Evaluation of a Microwave Radiative Transfer Model using Satellite Radiometer Observations

Yan Sun

Masters Thesis Defense

March 31, 2003

Objective

- To evaluate a microwave Radiative Transfer Model RTM named RadTb, which has application to satellite microwave remote sensing technology
- To establish the accuracy of the RadTb to calculate microwave brightness temperature over the ocean
  - Establish biases and standard deviations between measured and theoretical brightness temperatures

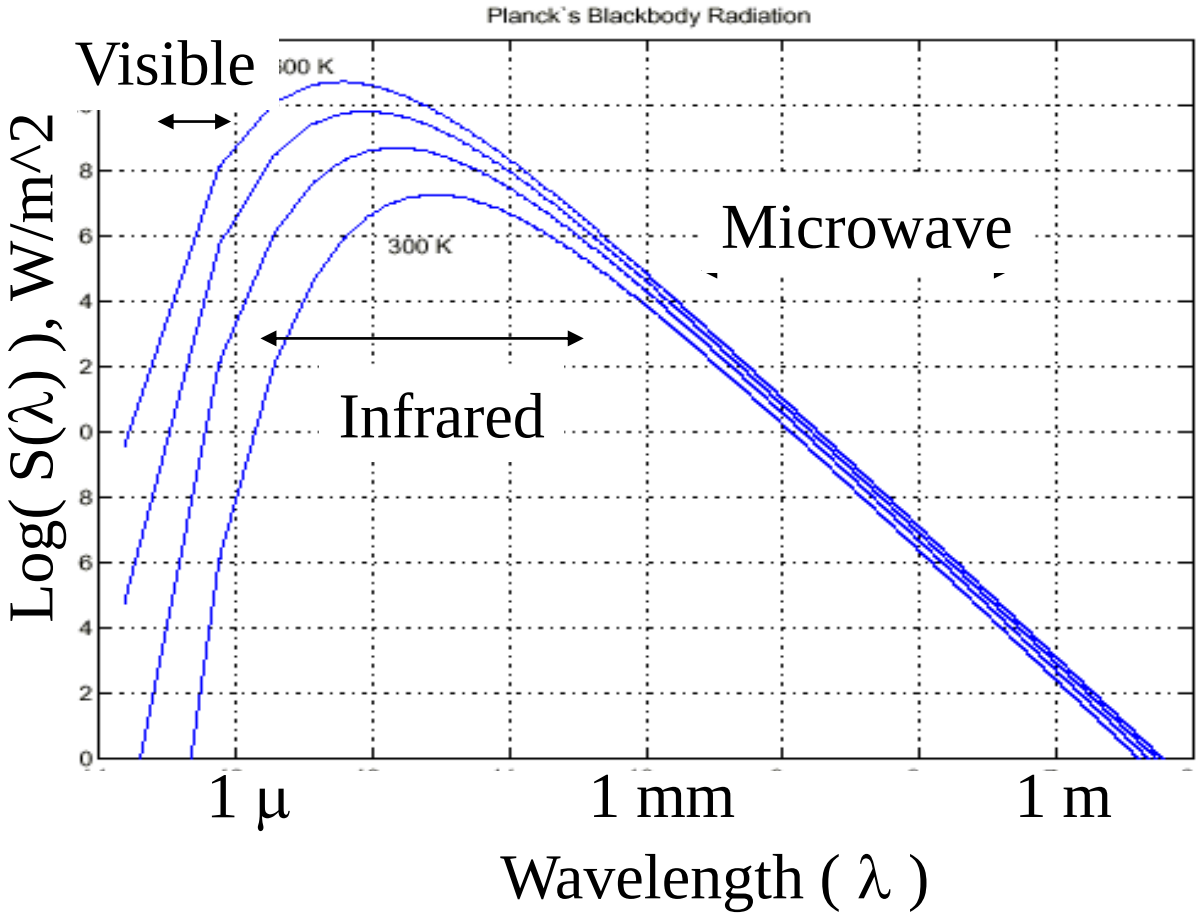
Blackbody Radiation

Blackbody Radiation

- **Thermodynamic principal:** all matter at temperatures > absolute zero both absorb and emit non-coherent EM energy (noise) simultaneously.
  - Absorption of EM energy causes its physical or thermodynamic temperature to rise which increases in the emitted EM radiation.
  - At thermal equilibrium, the physical temperature is constant and the rate of energy absorbed is exactly matched by energy emitted.

Planck's Blackbody Radiation

Matter at temperatures > absolute zero both absorb and emit non-coherent EM energy (noise) simultaneously.



Microwave Radiometry

- In the microwave region of the EM spectrum, the power collected by a microwave antenna is:

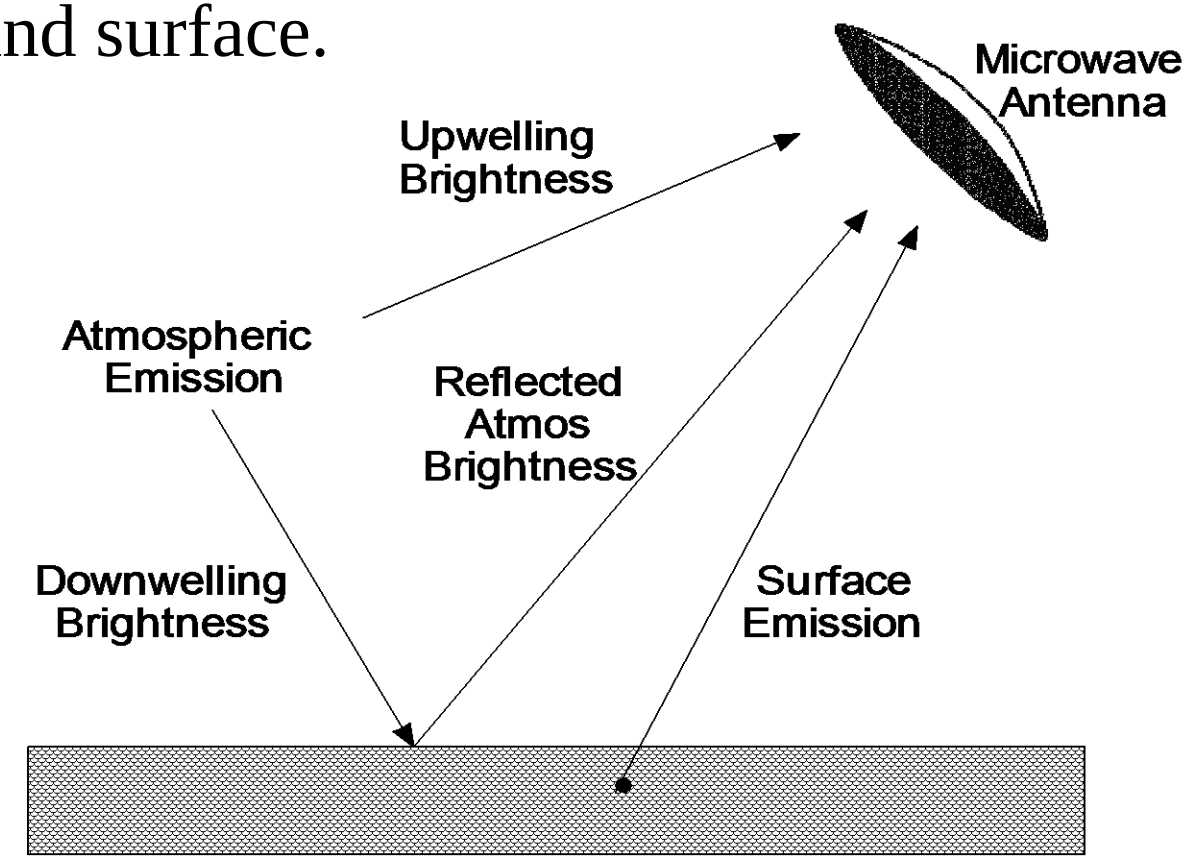
$$P_{blackbody} = k T_b * Bandwidth$$

- Microwave Brightness Temperature, $\boldsymbol{T_b}$, of a media is the product of the media emissivity and its physical temperature. For blackbodies, ε = 1.0

$$T_b = \varepsilon * T_{phys}$$

Radiative Transfer Theory

The T_B measured by a spaceborne radiometer is the linear sum of individual power contributions from the atmosphere and surface.



Microwave Emissivity

Emissivity of matter is the efficiency of self radiation (emission). It varies with:

- EM wavelength (radiometer operating frequency)
- EM polarization & incidence angle
- Geophysical parameters (dielectric constant) of the physical media

Atmospheric Emissivity

- Atmospheric microwave emission is non-polarized (i.e., independent of antenna polarization)
  - Resonant absorption (emission) by water vapor - 21 GHz, 183 GHz, & 325 GHz
  - Resonant absorption (emission) by oxygen - 60 GHZ & 120 GHz
  - Non-resonant absorption of hydrometers (cloud water and rain)

Ocean Emissivity

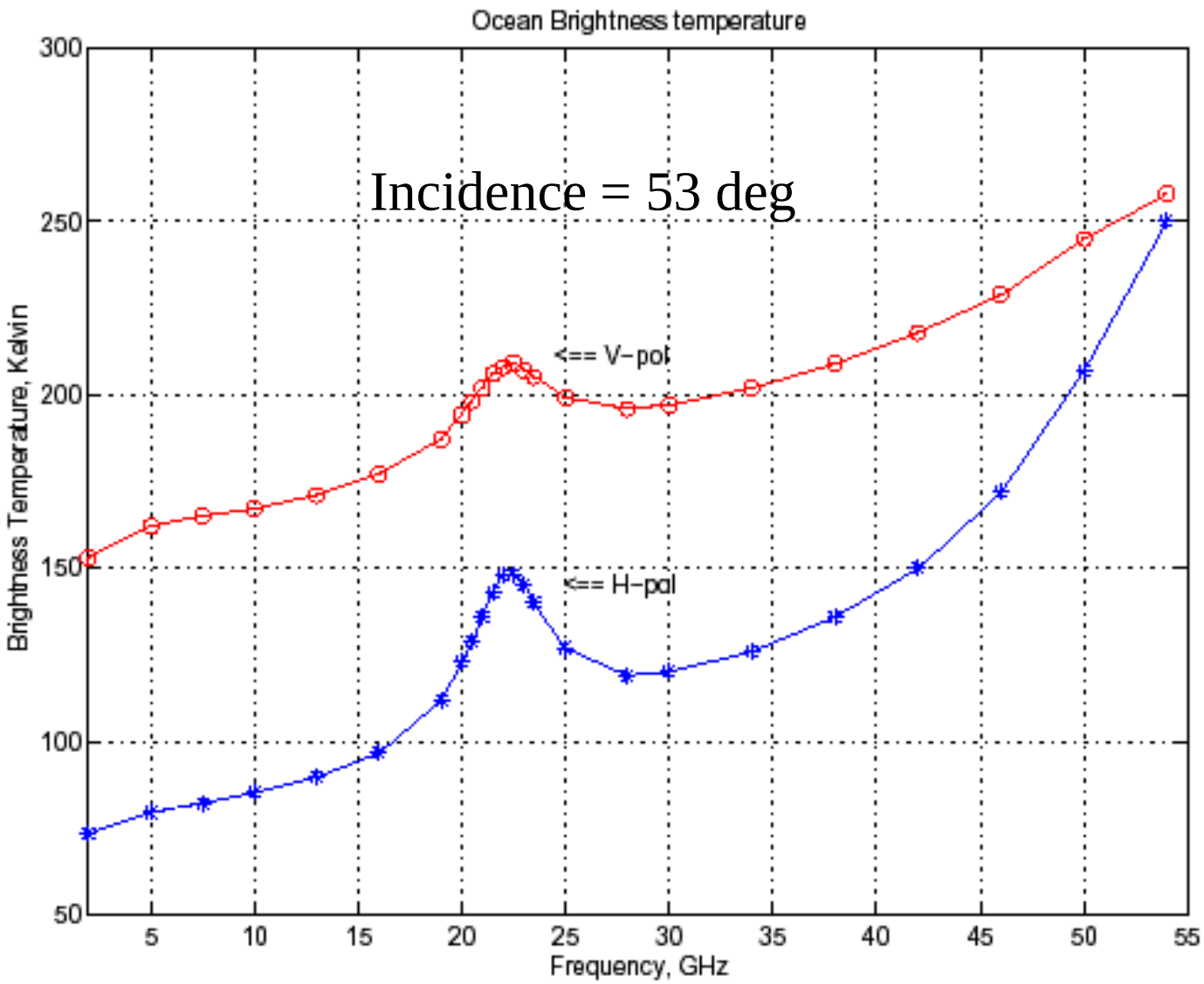
- Ocean microwave emission is strongly polarized and depends upon the dielectric properties of sea water.
  - Emissivity: 40% (H-pol) ; 60% (V-pol)
  - is a function of geophysical parameters:
    - Salinity
    - sea surface temperature
    - small scale ocean wave roughness (surface wind speed).

RadTb Radiative Transfer Model

- Developed by the US Naval Research Lab in 1980's
- Frequency range: 1 GHz to 100 GHz
- Incidence angles: 0 deg to > 80 deg
- Dual polarizations V and H
- Environmental parameters:
  - Atmospheric parameters; water vapor, oxygen, air temp, cloud liquid water, and pressure
  - Ocean parameters; salinity, sea surface temp, and wind speed

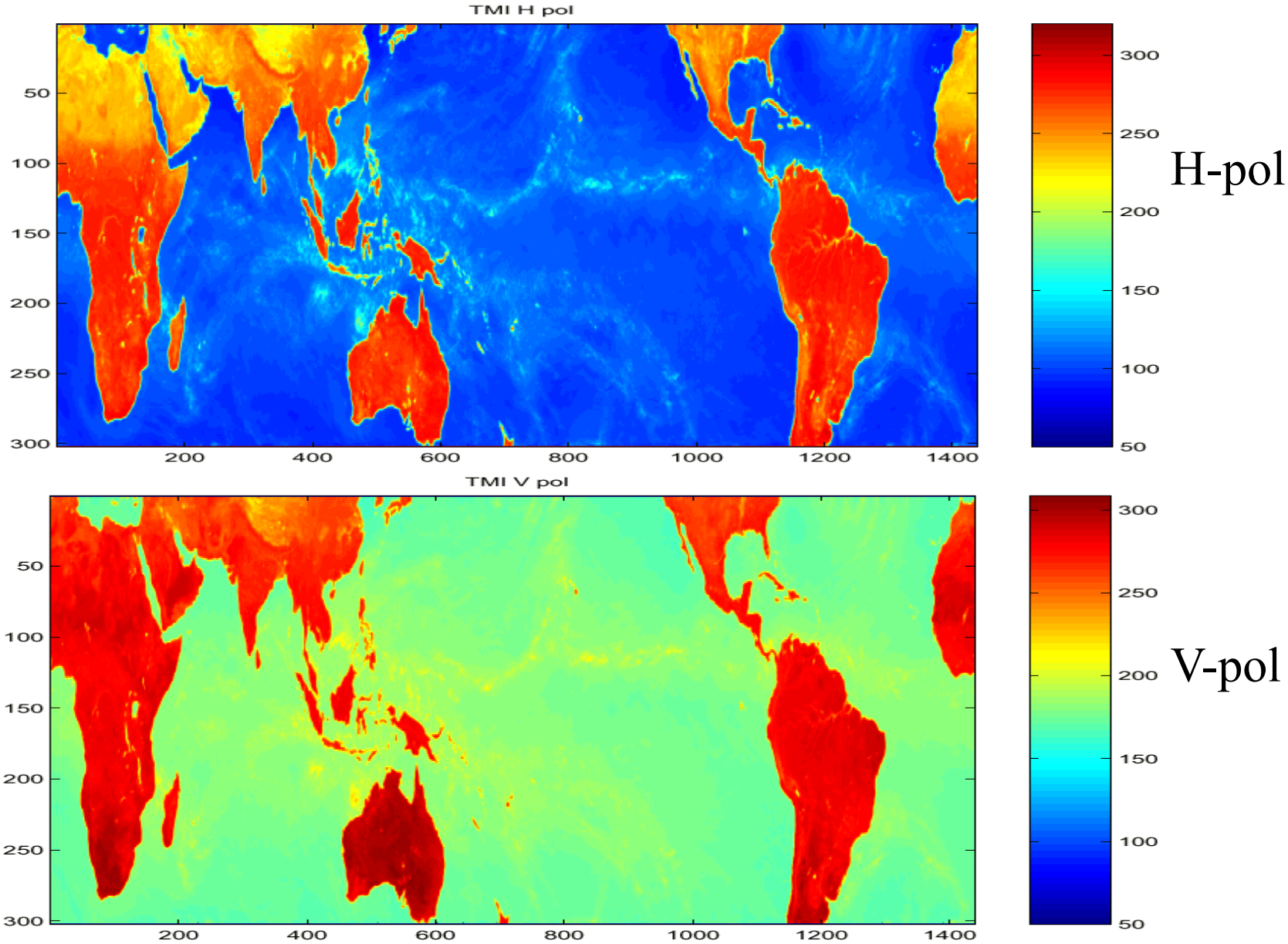
Example Ocean Brightness T_b

CFRSL



Example Measured Tb @ 13.4 GHz

CFRSL



RTM Model RadTb Validation

RadTb Validation - Data Selection

Selected Topex/Poseidon Microwave Radiometer (TMR) Tb Measurements to test the RTM

- Nadir viewing geometry is simplest to interpret
  - At nadir, Tb's are polarization independent
- Wide frequency range: > octave bandwidth
  - 18 GHz – 37 GHz
- Data are available from Jet Propulsion Laboratory (JPL)

Environmental Parameters

- Environmental parameters for both the atmosphere and ocean surface
  - Must be collocated in space and time with TMR Tb's
  - Matched TMR spatial resolution

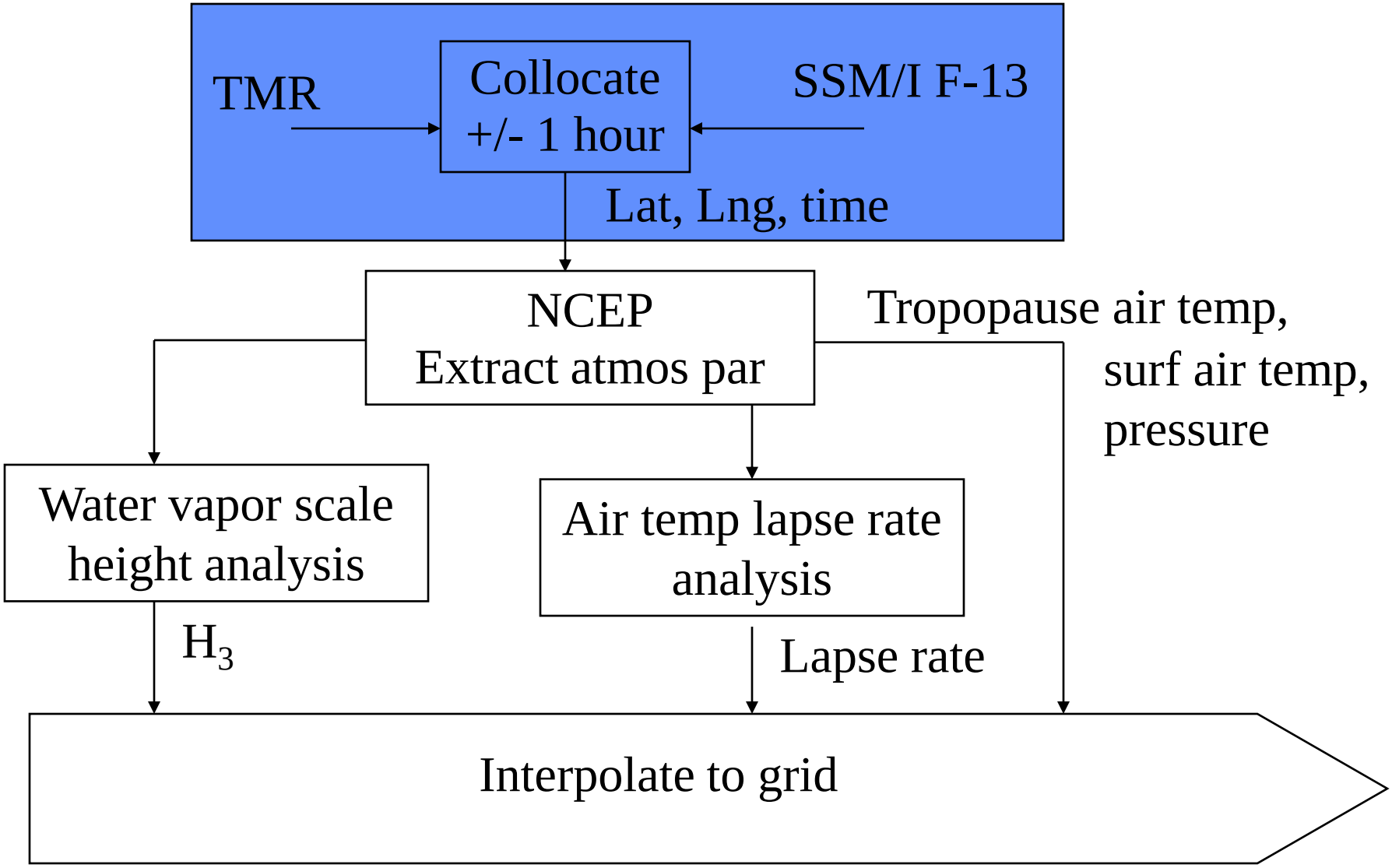
    ~ 1/16 deg grid (6 km x 6 km Lat/Lng grid)
  - Time window +/- 1 hour

Environmental Parameters – cont.

- Data sources:
  - Wind speed and columnar water vapor from TOPEX Master Geophysical Data Record (MGDR)
  - Cloud liquid water from Special Sensor Microwave Imager (SSM/I) on DMSP
  - Atmospheric temp, pressure and humidity profile from NOAA numerical weather model
  - Salinity and sea surface temp from NOAA databases

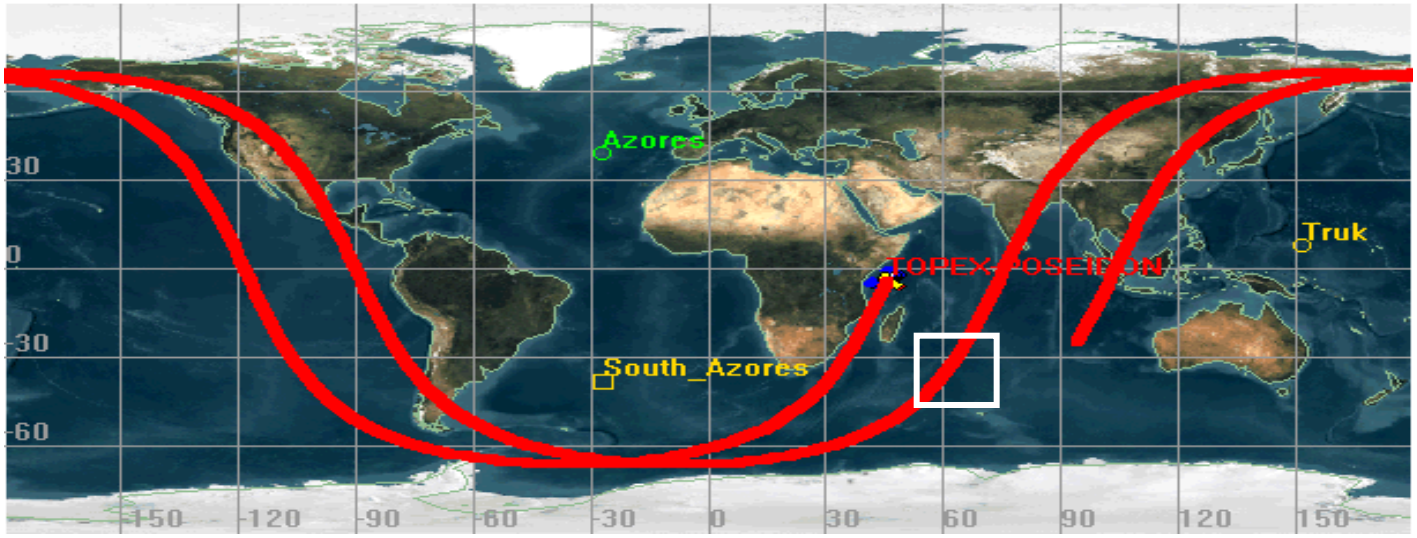
Validation Procedure

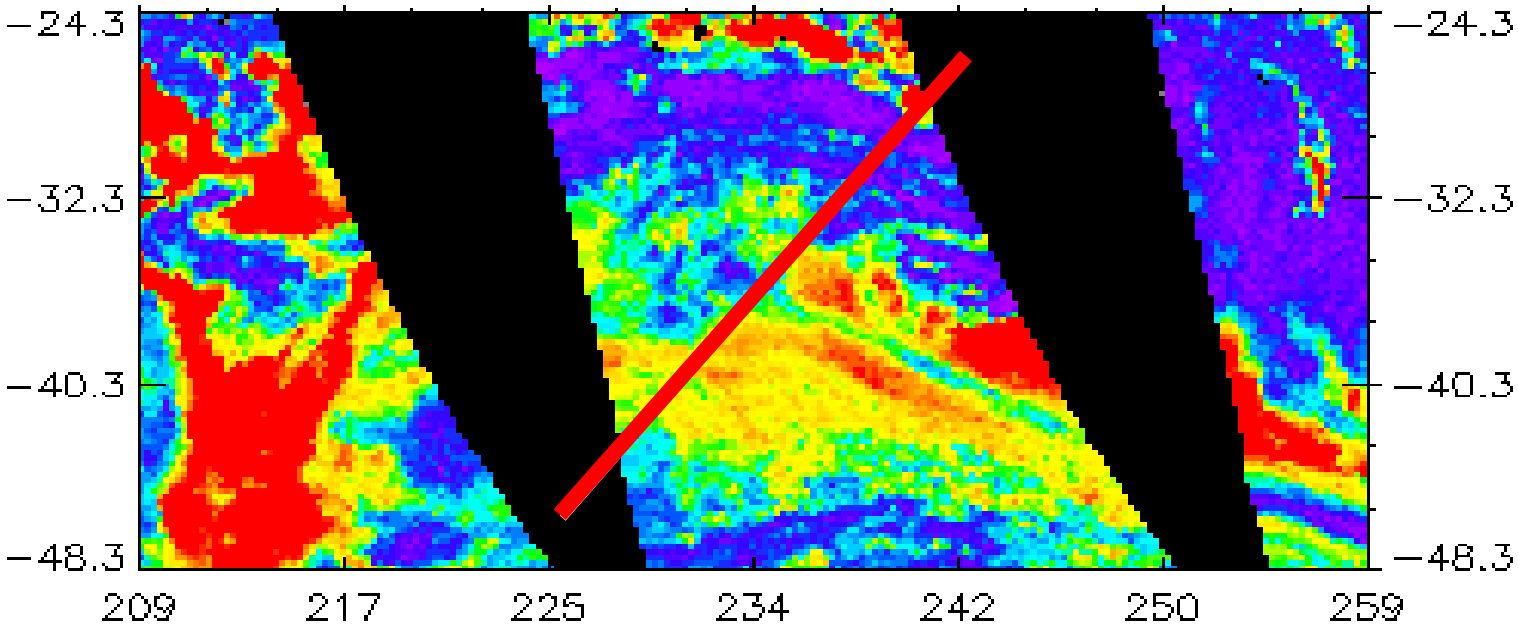
CFRSL



Spatial Collocation of TMR & SSM/I

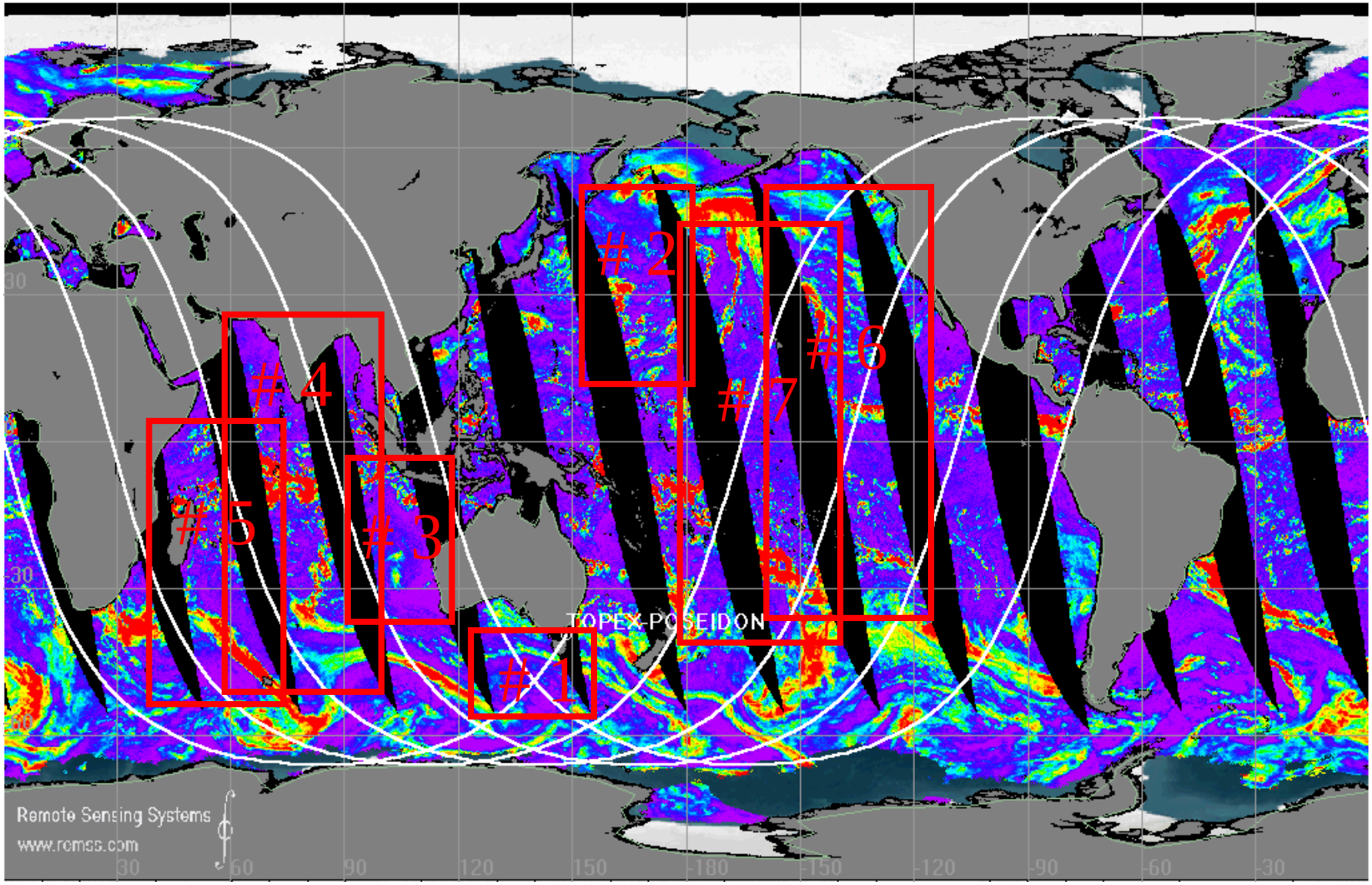
CFRSL





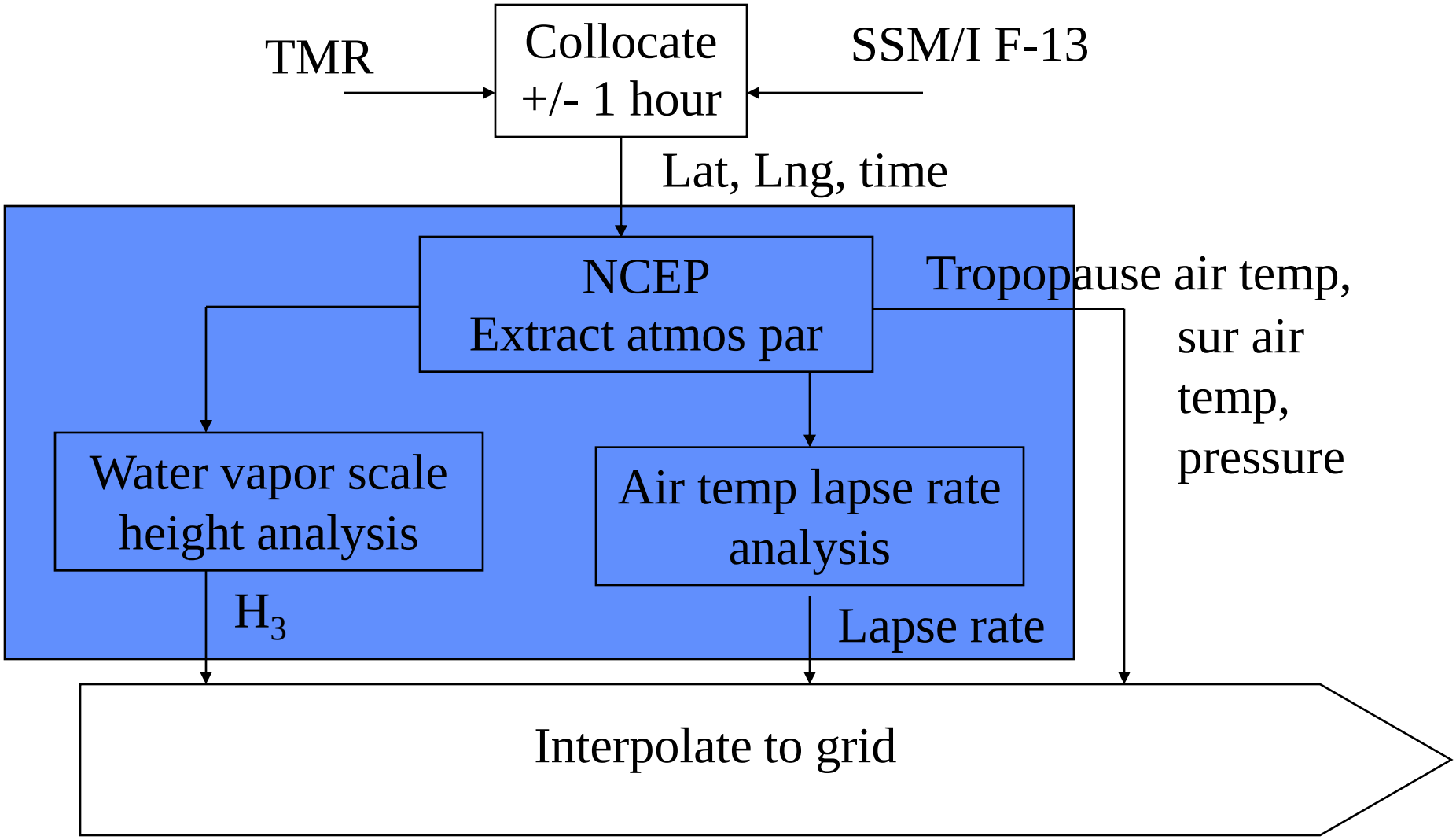
7 Collocation Areas

CFRSL



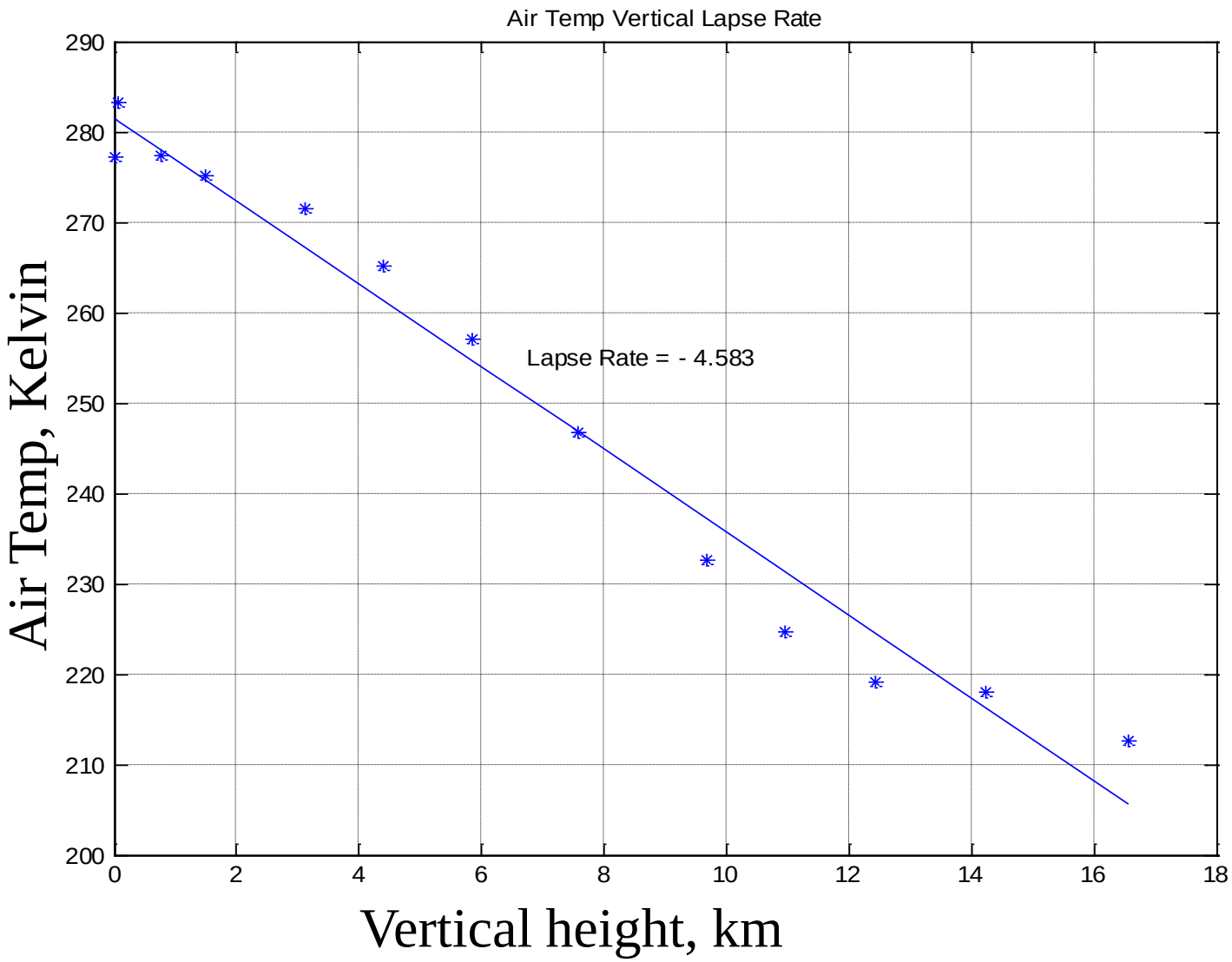
Validation Procedure

CFRSL



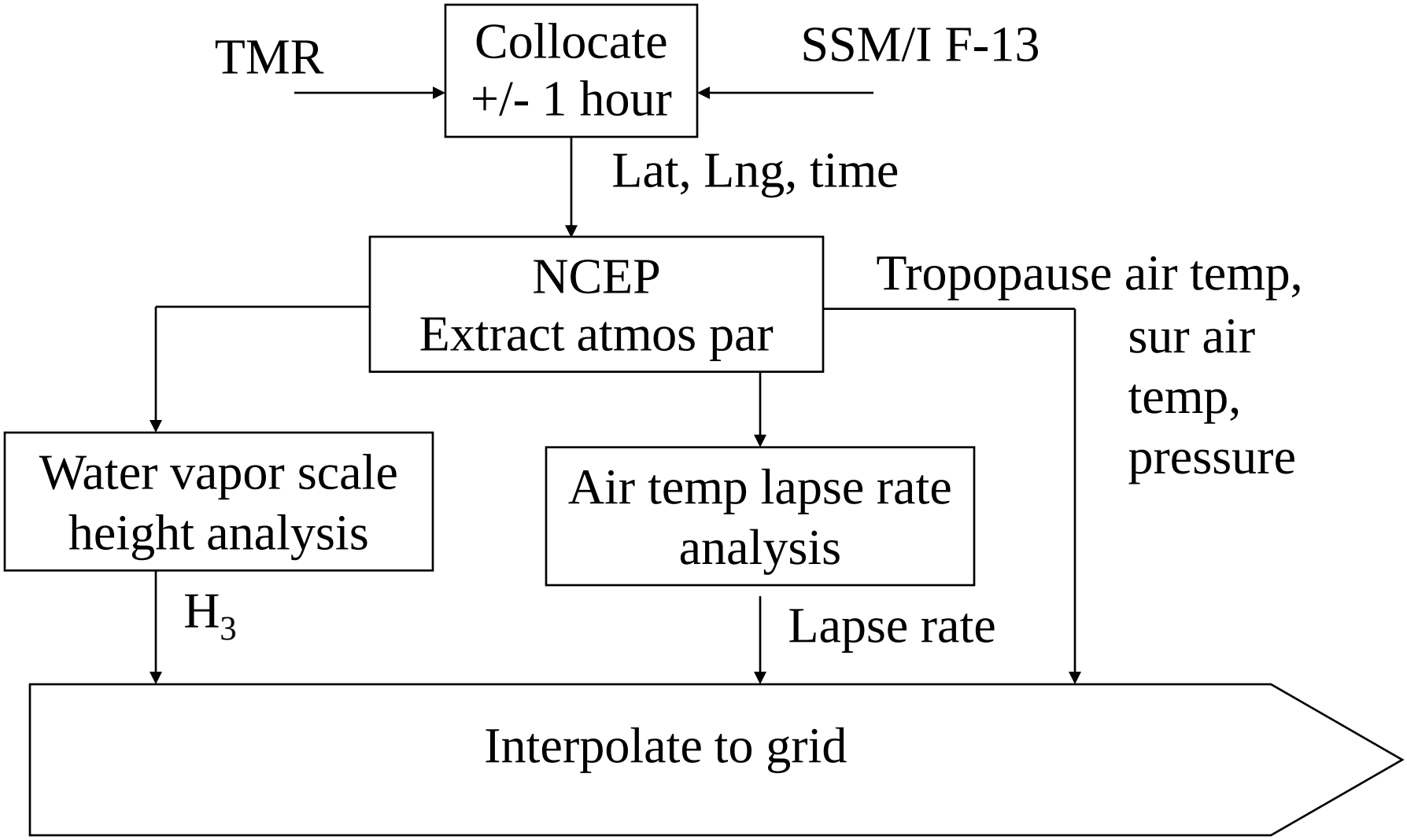
Atmospheric Temp Lapse Rate

CFRSL

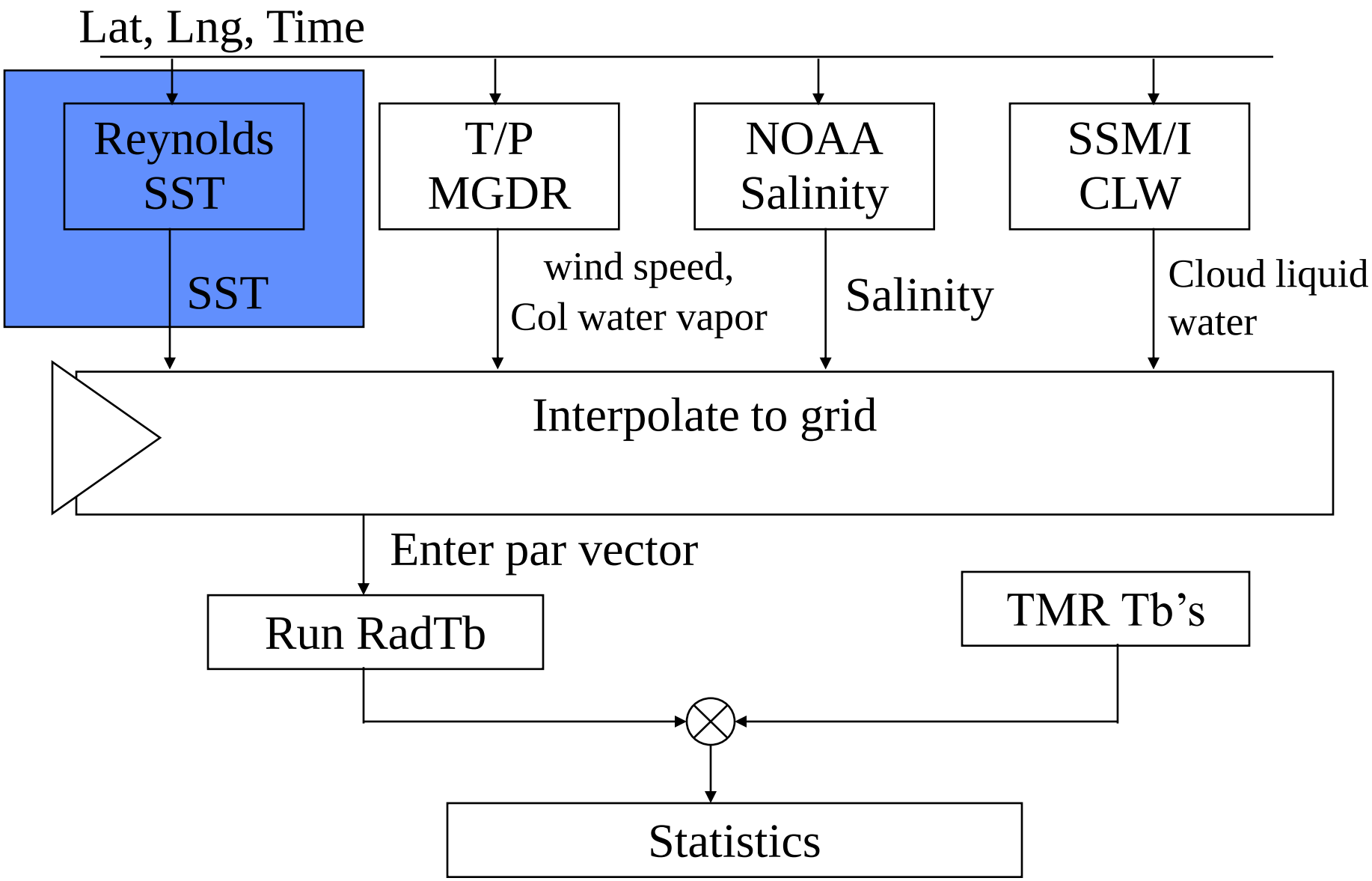


Validation Procedure

CFRSL



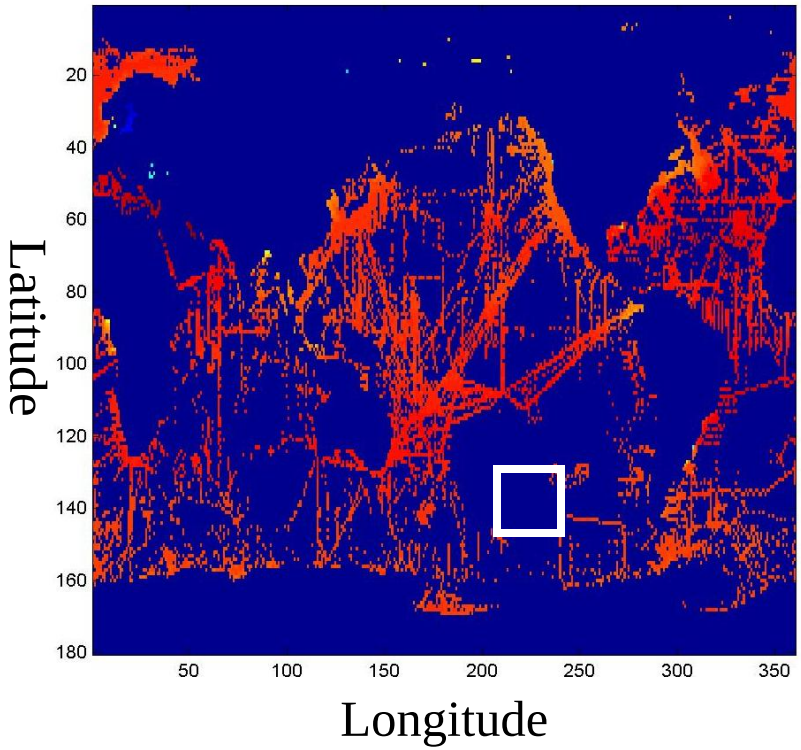
Validation Procedure – cont.

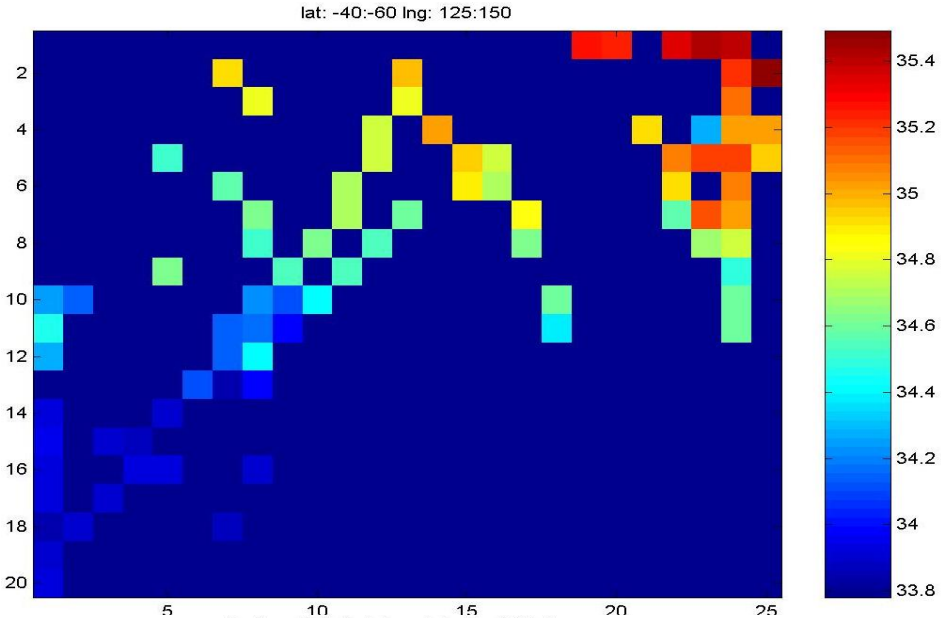


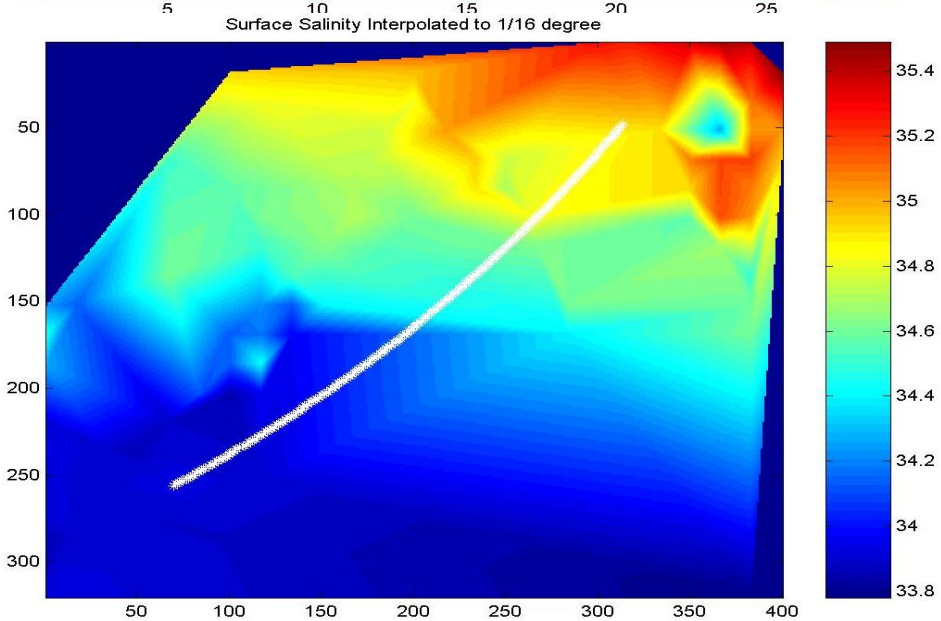
Spatial Interpolation of Salinity

CFRSL

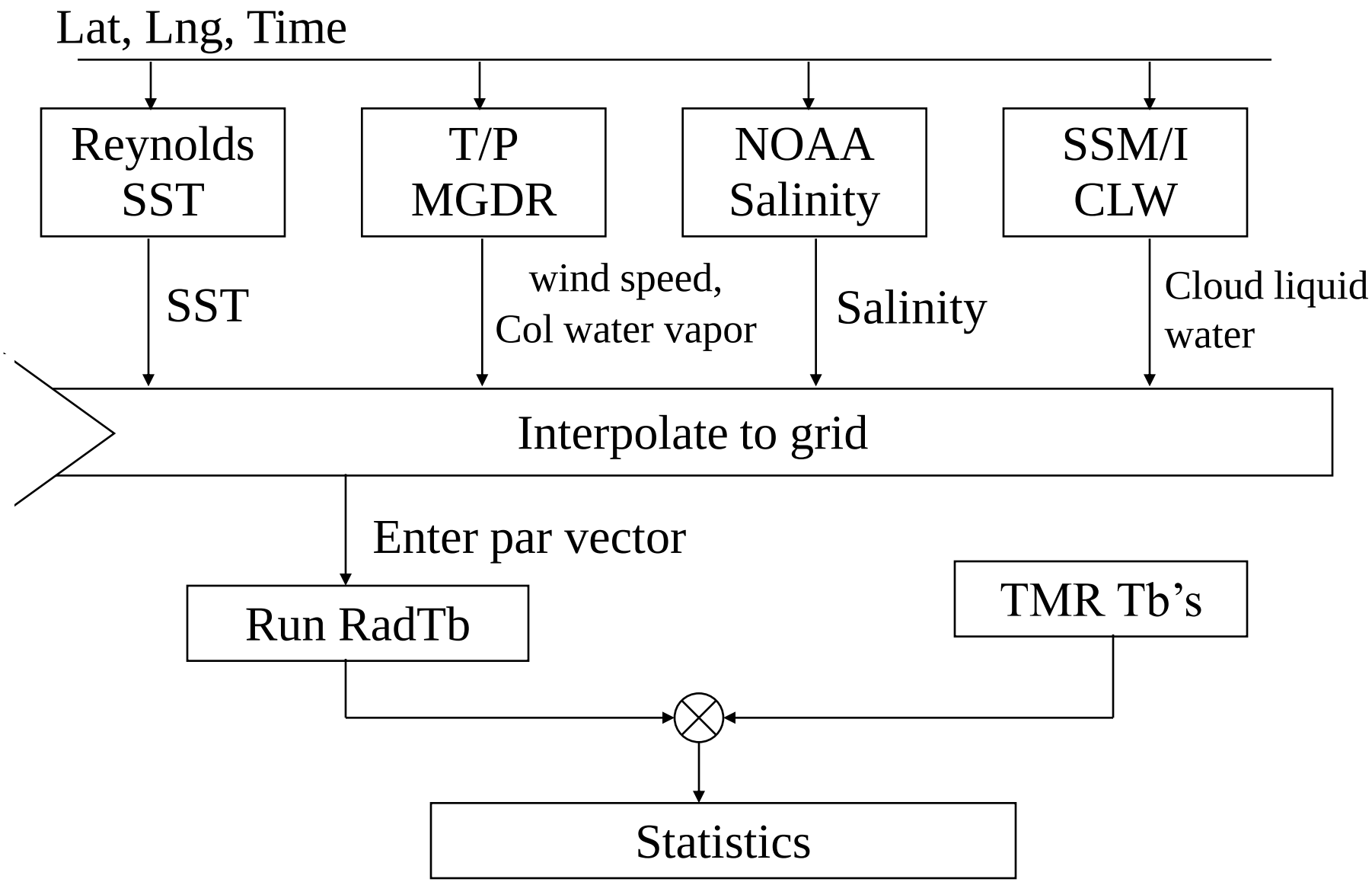
Collocation # 1







Validation Procedure – cont.



RadTb Input/Output Parameters

CFRSL

Input:

Lat (deg)	Lng (deg)	Sur Pressure PS (mb)	Sur Air Temp TSC (C)	Air Temp Vertical Lapse Rate RLAPSE (C/Km)	Sur Abs Humidity AHS (gm/m3)	Colm Density of Water Vapor H2OV (gm/cm2)	Temp of Tropopause TTP (K)
-55.97	129.34	1007.16	4.10	-3.87	6.26	1.83	222.02
-55.93	129.40	1007.44	4.13	-3.87	6.23	1.82	221.98
-55.89	129.47	1007.46	4.13	-3.87	6.22	1.83	222.00

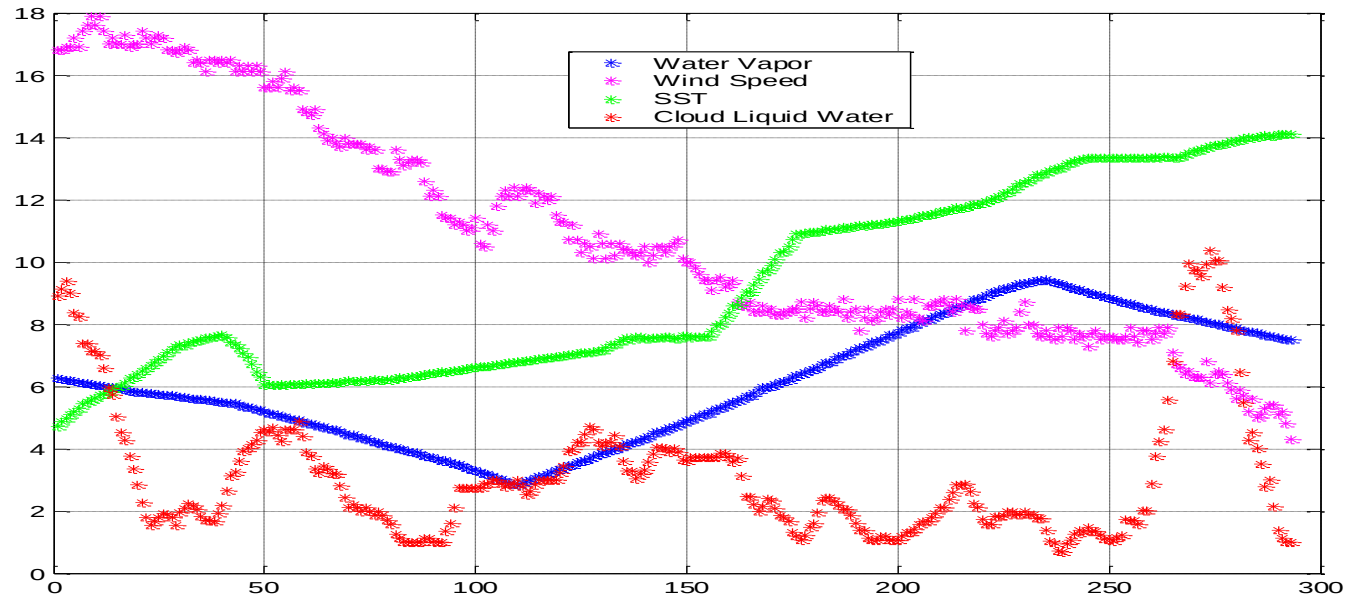
mixing ratio	Colm Density of Cloud Water H2OL (gm/cm2)	Cloud base HCB (Km)	Cloud top HCT (Km)	Rain Rate	Sur Wind Speed WMPS (m/sec)	Sea Sur Water Temp TSEAC (C)	Sea Sur Salinity SALIN (parts/1000)
2.00E-06	0.0178	0.30	1.30	0	16.8	4.72	33.9
2.00E-06	0.0183	0.30	1.30	0	16.8	4.86	33.9
2.00E-06	0.0188	0.30	1.30	0	16.9	4.97	33.9

Output:

M 18 (K)	M 21 (K)	M 37 (K)	C 18 (K)	C 21 (K)	C 37 (K)
145.01	165.05	182.77	147.31	167.27	184.36
145.29	165.14	182.66	147.33	167.2	184.47
145.21	165.14	182.4	147.59	167.55	184.81

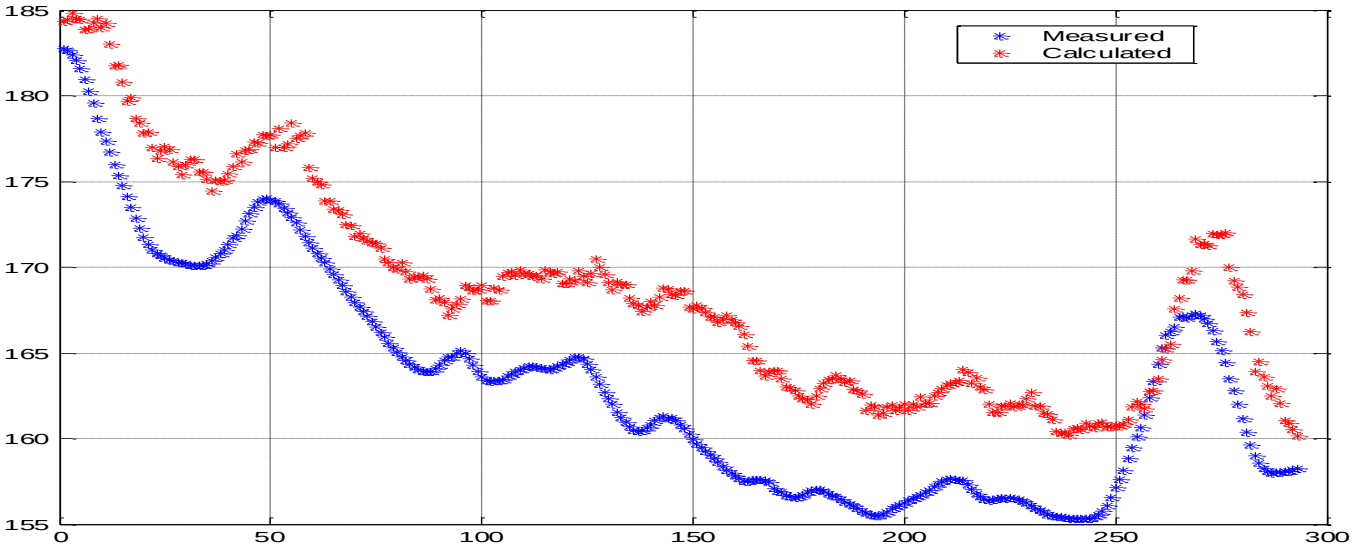
Measured and Calculated Tb's

CFRSL



Collocation #1 parameters

- Water Vapor
- Wind Speed
- SST
- Cloud Liquid Water x 5000

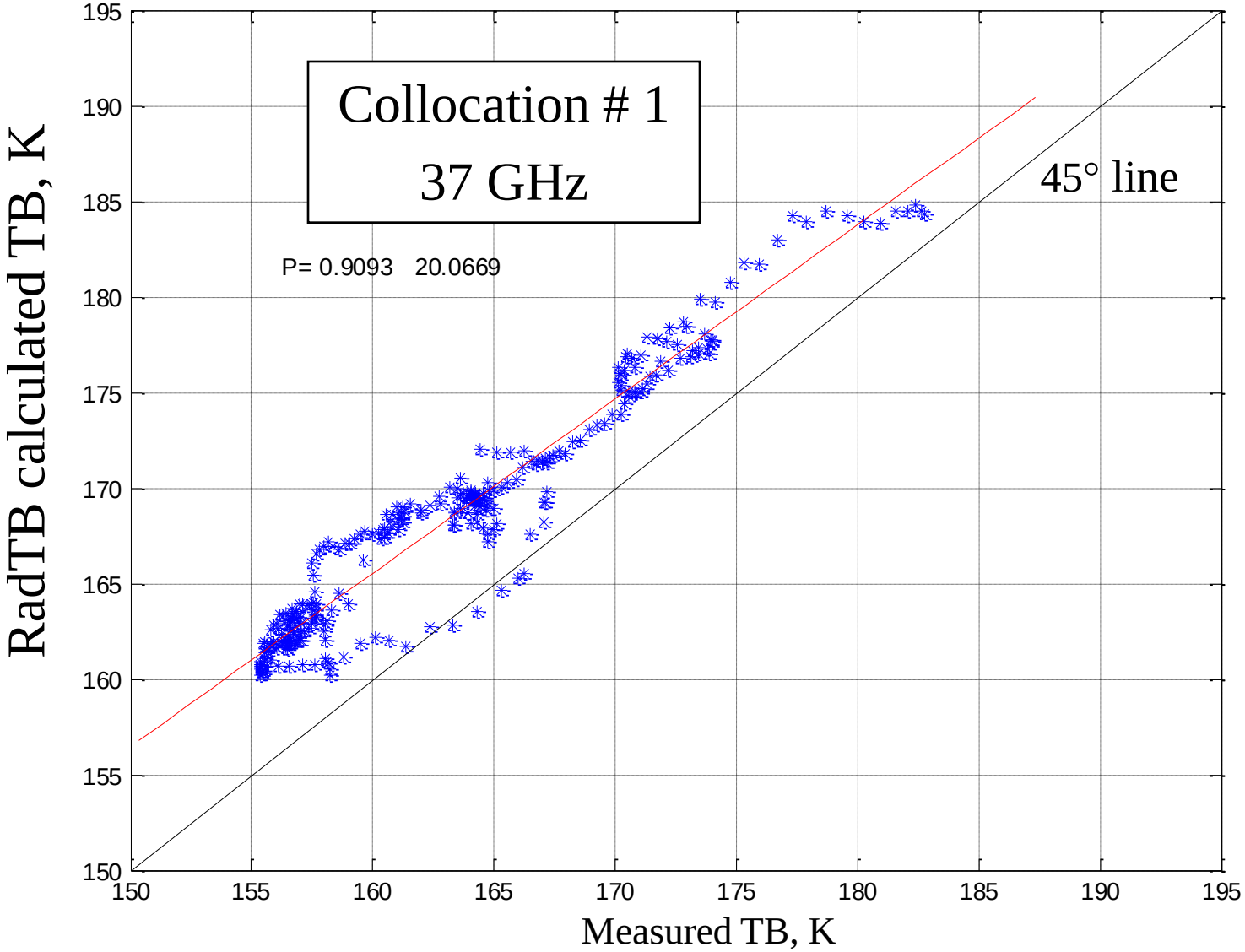


37 GHz time series plot

- Measured
- Calculated

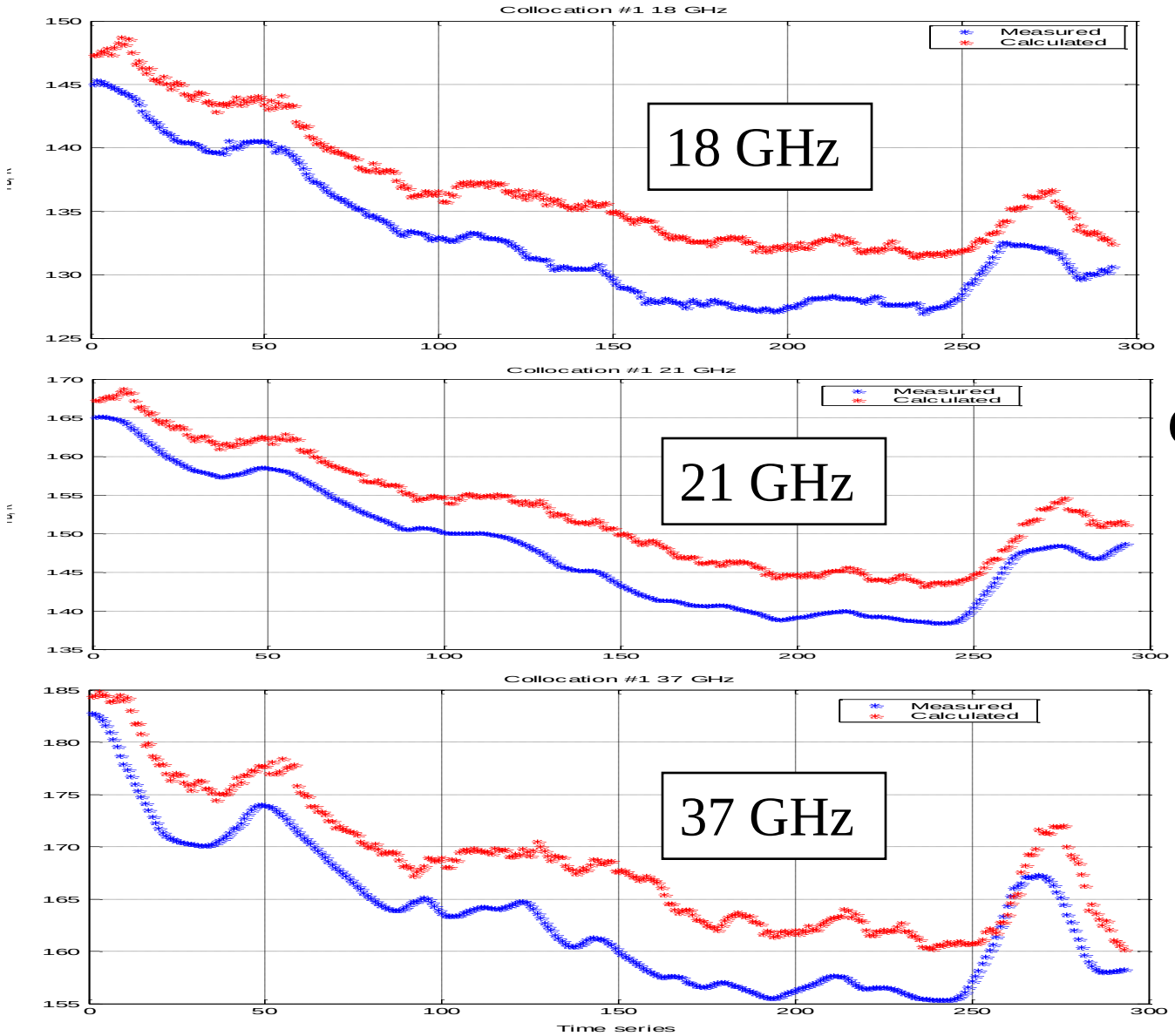
Scatter Plot

CFRSL



Measured and Calculated Tb's

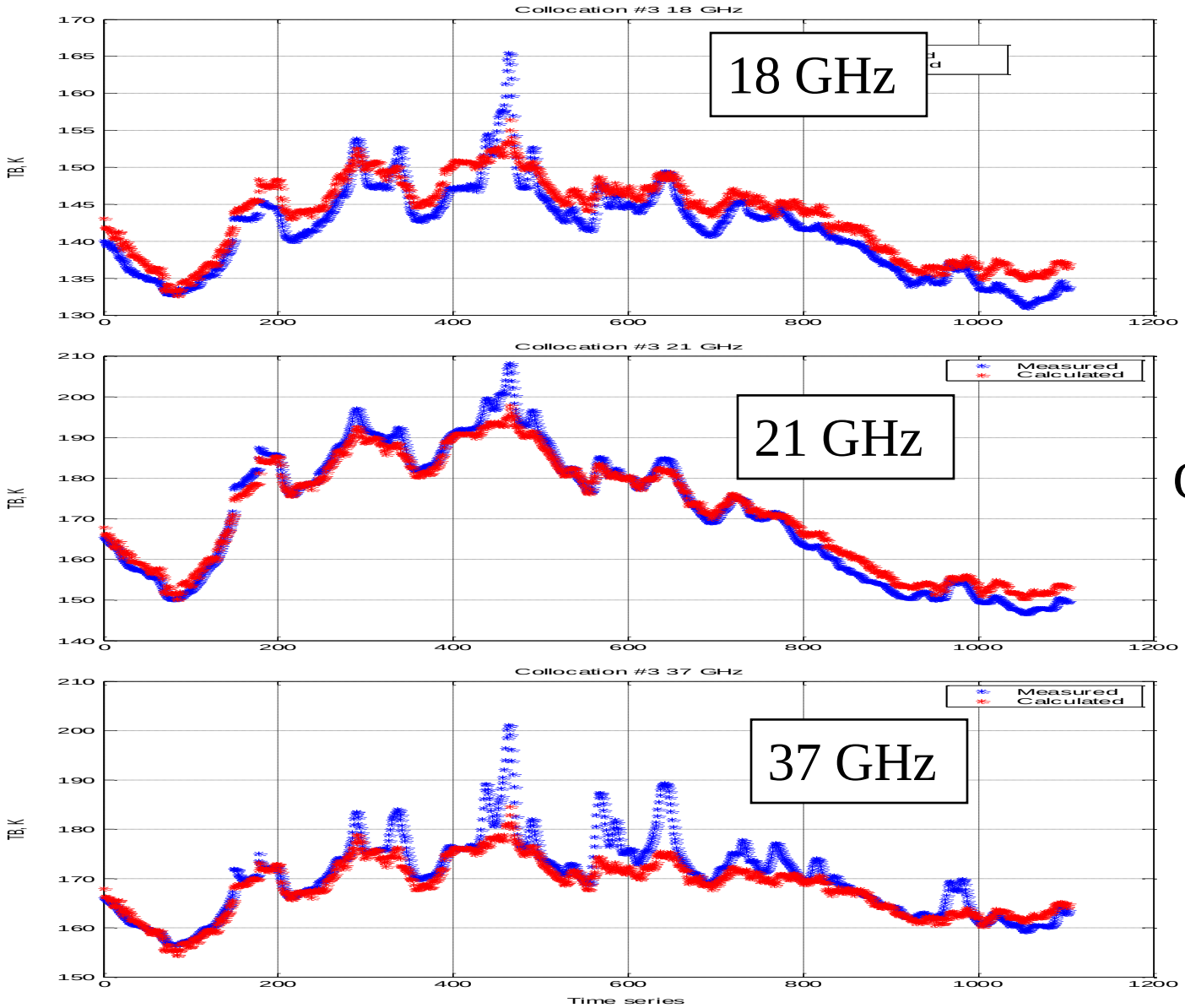
CFRSL



Collocation #1

Measured and Calculated Tb's

CFRSL



Collocation #3

Group Comparisons into 3 Similar Par Boxes

Collocation	Col Water vapor gm/cm2	Cloud liquid water g/cm2 *10e-4	Wind speed m/s	SST ºC
1	1.26 (L)	6.32 (L)	10.85 (H)	9.219 (L)
2	1.60 (L)	5.22 (L)	8.27 (H)	15.387 (M)
3	2.90 (M)	5.74 (L)	6.61 (M)	25.766 (H)
4	2.43 (M)	3.80 (L)	7.73 (M)	23.294 (H)
5	2.58 (M)	5.01 (L)	7.03 (M)	34.872 (H)
6	2.63 (M)	7.21 (L)	7.84 (M)	20.797 (H)
7	2.78 (M)	7.55 (L)	6.83 (M)	24.141 (H)

	Low	Medium	High
Water vapor (gm/cm2)	< 2	2 ~ 4	> 4
Cloud liquid water*10e-4 (g/cm2)	< 10	10 ~ 20	> 20
Wind speed (m/s)	< 4	4 ~ 8	> 8
SST (°C)	< 10	10 ~20	> 20

Statistics Table

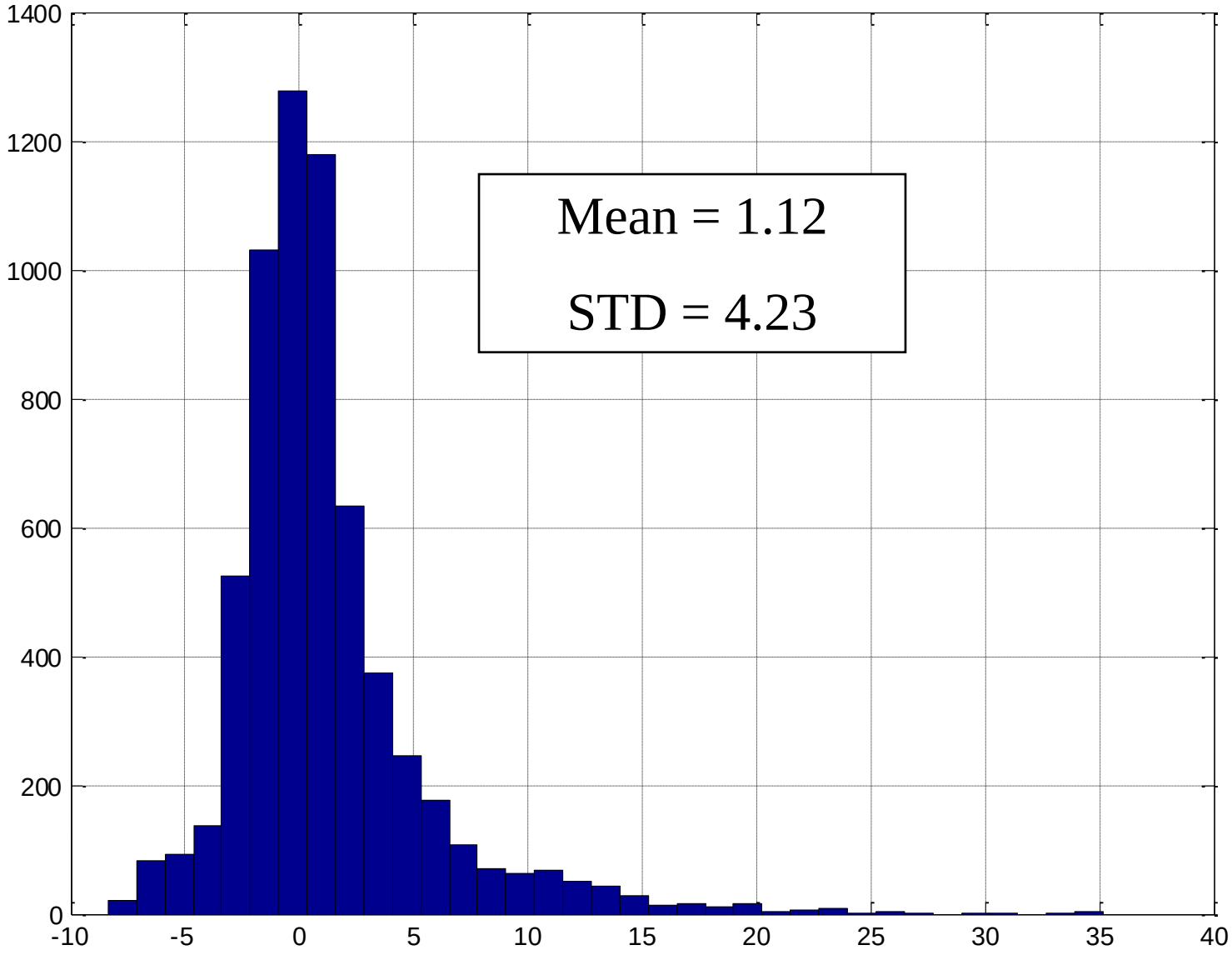
CFRSL

	Water Vapor	CLW	Wind Speed	SST
Box 1	L	L	H	L
Box 2	L	L	H	M
Box 3	M	L	M	H

Frequency GHz		mean (meas. TB - mod. TB)	standard deviation (meas. TB - mod. TB)
18	Box 1	-4.06	0.91
	Box 2	1.38	3.22
	Box 3	-3.13	2.90
21	Box 1	-4.87	1.10
	Box 2	8.01	7.43
	Box 3	-1.85	3.46
37	Box 1	-5.26	1.74
	Box 2	3.96	5.54
	Box 3	1.12	4.23

Histogram Figure for Box 3 @ 37 GHz

CFRSL



Conclusions

This thesis has

- Evaluated the RadTb model to determine systematic errors in the calculation of ocean microwave brightness temperature
  - Significant range of environmental parameters
  - Wide frequency range
- Model performs reasonably well; however significant systematic biases are identified
- Future Work
  - Evaluate performance over off-nadir incidence and polarization
  - Improve RTM to remove systematic errors