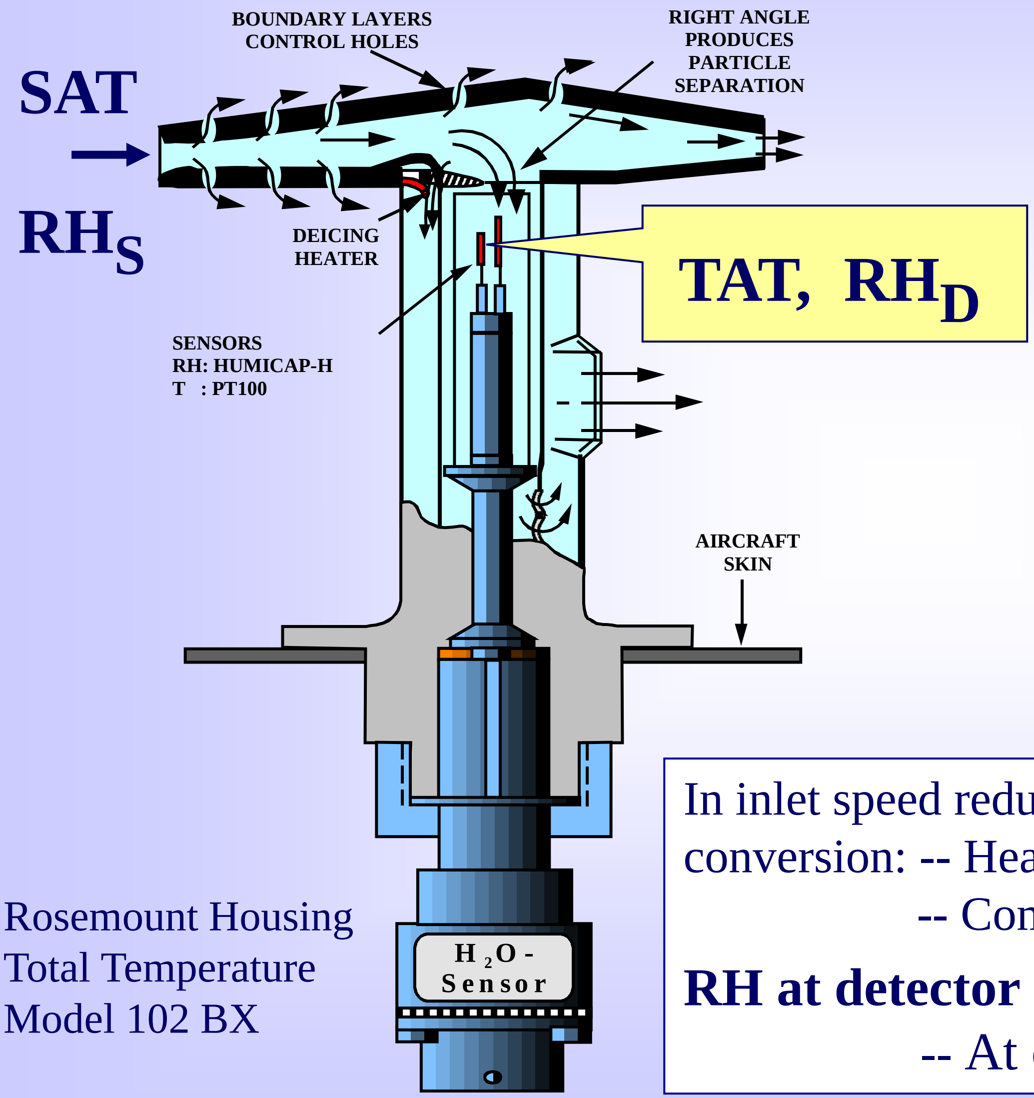
„Upper Tropospheric Humidity (UTH) and its Control“

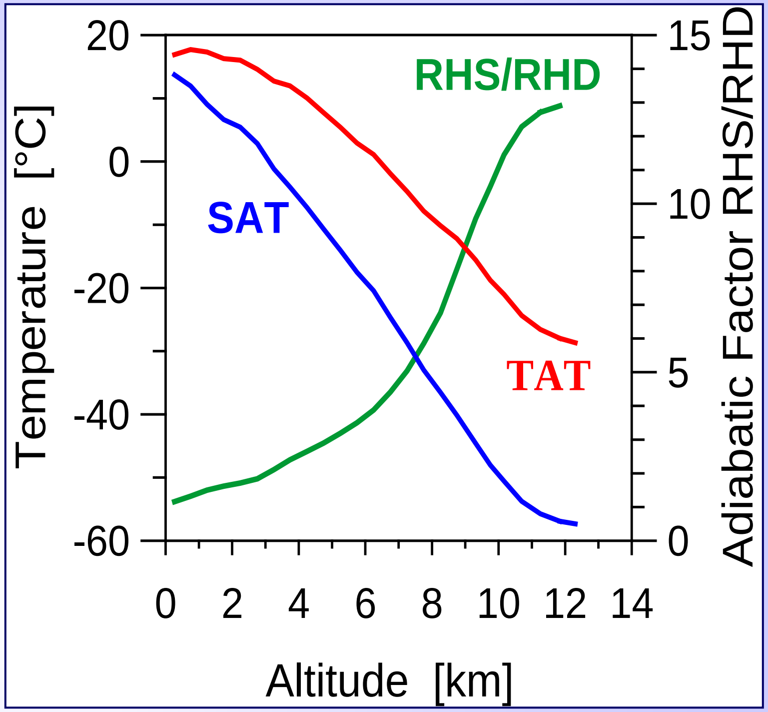
Lack of Measurements

State of the Art:

- Urgent need for accurate climatologies of H_2O in the UT/LS
- Radiosoundings: *H_2O not reliable above 5 km altitude*
- Satellites: *limited vertical or horizontal resolution,*
  limited performance in case of clouds
- Only accurate measurements from scientific ballooning or aircraft campaigns: *very limited in space and time*

MOZAIC: Humidity Sensor in Rosemount Air Inlet System





Rosemount Housing
Total Temperature
Model 102 BX

In inlet speed reduction (Mach≈0.8 to 0) with adiabatic conversion: -- Heating (SAT to TAT) : in UT ≈ 30°C
-- Compression (P_S to P_D): in UT ≈ Factor 1.6

RH at detector (RH_D) << RH sampled air (RH_S)
-- At cruise altitude $RH_S \approx 13$ X RH_D

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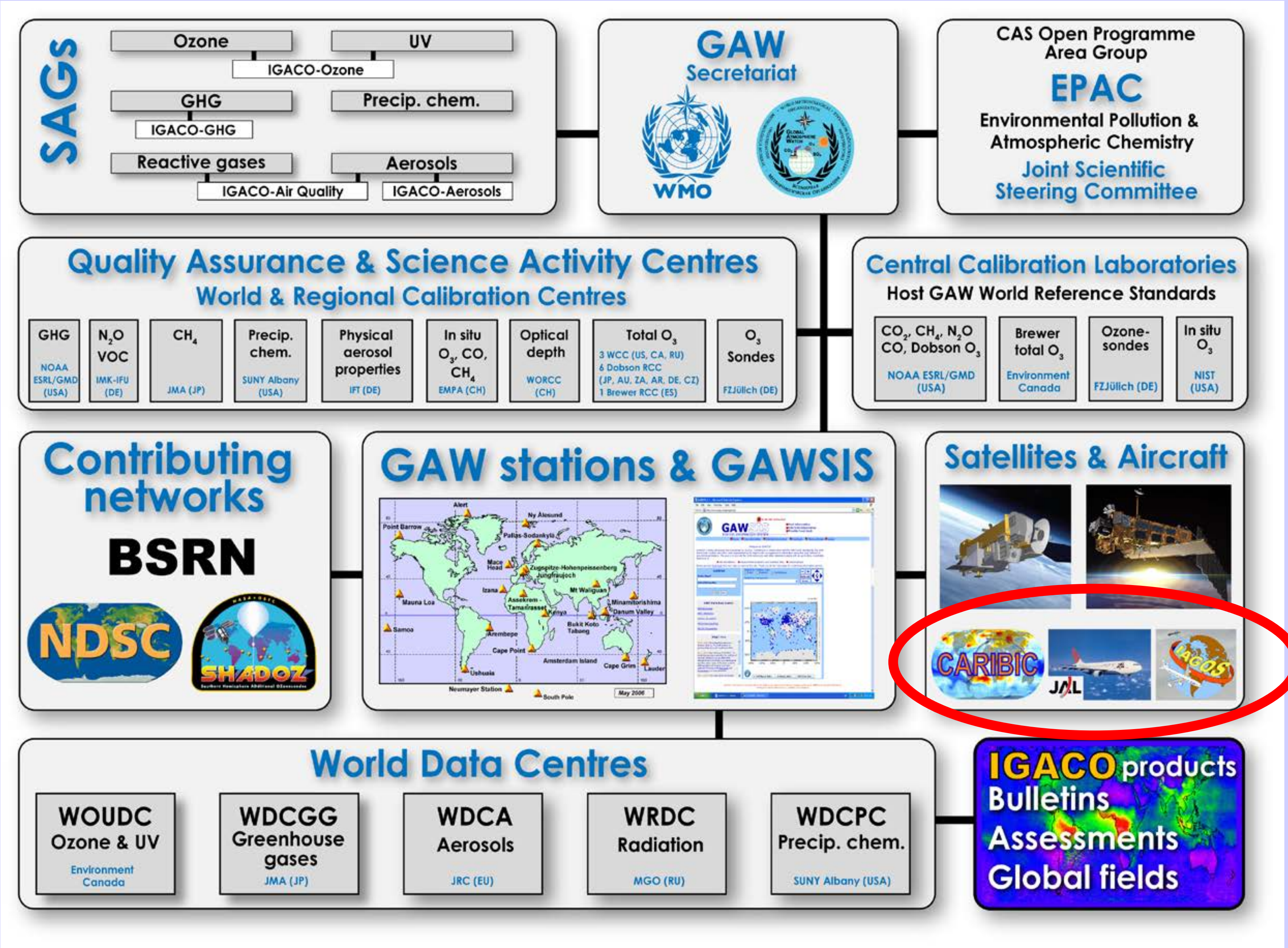

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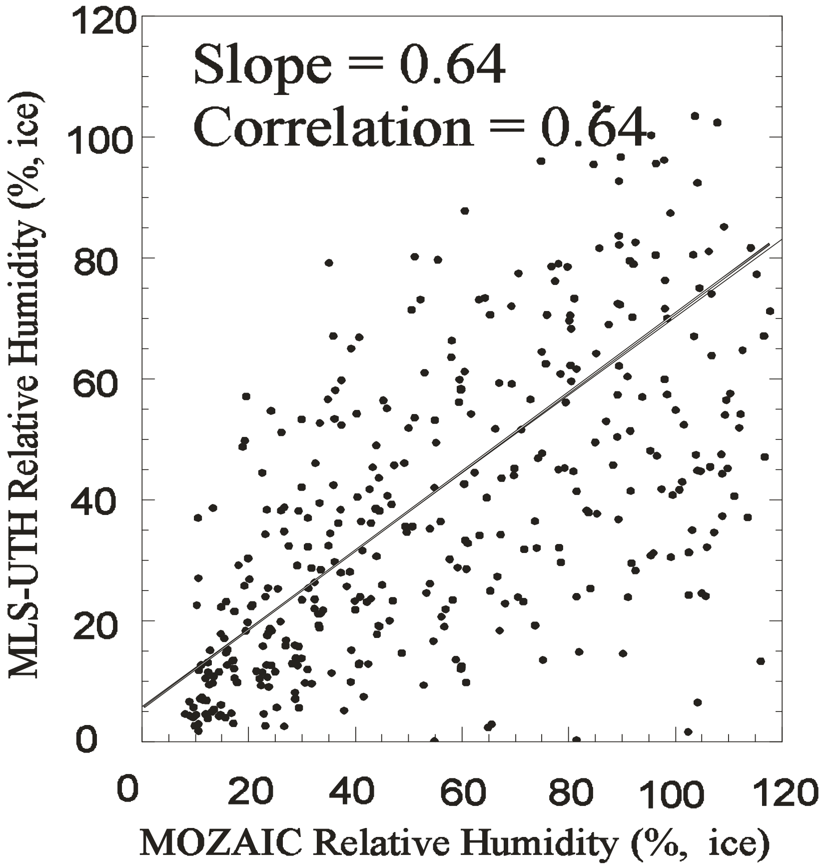
MOZAIC-UTH: Comparison with MLS/UARS Satellite



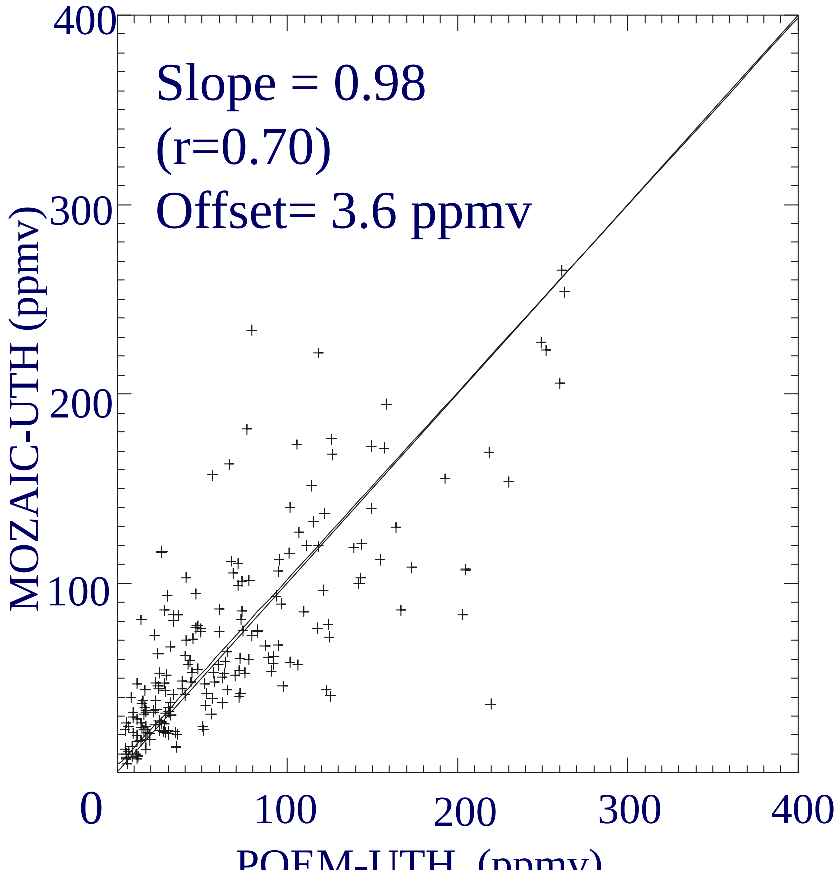
Coincidence criterion: 1° x 1° x 1 km x 3 h

Total: 384 Coincidences Aug.1994-Dec.1997

- MLS observe no ice super saturation (retrieval and/or limited horizontal resolution)
- MLS lower than MOZAIC (Slope=0.64)
- Large variations due to
  - Atmospheric variability &
  - Limited resolution of POEM (ΔZ=4-5 km)

Source: Read et al., UARS Microwave Limb Sounder upper tropospheric humidity measurement: Method and validation, J. Geophys. Res., 2001

MOZAIC-UTH: Comparison with POEM III Satellite



Coincidence criterion: 2.5º x 2.5º x 1 km x 6 h
Total: 200 Coincidences April 1998-Feb.2000

- POEM III= Polar Ozone and Aerosol Measurement III satellite operational since April 1998
- Good agreement POEM with MOZAIC (Slope=0.98)
- Large variations due to
  - Atmospheric variability &
  - Limited resolution of POEM (ΔX=250 km)

Source: Nedoluha et al., POAM III measurements of water vapor in the upper troposphere and lower most stratosphere, J. Geophys. Res., 2002