DRAFT ITU-R REPORT :
IDENTIFICATION OF DEGRADATION DUE TO INTERFERENCE
AND
CHARACTERIZATION OF POSSIBLE MITIGATION TECHNIQUES FOR PASSIVE SENSORS

Dave McGinnis
NESDIS spectrum manager
Silver Spring, MD 20910

Rich Kelley
Alion Science
Suitland, MD 20746

Jean Pla
CNES
Toulouse, FR

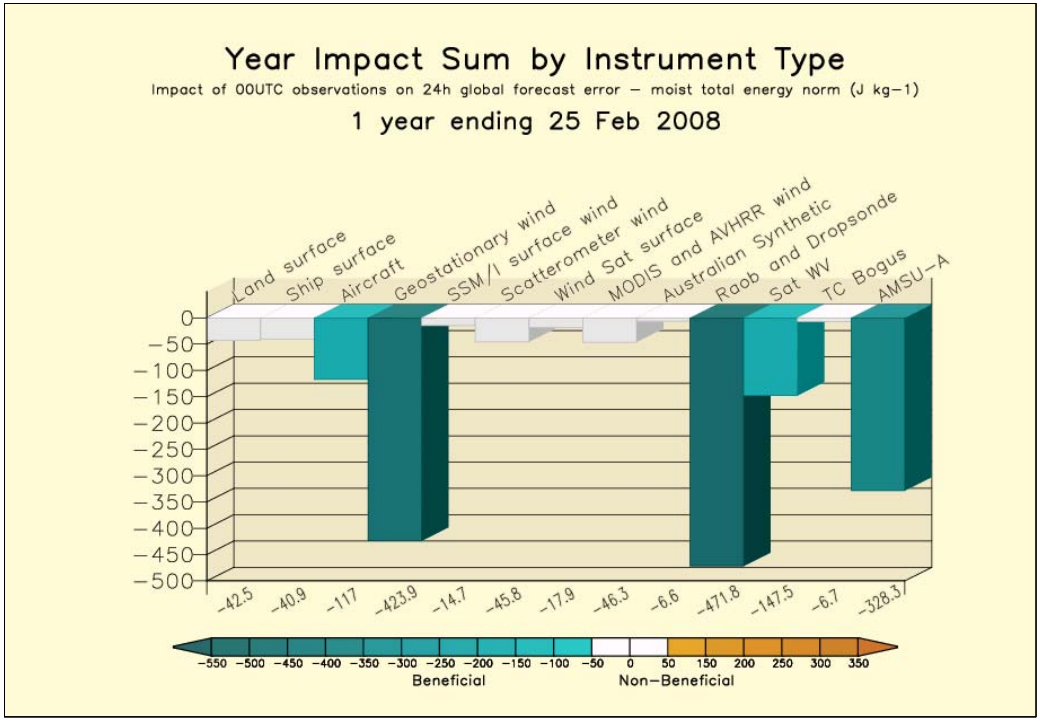
audience for the report

- International Telecommunications Union (ITU)
  - 191 member states
  - more than 700 sector members and associates
- neither meteorologists nor atmospheric scientists
- Those unconversant in
  - passive environmental remote sensing techniques and applications

passive sensing products

- data records of measurements
- images derived from the records
- Plots
- Forecasts
- Warnings

NWP accuracy depends on microwave data*



*NRL Monterey web page (http://www.nrlmry.navy.mil/obsens/dev/obsens_main_od.html)

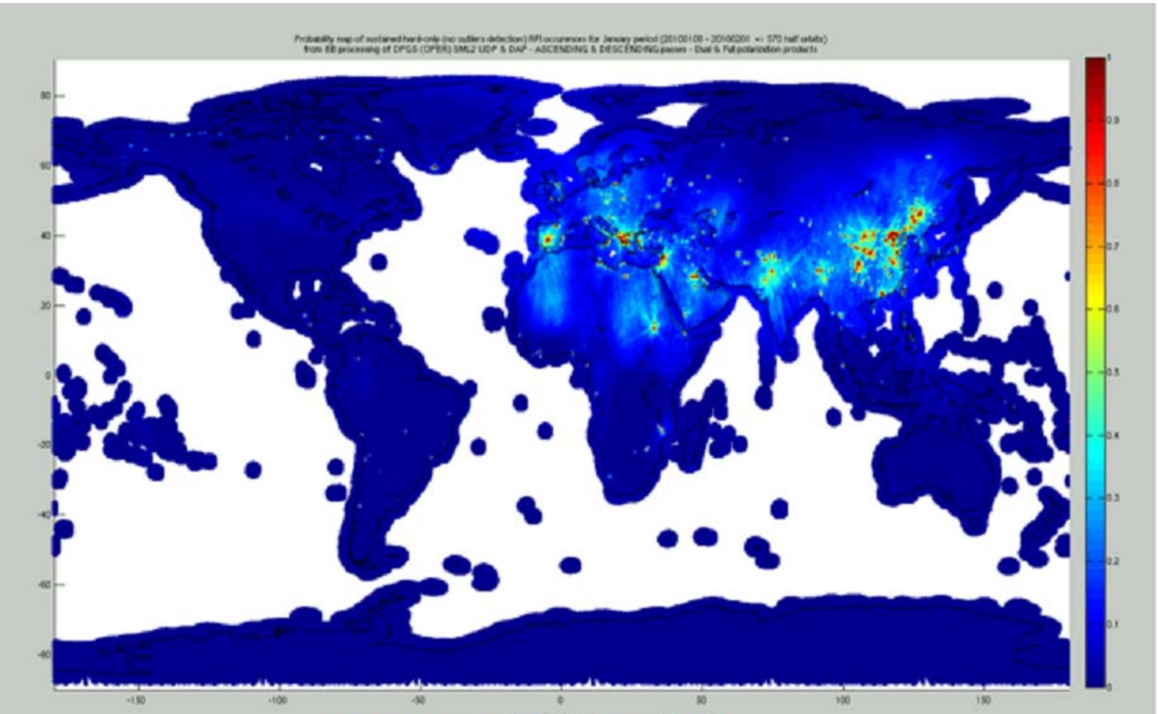
Product quality and RFI

- RFI increases mean power compared to geophysical background
  - post-processing can eliminate abnormally high observations
  - low level RFI can be difficult to separate from geophysical information

- RFI is not anticipated unless there is *a priori* reason
  - active radiocommunication services co-allocated with passive services
  - use by a passive sensor of an unallocated frequency band that is used by active radiocommunication services.

Data availability and rfi

- ITU rec RS. 1028-2[1] governs data availability
- Removing rfi can remove data
    - reduces data availability

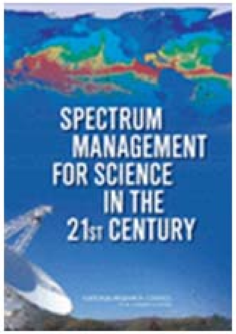


SMOS probability of rfi

SMOS RF band pass filter centre frequency is 1413.5 MHz with a 3 dB passband of 20 MHz

Industry understanding

- passive microwave sensing science
  - evolved significantly since the 1970s
  - major international NWP centres use microwave data as a key part of its support of the "daily weather forecast"
- A 2006 survey in the U.S.
  - 1465 respondents
  - average household accesses weather forecasts 115 times per month
- important for industry to understand importance that passive microwave sensing plays in the daily lives of many humans



Passive remote sensing mitigation

- **rfi prevention through regulation**
  - active services operate in the same bands as passive services
    - can cause harmful interference
  - bands are afforded protection by
    - exclusively passive allocations
    - RR No. 5.340 (prohibits all emissions in certain bands)

mitigation techniques

- narrow band interfering signals
  - A multiple sub-band interference “mitigator”
    - planned for CMIS instrument
    - employs aux rcvr with in-band channels
    - Performs least squares fit to data
    - If all sub-bands provide a good fit then
      - no corrections are made.
    - if a sub band does not fit, then
      - least squares is repeated, deleting data from sub-band
- broadband interfering signals
  - Traditional radiometers
    - integrate power over timescales >= milliseconds
    - poorly-suited to suppressing rapid time-varying interference
  - Future microwave radiometers
    - employ on-board digital processing for interference suppression, viz ADD

Conclusion

- importance of passive microwave sensing in forecasting weather and climate as well as all Earth observation activities
  - Justifies need for operations without degradation due to radio-frequency interference (RFI)
- Three categories of RFI received by a passive sensor
  - High levels of RFI that are obviously inconsistent with natural radiation. As such, these can be detected, but the corresponding measurements are lost.
  - Very low levels of RFI below protection criteria, that cannot be detected by on-board passive sensors, and hence do not have impact on the output products.
  - Low levels of RFI that cannot be discriminated from natural radiations and hence represent very serious problem since degraded or incorrect data would be accepted as valid.
- In addition, even if it were possible to detect and mitigate RFI, it would result, in all cases, in a severe degradation of the corresponding output products.
- No mitigation techniques have been identified which can be applied to the microwave sensors and their products to allow RFI without degrading their performance reliability or availability.

Want to learn more

- Contact
  - Dave McGinnis…
    - 01.301.713.2789 x 149
    - Dave.McGinnis@noaa.gov
  - Rich Kelley….
    - 01.301.817.4636
    - Richard.Kelley@noaa.gov
  - Jean Pla
    - 33.5.61282059
    - Jean.Pla@cnes.fr
- Draft report available electronically…contact Rich

BACKUP

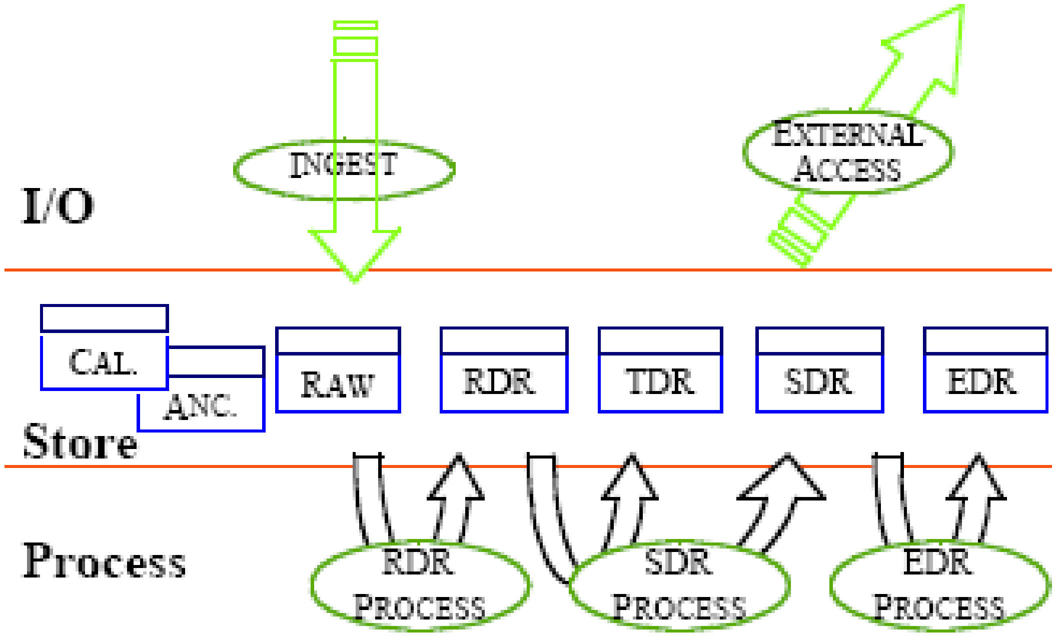
Passive sensing products

- Algorithms applied to brightness temperatures
  - provide geographic information on meteorological parameters (Level 2 products).
    - In some level 2 products ancillary information is used to generate the products. Such ancillary information includes terrain type, temperature and humidity information from other sensors.
- Atmospheric temperature profiles are created from measurements using instruments operating in the 50 to 60 GHz frequency range

Product hierarchy and descriptions

- Example from National polar-orbiting operational environmental satellite system (NPOESS)
- Two types of descriptors for products
  - hierarchical
    - Level 0, Level 1A, Level 1B, and Level 2
    - product types from raw (level 0) to refined (level 2).
  - record type
    - raw data, raw data records (RDR)
    - sensor data records (SDR)
    - temperature data records (TDR)
    - environmental data records (EDR).

Product generation process



Higher level products

- data records created in the SDR and EDR processes
- available for Level 3 products
  - developed from
    - archived records
    - information obtained from other sources
      - e.g. visual images, infrared (IR) images, radiosondes, radar images, etc.

Annex b contains a table of level 2 products by name and Frequency band

TABLE 1B

Atmospheric data products and associated sensing bands

Product area name	Product area function	Passive sensing bands, GHz	Band evaluation
Total Precipitable Water TPW, in mm	Water	31.4 *	Primary band for integrated liquid water.
		37	Primary/best use for integrated liquid water.
	Window	19.4	Primary channel for high liquid.
		22.3	Background reference channel for simultaneous retrieval of TWP
		23.8 *	Backgroun of TWP
		85.5	Thin clouds
		89.0 *	Thin clouds
Cloud Liquid Water CLW, in mm	Water	22.2	Primary ba content are
		23.8 *	Primary/be low content
	Window	19.4	Principal ba vapour line
		31.4 *	Backgroun

TABLE 3B

Land data products and associated sensing

Product area name	Product area function	Passive sensing bands, GHz	Band
Snow Cover SNOWC, in %	Sounding	23.8 *	Principal background chan vapour line.
	Window	31.4 *	Background reference cha vapour line, exclusively pa
		37.0	Window channel
		85.0	Window channel at high fr
		89 *	Window channel at high fr
Land Surface Temperature STEMP, in °C	Window	19	33% lower emissivity Perturbation due to surface temperature
		22.3	Primary band for integrate content areas.
	Sounding	23.8 *	Primary/best use for integrated water vapour content in low content areas.
	Window	31.4 *	Reference band for 23.8 GHz water vapour measurement.
		37	
		50.3*	

TABLE 2B

Ocean data products and associated sensing bands

		(2 bands)	
		57.2903 bands, GHz	Strongest from O_2 at 25 km
Ocean Surface Wind Speed OSWS, in m/s	Sea surface parameter	10.65	Best for horizontal resolution
		31	Best in correlating the "roughening" of the ocean surface with surface wind speed
		37	Same as above
Sea Ice Concentration SIce, in%	Window can scattering	19	Sea surface and sea ice emissivity
		23	Sea surface and sea ice emissivity. Improved resolution over the 19 GHz channel.
		31	Sea surface and sea ice emissivity. This measurement is needed for comparison to the 23 GHz to distinguish new ice form multiyear ice. Improvement over 37 GHz channel because it is an exclusively allocated band.
		37	Sea surface and sea ice emissivity.
		50.3 *	Sea surface and sea ice emissivity. Reduces impact of non-precipitation clouds.
		85	TBD
Sea Surface Temperature SST, in °C	Sounding for sea surface temperature	6.925	Best band for SST because nearest to 5.5 GHz peak sensitivity. Provides good horizontal spatial resolution. Only source in cloudy regions.

Passive remote sensing mitigation

- **RFI prevention through regulation**
  - It is well known that active services operating in the same bands as passive services
    - can cause harmful interference to the passive service operations.
    - exclusively passive bands have been allocated both nationally and internationally.
    - bands are afforded protection
      - these exclusively passive allocations
      - RR No. **5.340**

RFI prevention through regulation
radio regs (2008) and 23 ITU-R WP7C recs

- RS.515 Frequency bands and bandwidths used for satellite passive sensing
- RS.516 Feasibility of sharing between active sensors used on Earth exploration and meteorological satellites and the radiolocation service Note - Suppressed (RA-07)
- RS.577 Frequency bands and required bandwidths used for spaceborne active sensors operating in the Earth exploration-satellite (active) and space research (active) services
- RS.1028 Performance criteria for satellite passive remote sensing
- RS.1029 Interference criteria for satellite passive remote sensing
- RS.1165 Technical characteristics and performance criteria for systems in the meteorological aids service in the 403 MHz and 1 680 MHz bands
- RS.1166 Performance and interference criteria for active spaceborne sensors
- RS.1259 Feasibility of sharing between spaceborne passive sensors and the fixed service from 50 to 60 GHz
- RS.1260 Feasibility of sharing between active spaceborne sensors and other services in the range 420-470 MHz
- RS.1261 Feasibility of sharing between spaceborne cloud radars and other services in the range of 92-95 GHz
- RS.1262 Sharing and coordination criteria for meteorological aids in the 400.15-406 MHz and 1 668.4-1 700 MHz bands
- RS.1263 Interference criteria for meteorological aids operated in the 400.15-406 MHz and 1 668.4-1 700 MHz bands
- RS.1264 Feasibility of frequency sharing between the meteorological aids service and the mobile-satellite service (Earth-to-space) in the 1 668.4-1 700 MHz band
- RS.1279 Spectrum sharing between spaceborne passive sensors and inter-satellite links in the range 50.2-59.3 GHz
- RS.1280 Selection of active spaceborne sensor emission characteristics to mitigate the potential for interference to terrestrial radars operating in frequency bands 1-10 GHz
- RS.1281 Protection of stations in the radiolocation service from emissions from active spaceborne sensors in the band 13.4-13.75 GHz
- RS.1282 Feasibility of sharing between wind profiler radars and active spaceborne sensors in the vicinity of 1 260 MHz
- RS.1346 Sharing between the meteorological aids service and medical implant communication systems (MICS) operating in the mobile service in the frequency band 401-406 MHz
- RS.1347 Feasibility of sharing between radionavigation-satellite service receivers and the Earth exploration-satellite (active) and space research (active) services in the 1 215-1 260 MHz band
- RS.1416 Sharing between spaceborne passive sensors and the inter-satellite service operating near 118 and 183 GHz
- RS.1449 Feasibility of sharing between the FSS (space-to-Earth) and the Earth exploration-satellite (passive) and space research (passive) services in the band 18.6-18.8 GHz
- RS.1624 Sharing between the Earth exploration satellite (passive) and airborne altimeters in the aeronautical radionavigation service in the band 4 200-4 400 MHz
- RS.1628 "Feasibility of sharing in the band 35.5 36 GHZ between the Earth exploration-satellite service (active) and space research service (active), and other services allocated in this band "
- RS.1632 Sharing in the band 5 250-5 350 MHz between the Earth exploration-satellite service (active) and wireless access systems (including radio local area networks) in the mobile service
- RS.1744 Technical and operational characteristics of ground-based meteorological aids systems operating in the frequency range 272-750 THz
- RS.1745 Use of the band 1 668.4 1 710 MHz by the meteorological aids service and meteorological-satellite service (space-to-Earth)
- RS.1749 Mitigation technique to facilitate the use of the 1 215-1 300 MHz band by the Earth exploration-satellite service (active) and the space research service (active)
- RS.1803 Technical and operational characteristics for passive sensors in the Earth exploration-satellite (passive) service to facilitate sharing of the 10.6-10.68 GHz and 36-37 GHz bands with the fixed and mobile services
- RS.1804 Technical and operational characteristics of Earth exploration-satellite service (EESS) systems operating above 3 000 GHz
- RS.1813 Reference antenna pattern for passive sensors operating in the Earth exploration-satellite service (passive) to be used in compatibility analyses in the frequency range 1.4-100 GHz

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Mitigation of RFI risks

- no known way to replace data lost from excess RFI since passive sensing is generally a “real time mission” that can never be repeated or recaptured for any expired time period.

RFI detection and mitigation techniques

Frequency band	RFI detection or mitigation technique	Examples of mission or passive sensor	Measurement	RFI source
1.4-1.427 GHz	Agile digital detector?	Aquarius	Sea surface salinity	High power telecommunication transmission or radars
1.4-1.427 GHz 6.425-7.25 GHz	Asynchronous pulse blanking and FFT	Hydros	Soil moisture	Wideband sources-radars
6.425-7.25 GHz 10.6-10.7 GHz	Spectral difference method, principal component analysis	AMSR-E	Soil moisture, vegetation index Sea surface temperature	Narrow-band sources-fixed communication
6.425-7.25 GHz 10.6-10.7 GHz 22.21-22.5 GHz	Spatial filter using a dynamic discrete Backus-Gilbert technique	WindSat CMIS NPOESS	Soil moisture, vegetation index	Narrow-band sources-fixed communication
6.425-7.25 GHz	Sub-band diversity	CMIS	Soil moisture, vegetation index	Narrow-band sources-fixed communication
6.425-7.25 GHz	Using a provisional channel	AMSR2	Soil moisture, sea surface temperature	Narrow-band sources

RFI detection and mitigation techniques

- Brief description of above RFI detection and mitigation techniques:
- 1) Agile digital detector (ADD)
- The agile digital detector (ADD) can discriminate between RFI and natural thermal emission signals by directly measuring higher order moments of the signal than the variance that is traditionally measured. The ADD uses high-resolution temporal and spectral filtering methods to selectively remove the RFI that is detected.
- 2) Asynchronous pulse blanking and FFT
- The idea of this technique is to remove incoming data whose power exceeds the mean power by a specified number of standard deviations. Successful performance of this algorithm has been qualitatively demonstrated through local experiments with the digital radiometer. The HYDROS mission team had expressed an interest in possible inclusion of such a digital backend in the HYDROS instrument for the RFI mitigation in L-band. But the system developed can be applied in other RF bands: NPOESS sponsored project using this system at C-band in progress.
- 3) Dynamic discrete Backus-Gilbert technique
- The Backus-Gilbert (BG) technique was traditionally used to enhance the satellite data spatial resolution and/or to improve the sensor spatial coregistration behaviours under a benign RFI environment but was difficult to use in an RFI-ridden condition. However, a new dynamic Discrete Backus-Gilbert (DBG) method has been created for use in RFI noise environments to mitigate RFI effects on the data in conjunction with 4D data assimilation for soil moisture profiles. It resolves a lot of problems with the traditional BG method but still is computationally quite expensive.

Advantages and disadvantages of various mitigation techniques

Name of technique	Advantages	Disadvantages
Agile digital detector	Suitable for detecting narrow-band pulsed signals Can detect RFI at low levels – to the radiometric uncertainty No additional analogue detector needed Can be on-board real time technique Could potentially eliminate the effect of RFI on brightness temperatures	Technique only demonstrated for L-band where there are narrow-band unmodulated radars and not shown to be useful for detecting wideband modulated signals Increased temporal sampling rate resulting in large data files Loss of processor results in loss of the channel Places complex equipment on the spacecraft which cannot be maintained Additional processor may provide additional power requirements on the spacecraft
Spectral difference method	RFI can be detected and removed relatively easily	Sea and land require different techniques Limited to differences over 5 degrees Not an onboard real-time technique Detection of RFI in one channel is only certain if compared to another uncontaminated channel
Sub-band diversity	Can be implemented in near real time on the spacecraft Provides means to estimate uncontaminated measurement Can be implemented with analogue receivers	The inclusion of extra special receivers and processors on the spacecraft to detect RFI are at the expense of weight, space and power requirements which may only provide a limited improvement in data quality If the processing were to be performed on the ground, the extra data collected and stored to implement these techniques would require a higher data rate for transmission Detects only narrow-band interference
Asynchronous pulse blanking and FFT	Remove incoming data whose power exceeds the mean power by a specified number of standard deviations	The APB approach not shown to be effective in reducing corruption from long-term large scale RFI
Using a provisional channel	Uses two close frequency ranges (6.925 and 7.3 GHz) to measure the same radiance simultaneously (7.3 GHz channel is a secondary, which is only used when the primary channel (6.925 GHz) is contaminated with RFI).	Not used in a production environment Neither channel is protected Only one signal is sensitive to the measurement (6.925) the other signal is there for redundancy Multiple signals means multiple receivers means more expense and higher chance of failure
Spatial filter using a dynamic Discrete Backus-Gilbert technique	To enhance the satellite data spatial resolution Can be applied to all microwave bands	Increase noise floor of sensors Extensive computations Need separate RFI detection methods