

Thermodynamic Profiling for High-Impact Local Weather

Presentation to

Indian Institute for Tropical Meteorology

Pune, India 17 April 2015

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1978 NOAA Labs



1986 NASA JPL



1990 Radiometrics



2005 Radiometrics



2008 Radiometrics

Thermodynamic Profiler Evolution



Basic Physics and Retrieval Method

- Multi-channel microwave observations are converted to brightness temperatures using the Planck Radiation Equation
- Air temperature, humidity and liquid are linked to brightness temperatures by Radiative Transfer Equations
- Neural Networks convert brightness temperatures to temperature, humidity and liquid profiles



Planck Radiation Equation:

$$B_{\nu}(T) = \frac{2h\nu^3}{c^2} \frac{1}{(\exp(h\nu/kT) - 1)}$$

Chandrasekar Radiative Transfer Equation:

$$B_{\nu}(T_b) = B_{\nu}(T_c) \exp(-\tau_{\nu}) + \int_0^\infty B_{\nu}(T(s)) \alpha_{\nu}(s) \exp(-\int_0^s \alpha_{\nu}(s') ds') ds$$

Westwater et al., Principles of Surface-based Microwave and Millimeter wave Radiometric Remote Sensing of the Troposphere, Quaderni Della Societa Italiana Elletromagnetismo, 2005 (http://radiometrics.com/wp-content/uploads/2013/02/Westwater_QSIE_2005.pdf).





Absorption spectrum of a typical mid-latitude atmosphere for two altitudes and two water vapor densities





Microwave and infrared emission from air are converted into temperature, humidity and liquid profiles





Radiometer – Radiosonde Comparison

- An MP-3000A was operated during the 2010 Winter Olympics by the Canadian Met Service
- Radiosondes were launched at 6 hr intervals
- Off-zenith radiometer retrievals demonstrated accurate performance during rain, sleet and snow up to 20 mm/hr
- Radiometer and radiosonde temperature and humidity profiles correlate up to 10 km height
- Wind direction and precipitation are highly correlated



LAPS 700 m

Radiosonde 659 m

LAPS

679 m

LAPS

1243 m

4.4 km, 117 m

Radiometer 776 m

Radiometer, radiosonde and analysis grid point locations



Radiometer and other sensors (776 m elevation)



Radiosonde launch site (659 m elevation)



16-day radiometer and radiosonde comparison (Ware et al, Atmos. Res., 2013)



Severe Storm Warning

- Severe thunderstorms including lightning, torrential rain and 100 mph wind gusts resulted in 22 deaths and widespread damage, leaving millions without power for five days in Washington, DC.
- Forecast index time series derived from local thermodynamic profiles showed extremely unstable conditions and risk of 100 mph winds more than seven hours in advance.





High Impact Local Weather Warnings >2-hr in Advance

- "...ground-based MWR observations can be used effectively to predict the occurrence of thunderstorms at least 2 h in advance."
 (Madhulatha et al, 2013)
- High Impact Local Weather includes: Fog, Lightning, Hail, Rain, Gust Fronts, Turbulence, Wind Shear, Icing



THE NATIONAL WEATHER SERVICE IN FORT WORTH HAS ISSUED A * TORNADO WARNING FOR... CENTRAL DENTON COUNTY IN NORTH CENTRAL TEXAS... * UNTIL 630 PM CDT 3 April 2014 * AT 547 PM CDT... STORM SPOTTERS AND DOPPLER RADAR OBSERVED A DEVELOPING TORNADO 3 MILES SOUTHWEST OF KRUM... MOVING EAST AT 20 MPH.

* THE TORNADO WILL BE NEAR... **DENTON** AROUND 605 PM CDT... CORINTH AROUND 615 PM CDT... SHADY SHORES AND **LAKE DALLAS** AROUND 620 PM CDT... OAK POINT AROUND 625 PM CDT... KRUGERVILLE... CROSS ROADS AND LAKEWOOD VILLAGE AROUND 630 PM CDT...



- Hazardous Weather Testbed
- NOAA purchases
 <u>Boundary Layer</u>
 <u>Network</u> (BLN)
 radiometer data
- WMO radiosonde site at Ft. Worth
- Tornadoes reported at red markers
 3 April 2014 afternoon



Sigma Soundings

- Combined radiometer and gridded analysis
- Sigma Sounding radiosonde comparisons during stable and unstable conditions
- Strong upper level wind shear before tornado
- Supercell and hail (>3 cm) probability
- Automated Strong Storm Category alerts (lower left in following slide)



Midlothian Sigma Sounding 3 hours prior to Denton Tornado

Weighted Forecast Index Totals provide High-Impact Local Weather Alerts (previous slide lower left corner)

Can be customized by Forecaster to optimize local alerts including fog, lightning, convection, hail, icing, low level wind-shear, turbulence, etc.

Weight	Parameter	Weak	Moderate	Strong
1	 200 mb Wind Sneed (kt.)		65	
1	500 mb Wind Speed (kt.)			54
1	700 mb Wind Speed (kt)			39
1	700 mb Dewnoint Depression (C)			14.2
1	850 mb Wind Sneed (kt.)		25	
1	850 mb Dewnoint (C)		20	12 2
1	700 - 500 mb lanse rate (C/km)	-8 2		10.0
1	Bowden Index	0.2	97 1	
1	BDN - Bulk Dichardson No	9	27.1	
1	BDN Sheer (m²/c²)	-		165 0
1	CAD Strength	4 5		100.0
1	CAPF 0-2 km ACL	0		
1	CAPE C C AM, ACL	Ŭ	1206	
1	Crowen SigGur Deveneter (mixed-lever lift)		1300	64
1	CT - Croce Totole			26 0
1	DCARE 6 0 here ACI			1160
1	Delte Thete-e (eDT)		10.2	1163
1	Pelca Ineca-e (erl) Rut - Recurst Valisity Tudoy		19.2	
1	BHI - Energy Helicity Index		2.2	
1	GORS HAI (Hybrid Microburst Index)	4		
1	Hail (Cm)			2.57
1	HI - Humidity Index			28.8
1	JI - Jefferson Index			31
1	K Index		29.1	
1	KO Index			-17.1
1	LFC-LCL height (m)	2339		
1	LFC - Level of Free Convection (mb)		686	
1	LI - Lifted Index			-6.0
1	MDPI - Microburst Day Potential Index		0.8	
1	NCAPE (Normalized CAPE)		0.18	
1	S Index		43.7	
1	SCP - Supercell Composite Parameter			14.7
1	Severity - Thunderstorm Severiry Index			1.8
1	SHIP - Significant Hail Parameter			3.0
1	SI - Showalter Index			-5.1
1	srH - storm-relative Helicity (0–3 km)		205	
1	STP - Significant Tornado Parameter			5.3
1	Surface Dewpoint (C)		17.6	
1	SWEAT Index		428.3	
1	T2 Gust (kt)	32		
1	TI - Thompson Index			35
1	TQ Index		17	
1	TT - Total Totals			57.9
1	VGP - Vorticity Generation Parameter			0.437
1	VT - Vertical Totals			31.1
1	Waterspout Index	22		
1	WBZ - WetBulb Zero Hqt (ft,AGL) *		10169	
1	Windex (kt)		38	
1	WMSI - Wet Microburst Severity Index		30	
			======	
	Weighted Category Totals:	8	18	22
	······································	-		

RPM = 46%

Sigma Sounding vs. Radiosonde during Stable Conditions

- Good temperature and humidity agreement at all levels during stable conditions
- radiometer radiosonde station separation
 >30 km
- 1DVAR radiosonde-equivalent thermodynamic profiling accuracy (<u>Hewison et al, 2006</u>; <u>Cimini</u> <u>et al, 2011</u>)
- Full suite of continuous Forecast Indices derived from Sigma Soundings during all weather conditions



Radiometer (red), radiosonde (blue) – good agreement during stable conditions

Sigma Sounding vs. Radiosonde during Unstable Conditions

- Significant boundary layer temperature and humidity differences during unstable conditions
- Differences stem from large local temperature and humidity variability during convection
- Stability indices are strongly influenced by boundary layer thermodynamics
- Convective forecasting hours in advance with radiometer derived forecast indices (<u>Madhulatha et</u> <u>al, 2013</u>; <u>Ratnam et al, 2013</u>)



Flower Mound radiometer (red), DFW radiosonde (blue) – during convection



4-day radiometer observations including convection at Flower Mound



Half-day 20 deg north observations during stable conditions at Flower Mound



Half-day 20 deg north observations including convection at Flower Mound



All-Weather Accuracy

- Microwave profiler in operation at Pearson International Airport
- Co-located radiometer and precipitation sensors
- Rain rate greater than 60 mm/hr
- Off-zenith methods are accurate during heavy rain (Xu et al, Atmos. Res., 2014)



MP-3031A at Pearson International Airport (Toronto, Canada)





Profiles during heavy rain to 9 km height (RAOB display)



Weather Modification

- Idaho Power operates MP-3000A's for aircraft cloud seeding operations
- 3D mapping of supercooled liquid cloud seeding targets
- Accurate performance during heavy precipitation using off-zenith methods

Northwest

West MP-3048A 817m

Southwest

Boise Radiosonde 871m

Northwest, west and southwest observations @ 15° elevation



Liquid profile observations northwest, west and southwest @ 15° elevation



Powerful Local Weather Forecast and Nowcast Technology

- Radar Wind and Thermodynamic Profiler System (RWTPS)
- Sigma Soundings: Combined RWTPS and Gridded Analysis



Radar Wind and Thermodynamic Profiling System (RWTPS)



Sigma Sounding (radiometer plus gridded analysis) from a US National Weather Service radiometer at Denver, hours before multiple tornadoes were reported nearby.





Pearson (Toronto) International Airport



Chevron Oil Platform Gulf of Mexico



Dubai International Airport



Chinese Meteorological Administration



Los Angeles International Airport



US National Profiler Network