

South meets north South meets north over Suriname: ozone observations in Paramaribo

*by Paul Fortuin, Ronald van der A, Renske Timmermans,
Michiel van Weele and Hennie Kelder*

Introduction • The Inter-Tropical Convergence Zone (ITCZ) plays a vital role in determining the atmospheric circulation in the Tropics. Here, air from the south and the north meet, undergo various dynamical and chemical processes, rise through convection to higher altitudes and then flow out to extratropical latitudes. Over large regions in the Tropics, the ITCZ can be discerned as a cloudy band parallel to the Equator. Its latitudinal structure is quite narrow over the oceans on either side of the South American continent, so its annual migration between the Equator and approximately 10° north can be well followed. This migration also largely determines the seasonal variations of the areas within its range. In Suriname, for example, the two wet seasons coincide with the periods that the ITCZ is right overhead (December to January, April to July), the dry seasons occur when it is south or north of Suriname (respectively February to March and August to November). An observation site in Suriname therefore samples air from both the Northern and Southern Hemisphere, as well as air within the ITCZ itself, depending on the ITCZ position. Furthermore, due to the relatively flat orography of the north-eastern coastal region of South America, the air remains largely unperturbed when advected over such a site. Hence the orographic influence on the transport of air is minimal which greatly simplifies efforts to trace the air back to its region of origin. The tropical atmosphere comprises about half the global atmosphere, yet there are currently few systematic observation posts to study its behaviour.

All these features combined prompted a joint Suriname-Netherlands research initiative that led to the project RADCHiS (Research on the Atmospheric Dynamics and Chemistry in Suriname) and the establishment

of an ozone observation station in Paramaribo. Besides increasing our understanding of the atmospheric dynamics and chemistry in the Tropics, these observations play an important role in the validation of ozone products from the satellite instrument GOME (Global Ozone Monitoring Experiment).

Paramaribo station has received international recognition, as can be seen from the regional GAW (Global Atmospheric Watch) status it received from the World Meteorological Organisation (WMO), and its membership of the Network for Detection of Stratospheric Change (NDSC) and the project SHADOZ (Southern Hemisphere Additional Ozonesondes) of NASA (National Aeronautic and Space Administration).

The project RADCHiS • As the name suggests, the programme outline of RADCHiS is essentially to study the atmospheric dynamics and chemistry in the Tropics based on the following routine observations:

- continuous total ozone and UV (Ultra Violet) observations with a Brewer MKIII spectrophotometer,
- regular (weekly) balloon soundings measuring profiles of ozone, temperature, moisture and wind.

The research project is an initiative of KNMI, in co-operation with the Meteorological Service of Suriname (MDS). KNMI provides its expertise (a similar observation programme is being run in De Bilt, the Netherlands), whereas MDS provides the infrastructure and personnel needed to carry out this project. The Institute for Marine and Atmospheric Research of the University of Utrecht (IMAU) and the Max Planck Institute for Chemistry in Mainz (MPI-Mainz) are co-submitters, and therefore research partners, in this project. The corresponding principal investigators are Prof. Dr. J. Lelieveld and Nobel Prize winner Prof. Dr. P.J. Crutzen, who is one of the very first instigators of atmospheric research in the Tropics. The project was approved for funding by the Netherlands Organisation for Scientific Research (NWO), for a four-year period starting September 1998. Additional funding comes from the Netherlands Earth observation community - the Netherlands Institute for Aviation and Space Research (NIVR) and the Netherlands Foundation for Space Research (SRON) – and from KNMI. WMO kindly arranged an agreement between the Suriname and Netherlands governments so that the project could be implemented under the WMO Voluntary Co-operation Programme (VCP). The VCP status greatly simplifies the procedures needed to import scientific equipment into Suriname and furthermore gives WMO membership countries the opportunity to support and participate in the RADCHiS project.

The observation site • The selection of an observation site proved to be easy as the premises of the MDS in Paramaribo provides the ideal setting. The MDS building has a platform extending above the roof that offers an undisturbed view to all sides and more than enough space for the Brewer instrument and the sounding antennas (Figure 1). MDS also offered ample office space, along with a spacious operator room with a view on an open field

Discovering the tropical atmosphere



Figure 1. The observation platform on top of the Suriname Met Office building, with (left to right) an

outdoor video camera, the GPS antenna, UHF antenna and the Brewer MKIII.

where balloons could be launched and a filling hut constructed. The site is located at 5.8° N 55.2° W, at a latitude that is just about in the middle of the annual migration range of the ITCZ in this region. In fact, the meteorological equator – defined as the global average latitudinal position of the ITCZ – corresponds with this latitude.

An operator crew consisting of five MDS employees was selected and trained during the following two installations: the Brewer MKIII spectrophotometer in March and then the Vaisala sounding equipment in September 1999. Along with the second installation, an outdoor video camera was installed, pointing to the south-east and taking wide-angle pictures of the sky every two minutes. These pictures can be used to complement the Brewer and sonde observations, and when combined into an animation they can provide valuable information on the spatial and temporal scales of cloud processes.

The observational programme is now fully operational, with the Brewer performing continuous total ozone and UV measurements, besides so-called Umkehr measurements during sunrise and sunset. The German word 'Umkehr' refers to a technique through which an ozone profile can be derived from zenith-sky irradiation measurements when the Sun is skimming the horizon. On cloudless occasions, these Umkehr profiles can be used to extend the ozone profiles above the height level reachable with a balloon sonde (around 32 km). The balloon sondes are released on a weekly basis, measuring ozone with the Electrochemical cell (ECC) technique, along with temperature, moisture and wind speed plus direction.

The main focus is the study of atmospheric transport and dynamics in the Tropics

Research • The Paramaribo observations are used for various areas of research within KNMI. Apart from the main focus, the study of transport and dynamics in the Tropics, the observations are used for radiative transfer and UV research, and have found an important application in the field of satellite validation. First results on this research have recently been presented at international symposia and will be briefly discussed.

Transport and dynamics • Figure 2 shows 1.5 years of Brewer total ozone values (starting March 1999), along with sonde humidity and meridional wind measured at 1 km height (starting September 1999). Clearly, the wet seasons occur during transitions in the meridional wind direction, when the ITCZ migrates overhead. First analyses ¹⁾ indicate that photolysis of

Discovering the

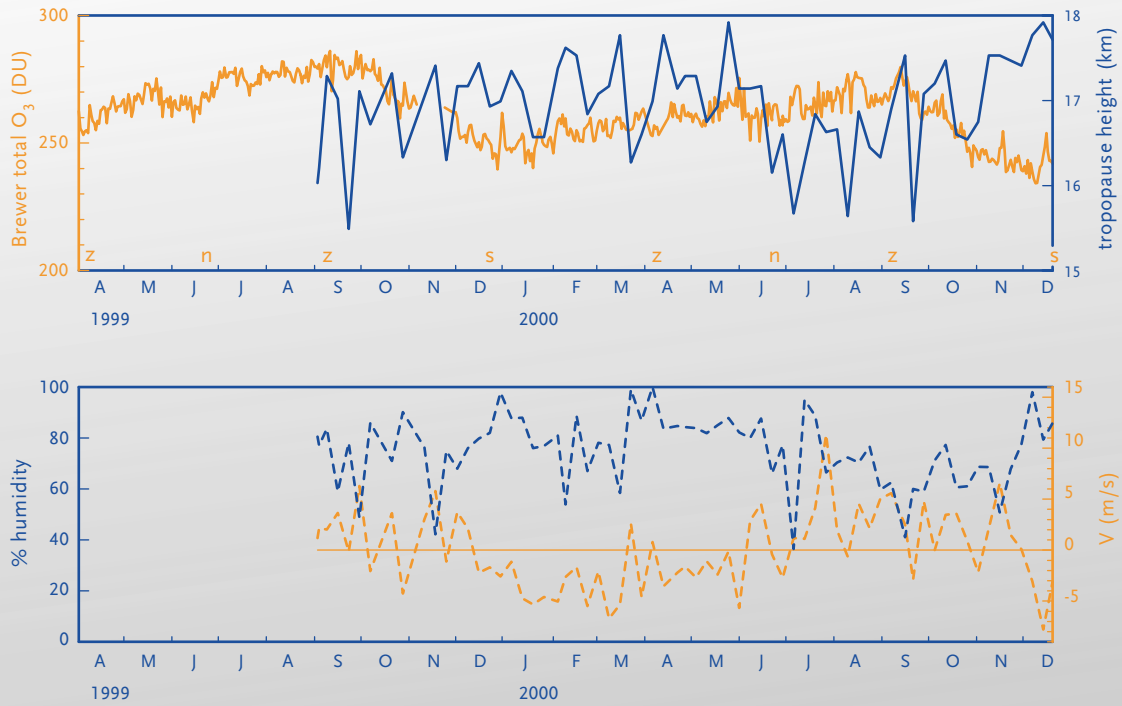


Figure 2. Top: Brewer total ozone and tropopause height (from sondes). Also shown are the moments when the Sun is right overhead ('z'), in northern solstice ('n') and in southern solstice ('s'). Bottom: relative humidity and meridional wind at 1 km height (from sondes).

tropical atmosphere

atmosphere

atmosphere

atmosphere

atmosphere

ozone in the stratosphere as well as vertical motion are the prime factors influencing seasonal changes in total ozone. The tropopause height (Figure 2) is an indicator of the strength of the vertical motion. Maximum total ozone values are reached around September when the Sun is at zenith during the long dry season, causing high photolysis of ozone. Minimum total ozone values occur when the Sun is in southern solstice, and coincides with the short wet season (December - January) when the ITCZ passes overhead. The long wet season (April - August) causes only a local minimum in total ozone as the increased ascent rate is now compensated by increased ozone photolysis as the Sun passes overhead. The ozone maximum in the year 2000 is about 10 DU (Dobson Unit) less than the 1999 ozone maximum. This is most likely due to the descending easterly phase in the quasi-biennial oscillation (QBO) ¹⁾, which induces a mean ascending motion ²⁾. Previous studies have shown that the QBO is caused by momentum transfer of equatorial waves that propagate into the stratosphere. From a first analysis of the Paramaribo wind fields, these waves seem to be mostly generated by deep convection up to 12 - 14 km, corresponding to the level where the equivalent potential temperature equals that of the Earth surface. First analyses also reveal that the ITCZ over Suriname has a structure similar to a cold front, with cooler air coming from the north-east trade winds. Also, there are indications that the annual cycle of ascent rates over Suriname are the result of local - rather than extratropical - wave driving.

Satellite validation • The ozone profiles and column values recorded at Paramaribo station are also used for validation of ozone retrieval products from GOME. In 1995, GOME was launched on ERS2 (Earth Remote Sensing), to measure the spectrum of back-scattered sunlight from the atmosphere in nadir direction. From this spectrum both the total ozone column and a collocated ozone profile is retrieved, which is unique for satellite measurements. In Figure 3 the ozone column measurements from the Brewer at Paramaribo are compared to collocated ozone columns retrieved from the

Both TOMS and GOME ozone columns show overall good agreement with the Brewer measurements

GOME and TOMS-EP (Total Ozone Mapping Spectrometer-Earth Probe) satellite instruments. Both TOMS and GOME ozone columns show overall good agreement with the Brewer measurements. The long-term variations are followed very well. The values from TOMS and GOME are on average respectively 3% higher and 1% lower than the Brewer values. The temporal short term variance in total ozone is better captured by TOMS, due to its smaller ground pixel: 40 by 40 km for TOMS versus 40 by 320 km for GOME.

Discovering the tropical atmosphere

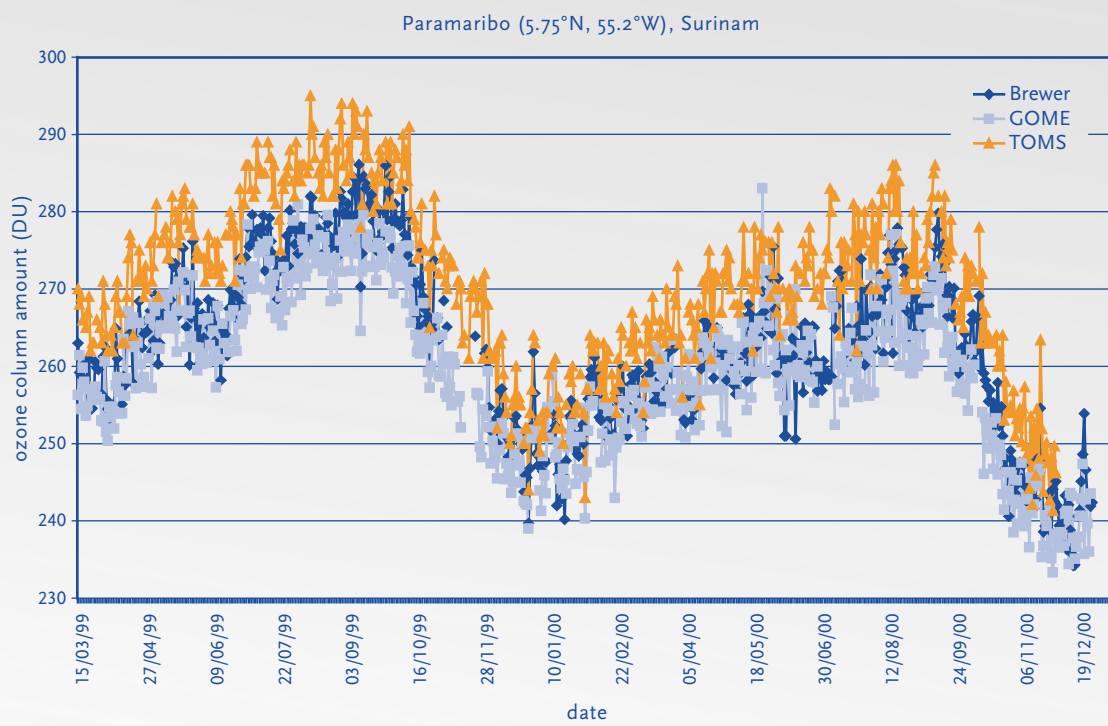


Figure 3. Brewer total ozone values at Paramaribo compared with TOMS and GOME satellite instruments.

The steep rise of ozone absorption from 340 to 260 nm in the observed back-scattered radiance offers the possibility to infer height-resolved information on the ozone concentration in the stratosphere as well as in the troposphere ^{3,4}). Every 12 seconds the GOME instrument makes an observation in the UV spectrum suitable for profile retrieval. This observation has a ground pixel size of 960 by 100 km, resulting in global coverage in a period of 3 days. The ozone profile retrieval is performed with the optimal estimation method ⁷), where the information of the observation is combined with a-priori information. The a-priori ozone profile is taken from the climatology of Fortuin and Kelder ⁵). The GOME ozone profiles are compared to local ozone sonde measurements at Paramaribo for the period of October 1999 till July 2000. In Figure 4 an example is given of ozone sonde measurements and collocated retrieved GOME profiles for November of 1999. The retrieved ozone profiles in Paramaribo follow the sonde profile very well. The deviations of the stratospheric values between GOME and the sonde are usual within the retrieval error (indicated with a horizontal bar in Figure 4). While deviations found at stations at mid-latitudes are usually within the retrieval errors, the GOME ozone profile at Paramaribo shows systematic deviations at certain layers. This shows the importance of ozone validations at a tropical station, also for satellite instruments to be launched in the near future, like SCIAMACHY (Scanning Imaging Absorption Spectrometer for Atmospheric Cartography), OMI (Ozone Monitoring Instrument) and GOME-2.

UV radiation • As can be expected, the Brewer UV measurements can show very high damaging UV (DUV) values. In the Netherlands, for example, the DUV-scale maximum lies at a value of 8, corresponding with 200 mWm^{-2} . In Suriname, this value is almost always exceeded around noon, the typical range is around UV index value 12. The UV insolation at Paramaribo is surprisingly constant over the year with typical maxima of UV index of 13 or 14 on a cloudfree day. The annual variation in UV insolation at Paramaribo is modulated by the variation in solar zenith angle (sza), Sun-Earth distance, ozone column and cloudiness ⁶). The bimodal distribution due to the variations in solar angle is partly compensated for by the annual cycle in the ozone column: the maximum ozone column in

The UV insolation at Paramaribo is surprisingly constant over the year

September coincides with the minimum sza. At Paramaribo the Sun crosses the zenith at local noon twice a year: in April and September (see Figure 5). The difference in UV insolation between both cycles is partly compensated by the Sun-Earth distance, which is smallest in January and yields about 6% more UV in January than in July. The scattered UV measurements show that a cloud-free noontime is the exception at Paramaribo, even in the dry seasons

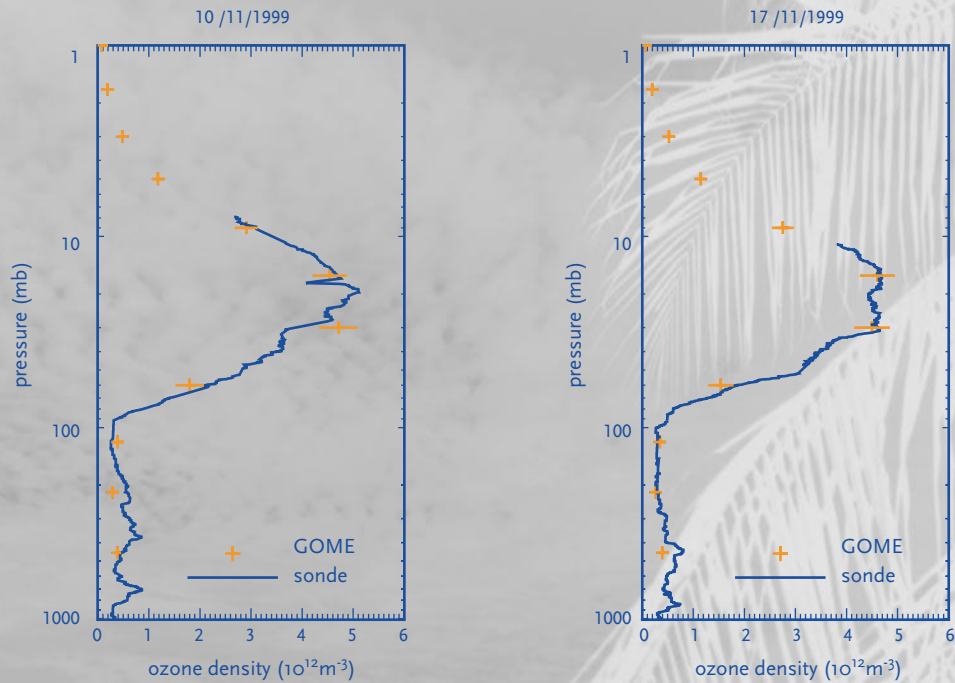


Figure 4. Collocated and coincidental ozone profiles at the ground station Paramaribo measured by an ozone sonde and the GOME satellite instrument.

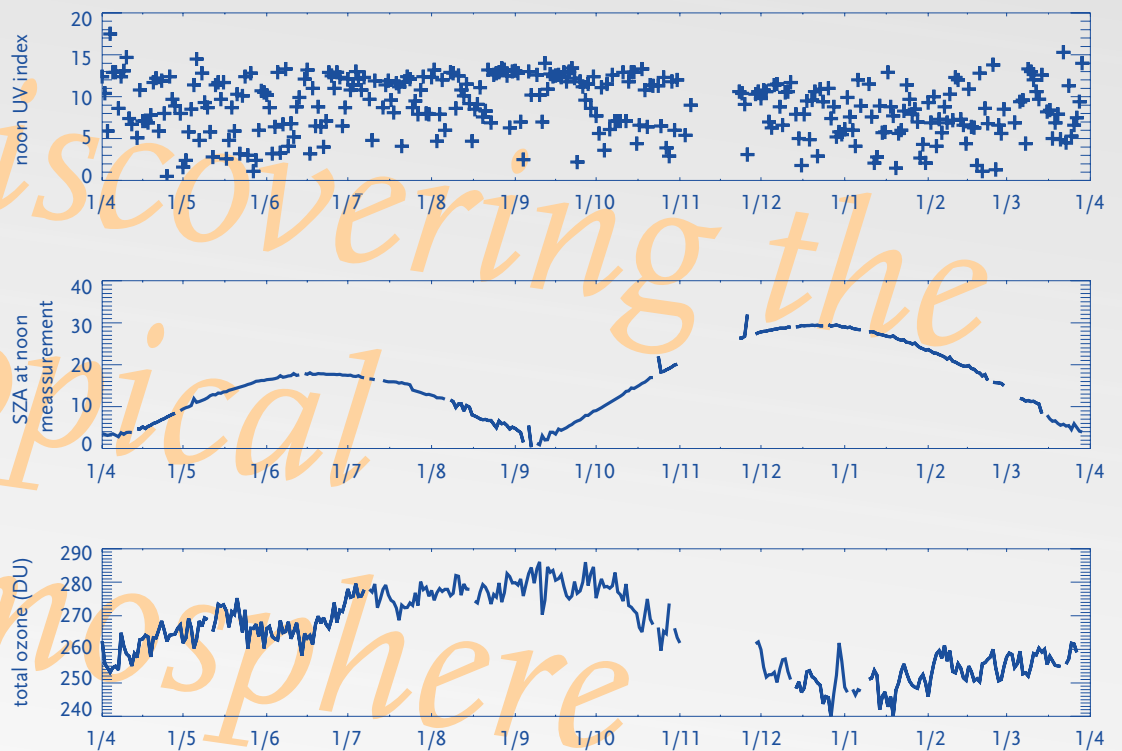


Figure 5: One year (1 Apr 1999 - 1 Apr 2000) of UV Index (top) and total ozone (bottom) measurements at Paramaribo. The figure in the middle gives the solar zenith angles of the spectrum for which the UV Index was determined, which is the first spectrum after noontime on each day.

(February - March; August - November). The maximum UV Index measured in Paramaribo thus far is 17.5 on 4th of April 1999, in partly cloudy conditions.

Outlook • In its short existence, Paramaribo station has yielded a valuable set of observations which already has led to new insights in atmospheric research and holds promise for future discoveries. Its strategic location under the migrating ITCZ provides a unique insight into many key features of the atmospheric circulation in the Tropics. Some of these dynamic features, like the El Niño event, which recurs every two to five years and has an influence on climate world-wide, act on long time scales. To study these features years of observations are required. It therefore would serve many interests to maintain and if possible expand this observation programme in the future, beyond the duration of the RADCHIS project. Also, new satellite instruments will be launched in the coming years which need to be validated in the Tropics. Prospects for expansion of the observation programme are good and first plans are being realised: the RIVM (National Institute of Public Health and the Environment) has donated an ozone monitor to sample smog levels in the boundary-layer over Paramaribo, and also intends to install a backscatter LIDAR (Light Detection And Ranging) instrument in Paramaribo within the next year together with KNMI. With this highly advanced instrument, the distribution of aerosols in the atmosphere can be monitored continuously, providing insight into many aspects of atmospheric transport and cloud formation. This combined set of instruments will provide an invaluable insight to atmospheric dynamics and chemistry in the Tropics.

We thank NWO, NIVR and SRON for their generous support of this project. More specifically we like to thank the personnel of NWO-ALW for their positive and serviceable attitude in many matters.

- 1) Fortuin, J.P.F., H. Kelder and C.R. Becker, 2001. *Paramaribo station: analyses of new atmospheric observations in the Tropics*. Proceedings SPARC2000 Conference, Mar del Plata, Argentina.
- 2) Plumb, R.A. and R.C. Bell, 1982. *A model of the quasi-biennial oscillation of the stratospheric winds on an equatorial beta-plane*. Quart. J. Royal Meteorol. Soc., **108**, 335-352.
- 3) A, R.J. van der, R.F. van Oss and H.M. Kelder, 1998. *Ozone profile retrieval from GOME data, Satellite Remote Sensing of Clouds and the Atmosphere III*. Proceedings of SPIE, Vol. 3495, 221-229, Barcelona, Spain.
- 4) Munro, R., R. Siddans, W.J. Reburn, and B.J. Kerridge, 1998. *Direct measurement of tropospheric ozone distributions from space*. Nature, **392**, 168-171.
- 5) Fortuin, J.P.F. and H.M. Kelder, 1998. *An ozone climatology based on ozonesonde and satellite measurements*. J. Geophys. Res., **103**, 31709-31734.
- 6) Weele, M. van, J.P.F. Fortuin and H.M. Kelder, 2001. *Year-round spectral UV-measurements at tropical Paramaribo, Suriname*. Proceedings SPARC2000 Conference, Mar del Plata, Argentina.
- 7) Rogers, C.D., 1976. *Retrieval of atmospheric temperature and composition from remote measurements of thermal radiation*. Rev. Geophys. Space Phys., **14**, 609-624.