AN EXAMINATION OF

LORAN SIGNAL PROPAGATION

TEMPORAL VARIATION MODELING

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OVERVIEW

- SEASONAL VARIATION COMPONENT OF THE RNP.3 MODEL
- A MORE DIRECT WEATHER-BASED SEASONAL VARIATION MODEL
- RESTRUCTURING THE MODEL TO FACILITATE CHAIN CALIBRATION EFFORTS
- DATA PROCESSING STATUS AND PLANS

THE RNP.3 MODEL OF THE MARCH 2004 REPORT TO DOT HAD 5 PHASE ERROR COMPONENTS:

- RESIDUAL SPATIAL VARIATIONS AFTER AIRPORT SURVEYS
- ATMOSPHERIC NOISE EFFECTS ON PHASE MEASUREMENTS
- BIAS ERRORS IN THE TRANSMITTED SIGNAL
- NOISE JITTER IN THE TRANSMITTED SIGNAL
- TEMPORAL VARIATIONS IN THE SIGNAL PROPAGATION

IMPORTANT FEATURE OF THE TEMPORAL VARIATION COMPONENT

IT HAS TWO ELEMENTS:

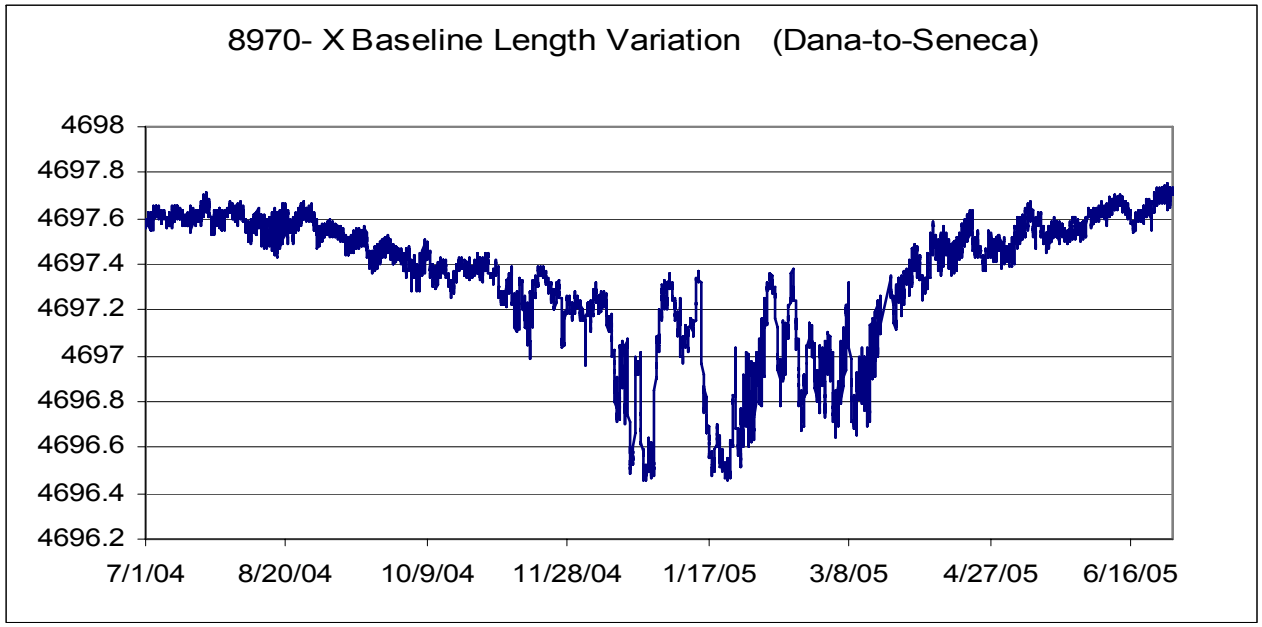
ONE THAT WAS CORRELATED FROM PATH TO PATH

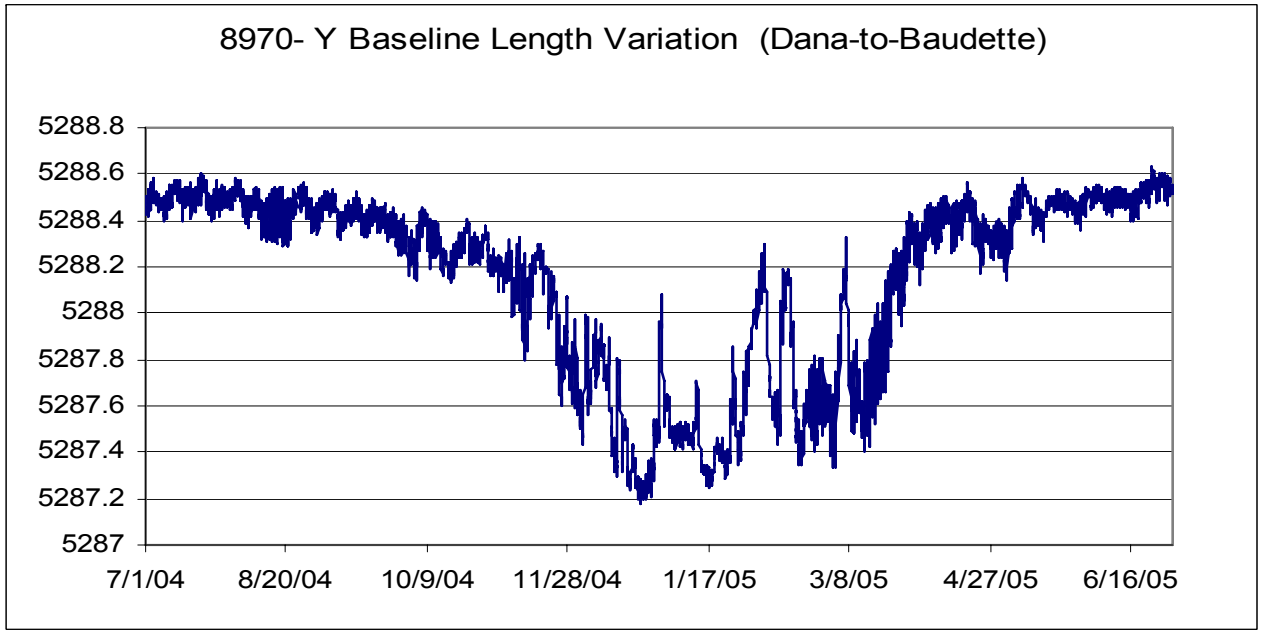
ONE THAT WAS UNCORRELATED FROM PATH TO PATH

IN THE CALCULATION OF SYSTEM AVAILABILITY, ANY CORRELATED ELEMENT IS ALMOST ALWAYS MORE BENIGN

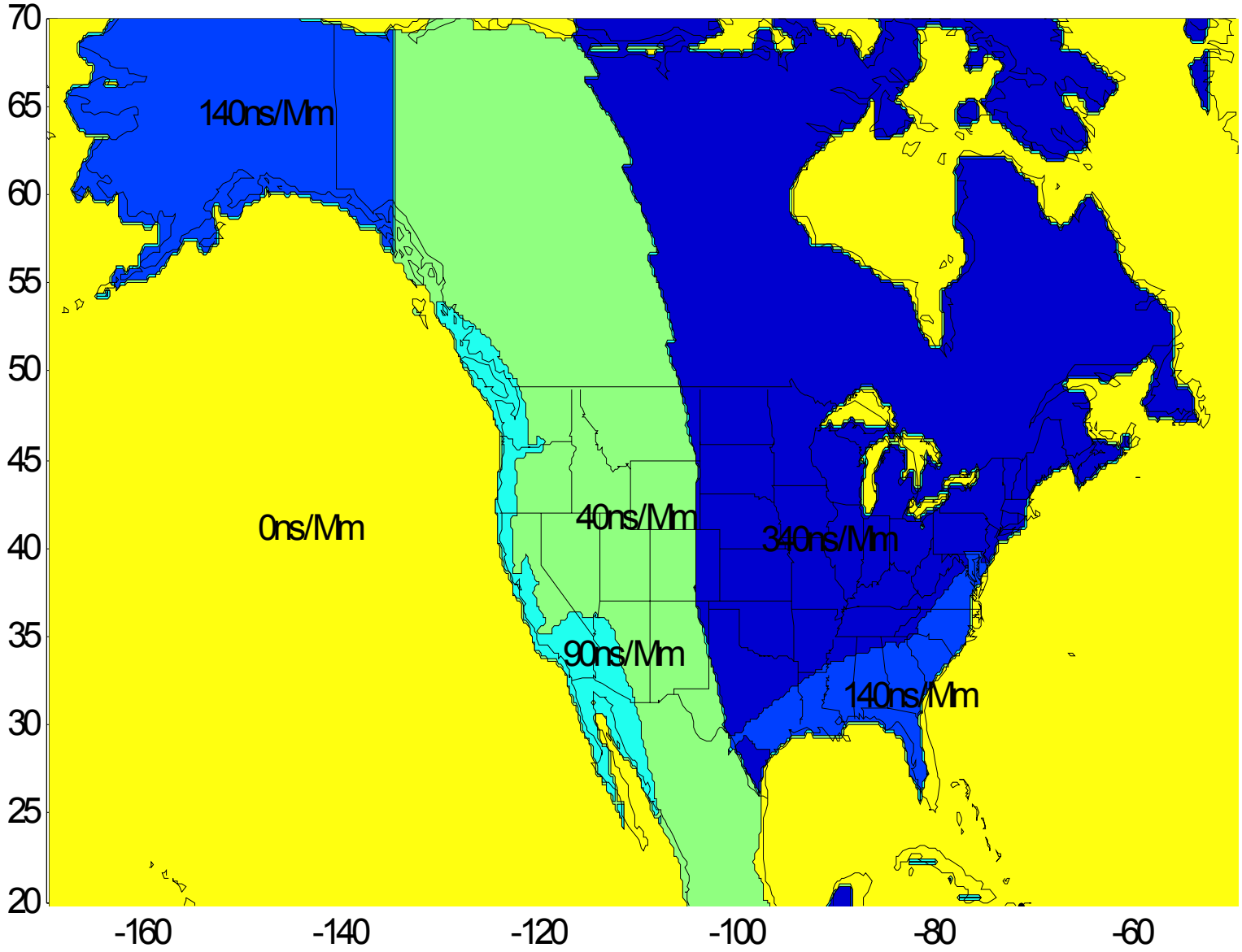
THUS, CONSIDERABLE EFFORT WAS EXPENDED TO SEPARATE THE TWO ELEMENTS

EXAMPLE OF CORRELATION IN SEASONAL PHASE VARIATION





CONTOUR USED TO COMPUTE TEMPORAL VARIATION IN MARCH 2004 REPORT TO DOT

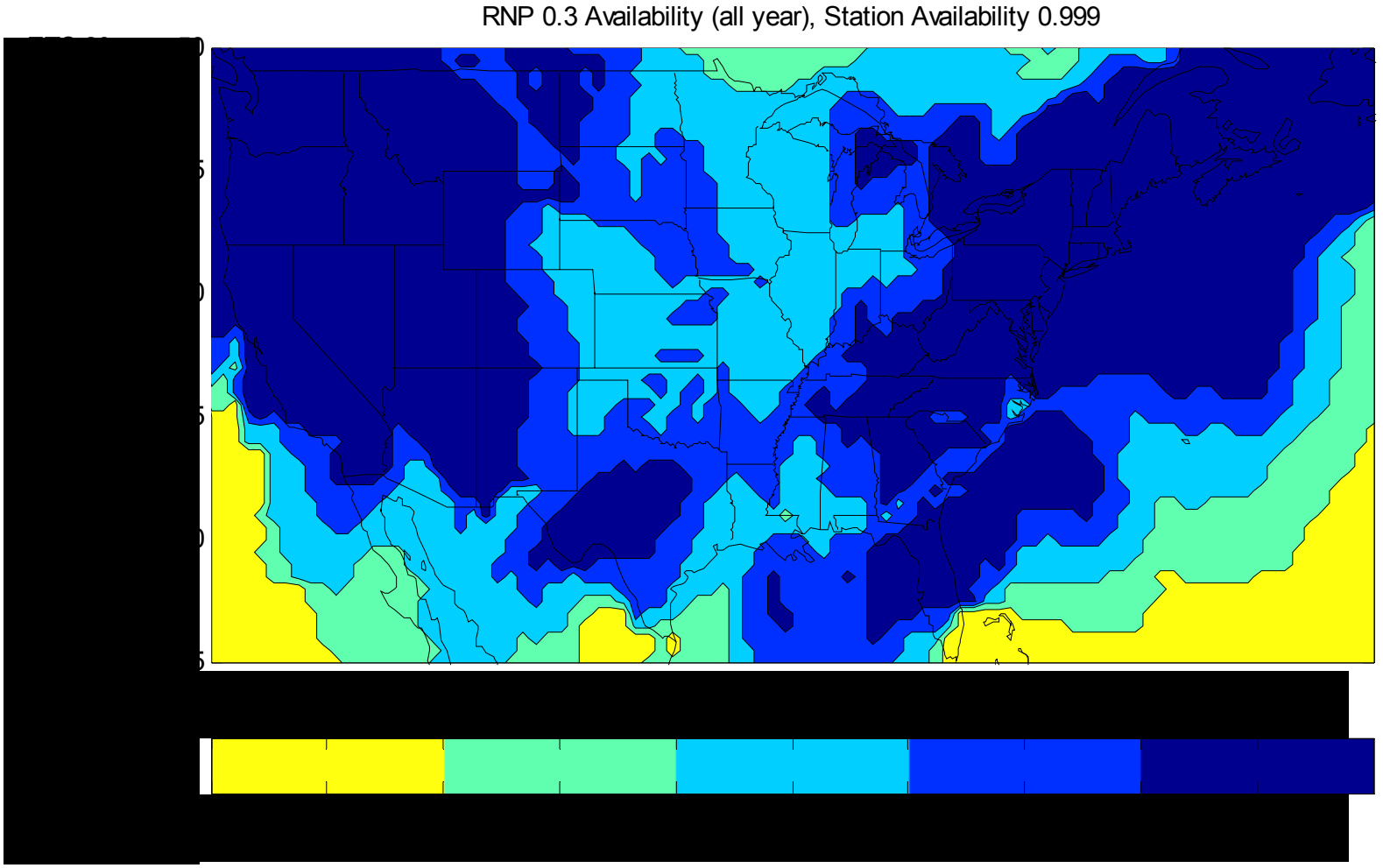


THERE WERE LIMITATIONS OF EARLIER TEMPORAL VARIATION STUDIES FOR 2004 PURPOSES

- DONE OUTSIDE THE CONCEPT OF 99.99999%
- NOT EXTENDED TO ALASKA
- DONE BEFORE THE MID-CONTINENT EXPANSION
- MINIMAL LOOK AT THE GREAT LAKES CHAIN OUTSIDE THE SOO

OUR APPROACH TO ACCOMMODATING THESE LIMITATION WAS TO BE CONSERVATIVE, I.E., TO **OVERBOUND**

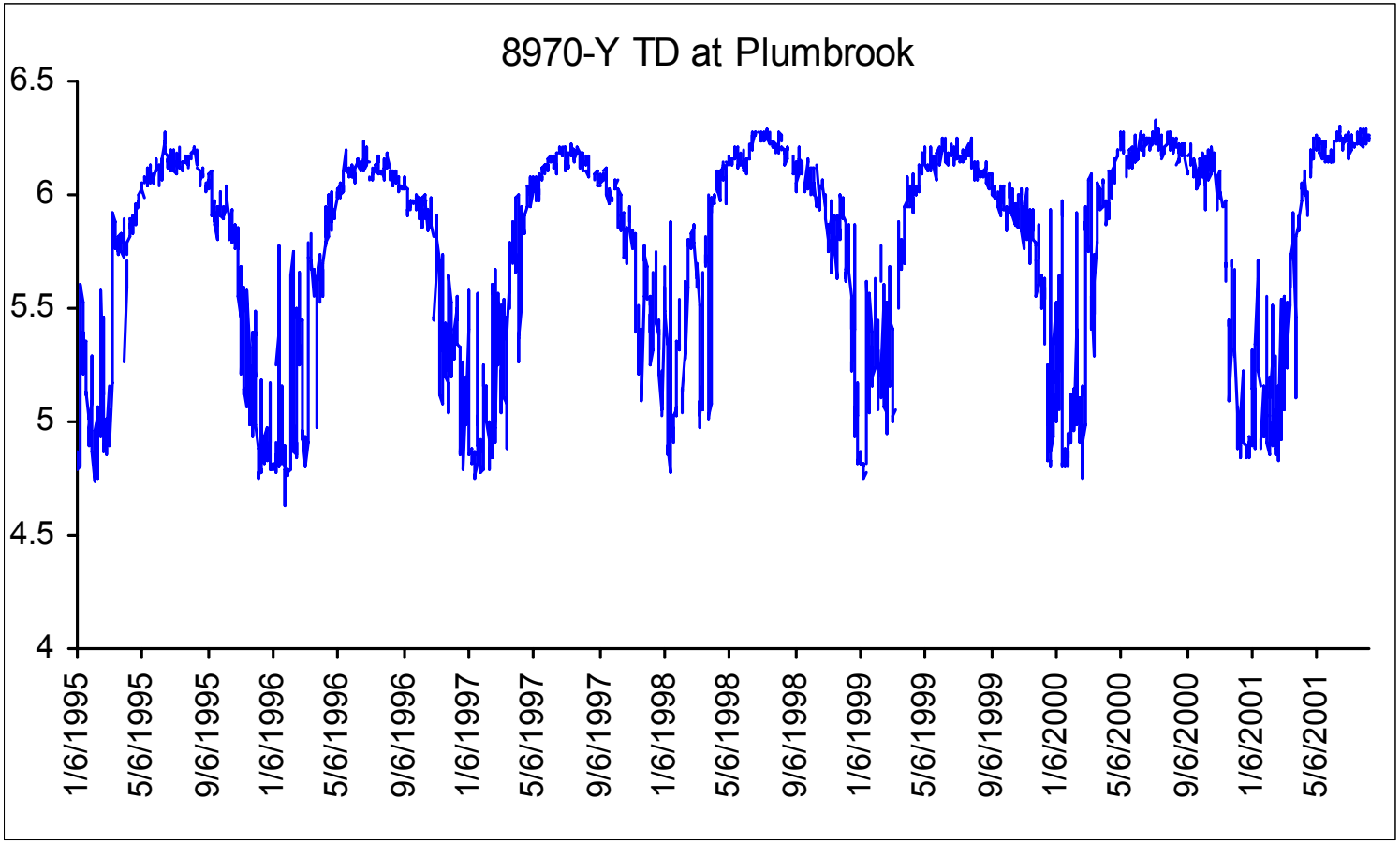
HERE IS A SAMPLE MOTIVATION FOR ASKING IF THE MODELING CAN BE IMPROVED – SPECIFICALLY IN THE MID-CONTINENT AND GREAT LAKES REGIONS



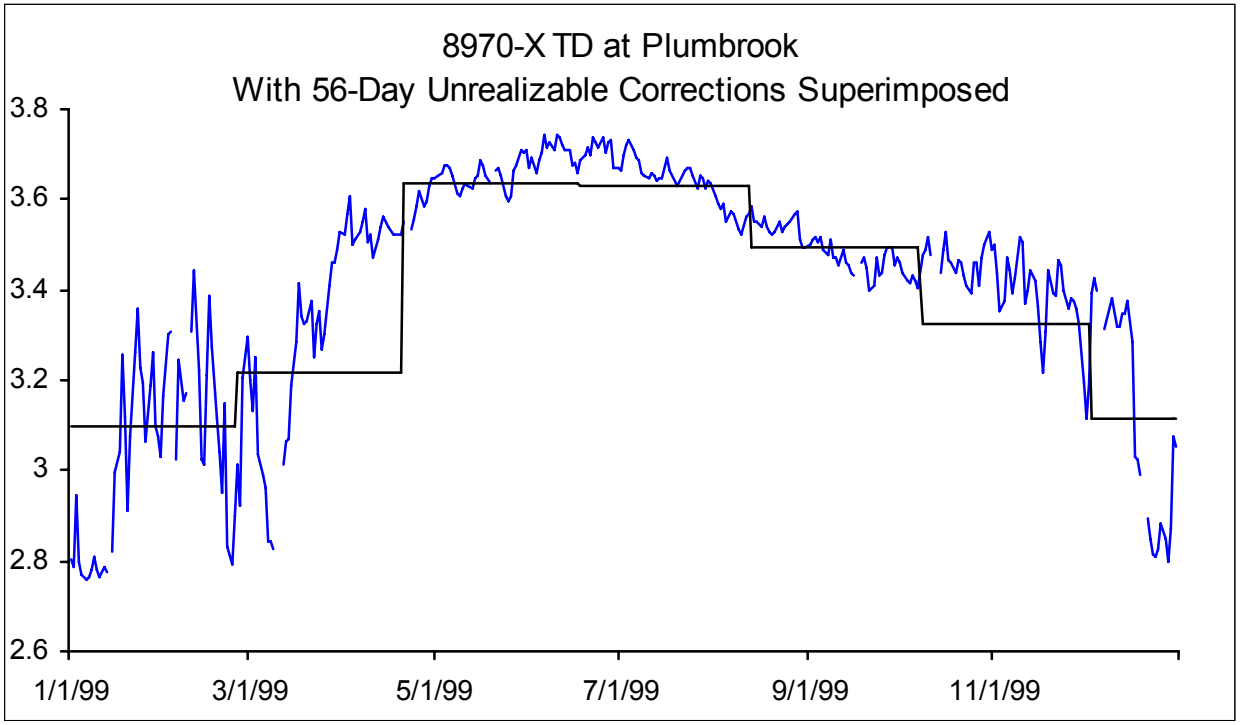
IN LATE 2004, WE BEGAN THE PROCESS OF ASSESSING THE TEMPORAL VARIATION MODEL PERFORMANCE

- USING THE EXISTING COAST GUARD TRANSMITTER AND RECEIVERS
- IDEALLY, AFTER ALL THE EQUIPMENT CHANGES – ESPECIALLY THE TRANSMITTERS
- BUT WE WOULD JUST BE FINISHING THE DATA COLLECTION
- THUS, WE STARTED LOOKING AT DATA FROM AFTER MAY 2003 AND EXPENDED CONSIDERABLE EFFORT TO ACCOUNT FOR THE EFFECTS OF EQUIPMENT CHANGES

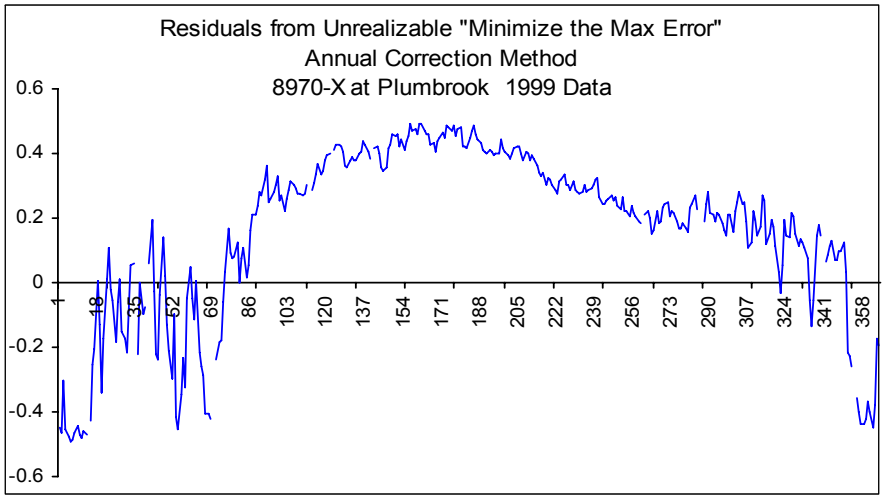
ASF CORRECTIONS WILL NOT VARY FROM YEAR TO YEAR

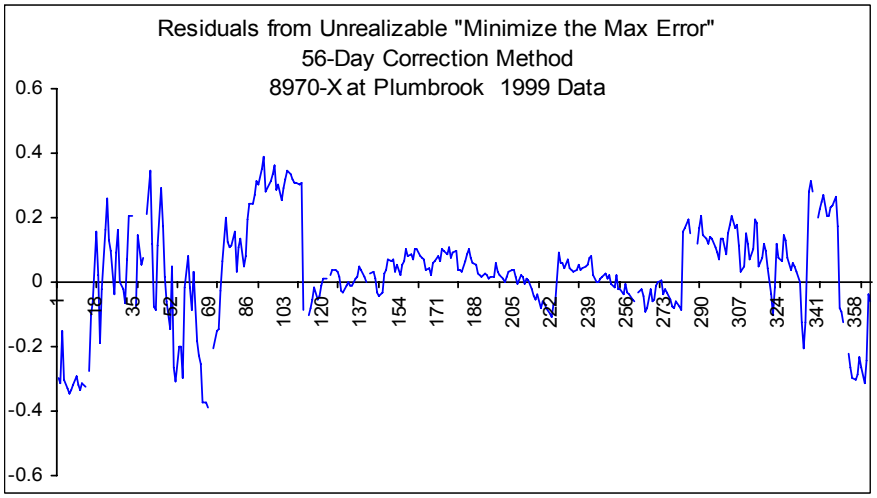


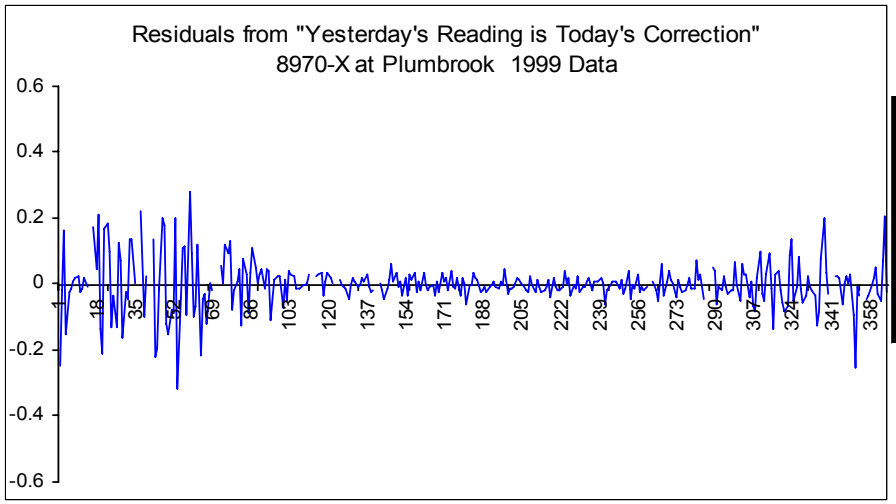
CORRECTIONS SEVERAL TIMES A YEAR – AN ENORMOUSLY DIFFICULT TO IMPLEMENT MATTER - WOULD NOT BE SO EFFECTIVE AS ONE MIGHT IMAGINE



HERE ARE SOME RESULTS IN ATTEMPTING MORE FREQUENT CORRECTIONS

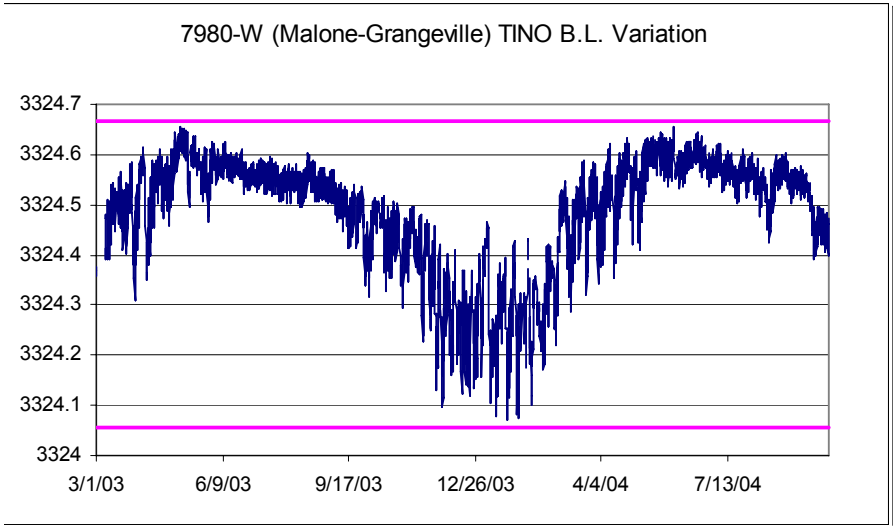


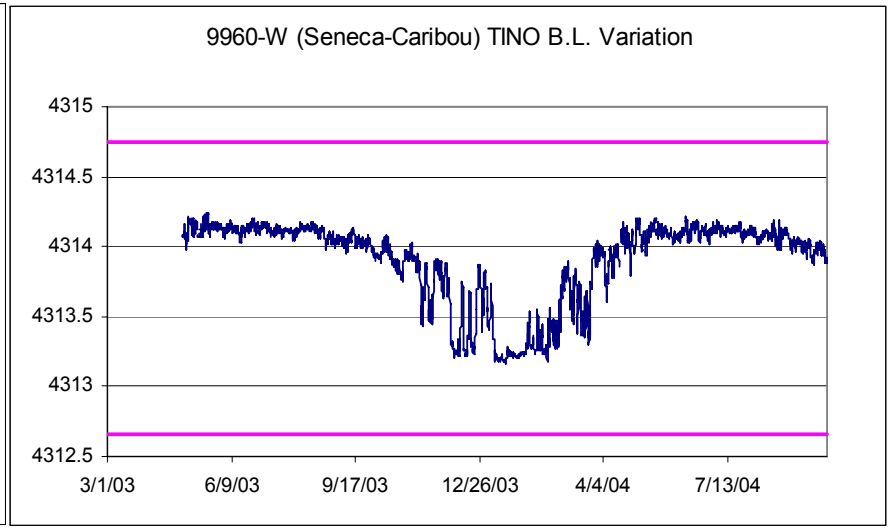


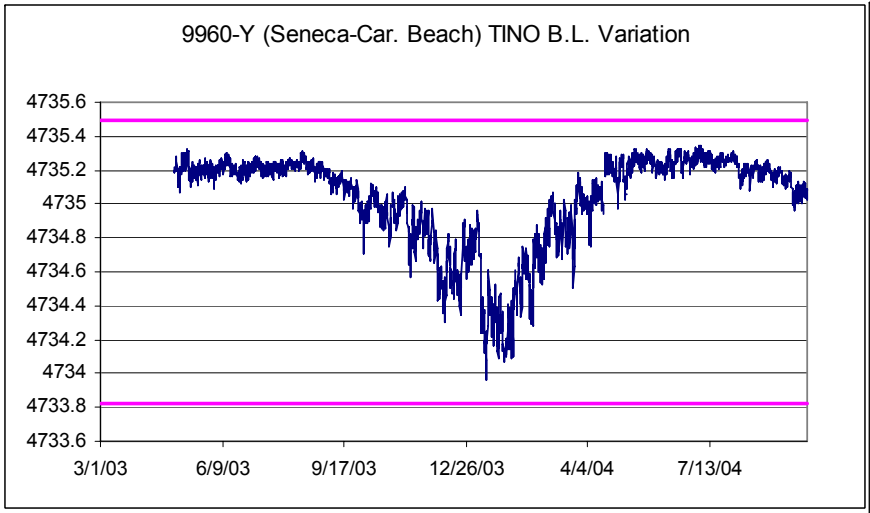


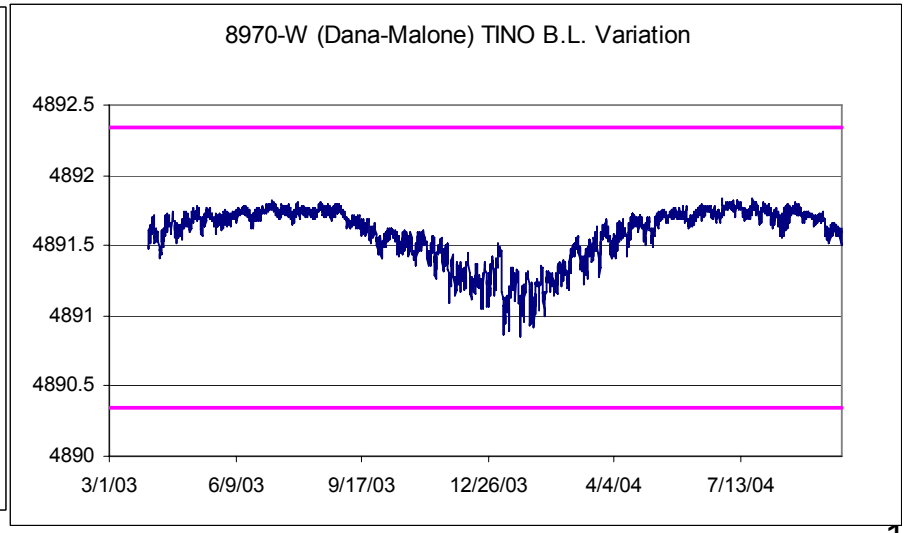
Correction Interval	Maximum Error	
Annual	0.493	100%
56-Day	0.392	79%
14-Day	0.298	60%
Previous Day	0.318	65%

EXTENSIVE ANALYSIS IN TIME DOMAIN AND POSITION DOMAIN

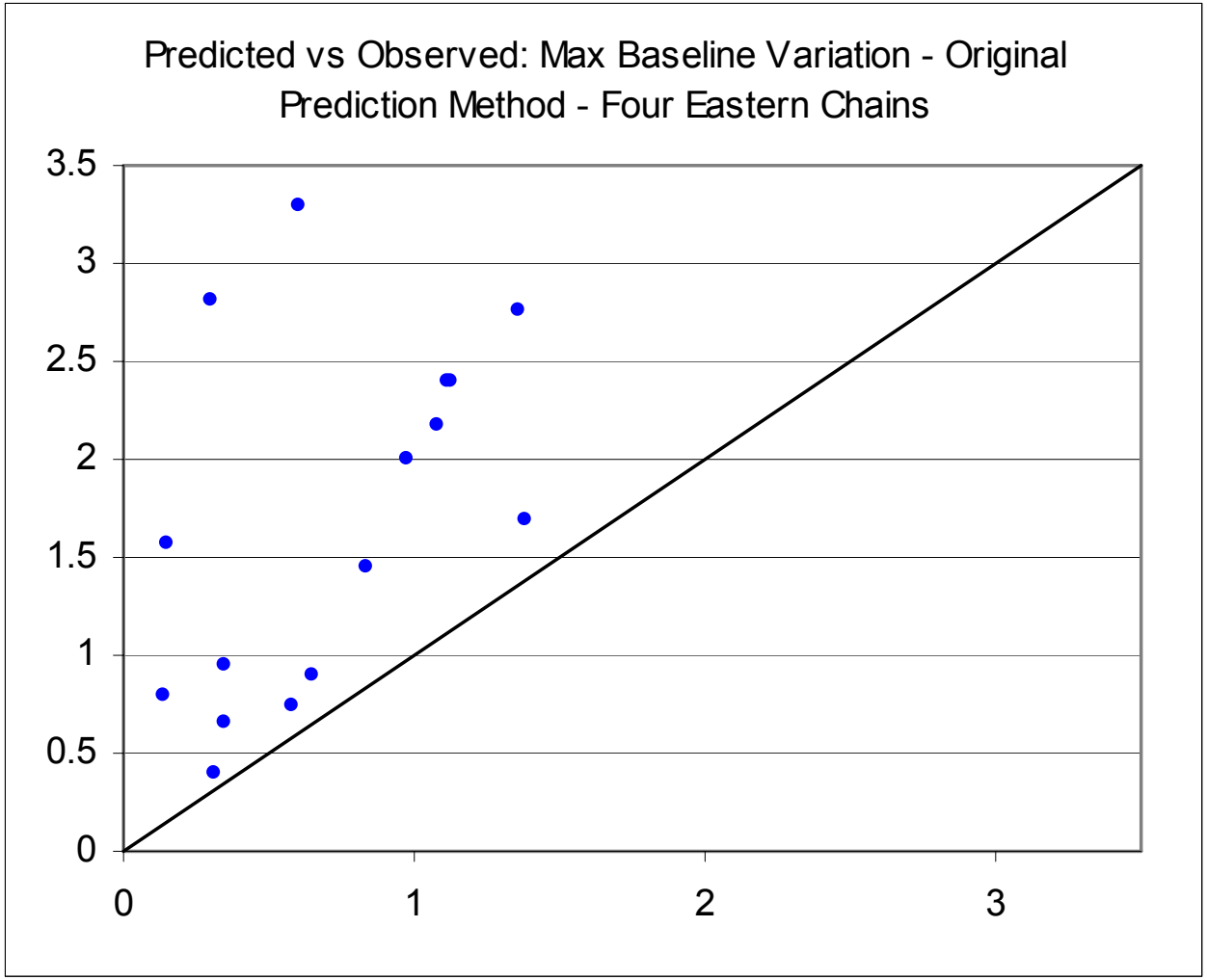




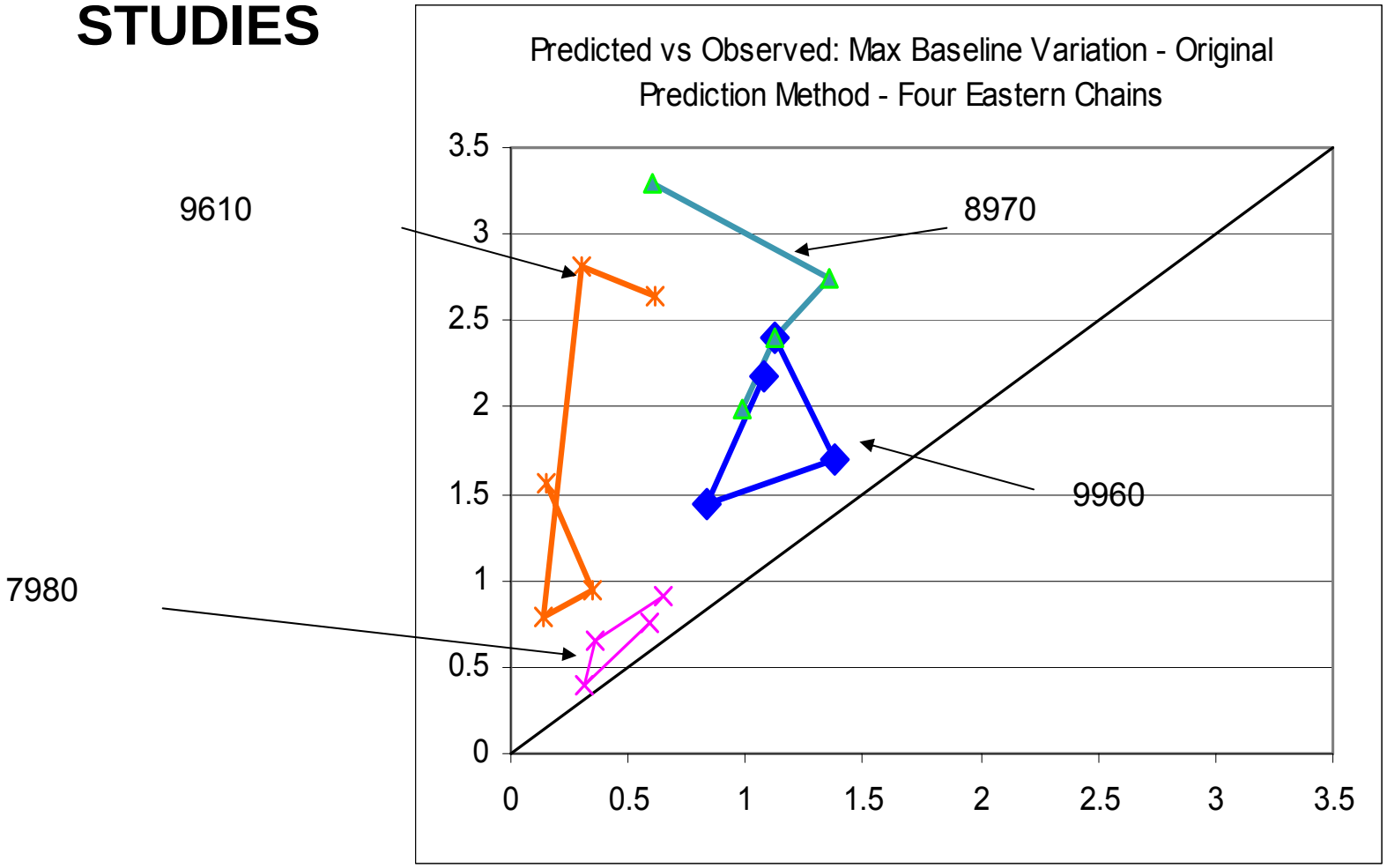




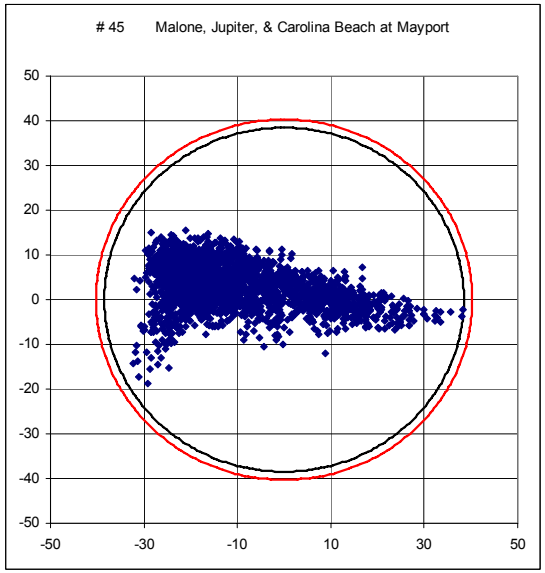
RESULTS WITH MODEL USED IN THE REPORT

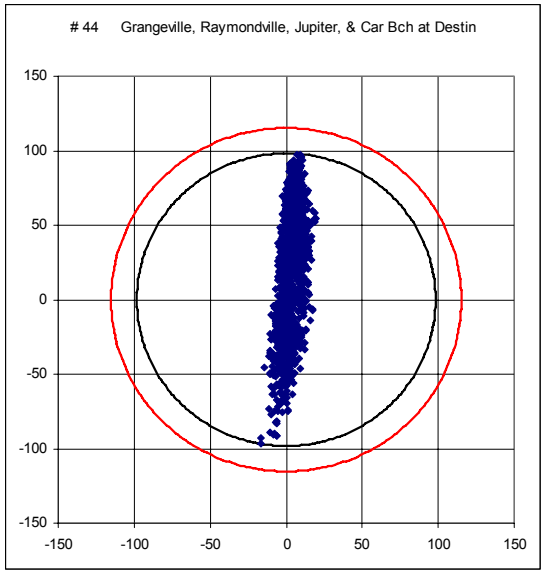


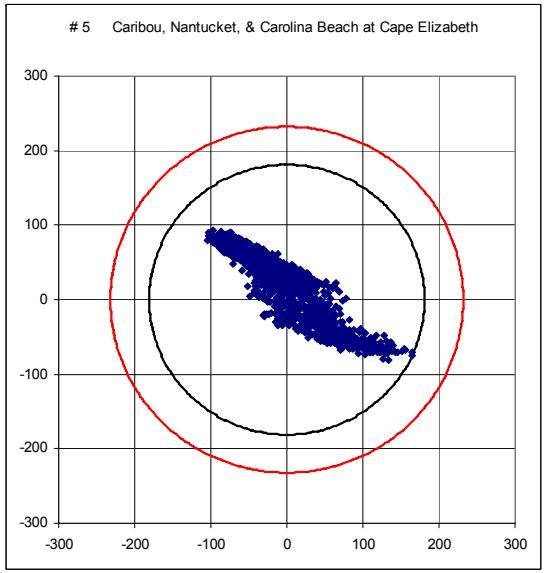
THE LARGEST OVERBOUND IS IN THE "MID-CONTINENT" AND GREAT LAKES REGIONS WHERE WE COMPENSATED FOR LACK OF PREVIOUS STUDIES

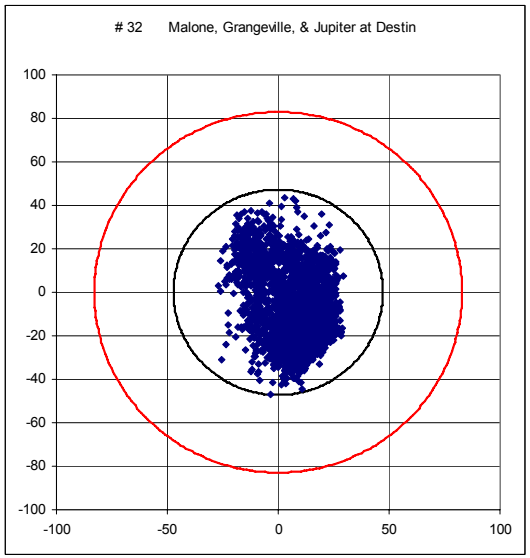


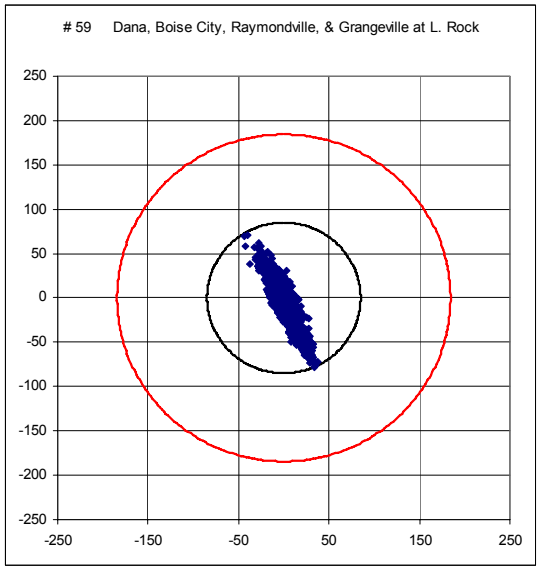
WE ALSO LOOKED AT THE PERFORMANCE IN THE POSITION DOMAIN

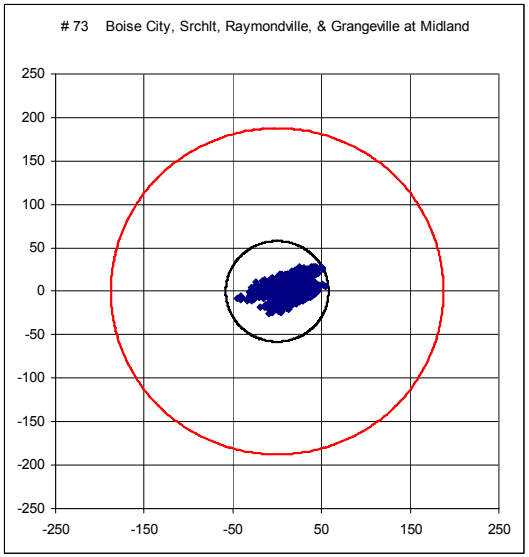












THESE RESULTS LED US TO CONCLUDE IT WAS WORTHWHILE TO TRY TO IMPROVE UPON THE MODEL USED IN THE REPORT

- A RE-DO OF THE SEMI-EMPIRICAL MODEL FOR PREDICTING MAXIMUM SEASONAL VARIATIONS
  - CONSISTENT RESULTS
  - PERHAPS A SLIGHT IMPROVEMENT
- RETURNING TO A MODEL WHICH IS MORE SPECIFICALLY BASED ON THE SEASONAL WEATHER CHANGES WHICH CAUSE THE LORAN VARIATIONS

REVIEW OF THE UNDERLYING THEORY

- SIMPLIFIED RESULTS FROM JOHLER & DOHERTY'S 1979 STUDY OF THE SUBJECT SHOW WE SHOULD EXPECT STRONG CORRELATION BETWEEN THE SIGNAL PROPAGATION VARIATIONS AND

  N = deviation of the refractive index from unity (ppm)

  $N = (77.6/T)\,(P + 4810\, e/T)$

  where T is temperature, in ^{o}K

  P is atmospheric pressure, in mb

  and e is the partial water vapor pressure, in mb .

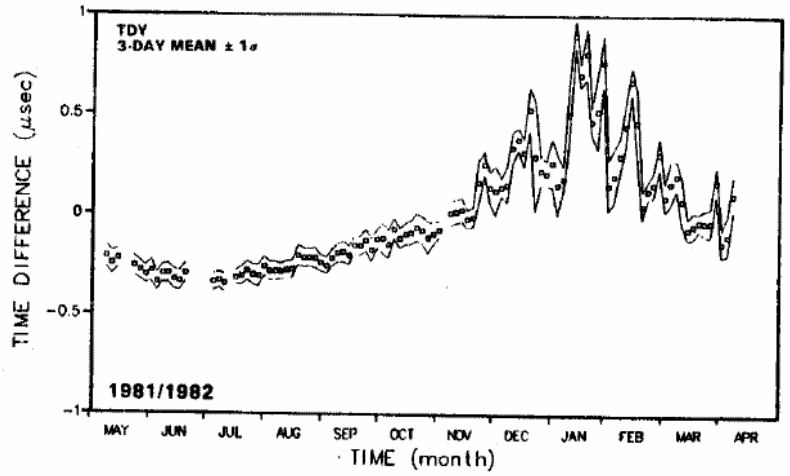
- MOST RELATED STUDIES HYPOTHESIZE IT IS SUFFICIENT TO SIMPLY CONSIDER THE "DRY TERM":

  $N = 77.6\, P/T$

HERE'S AN EXAMPLE FOR A 1982 STUDY FOR THE FAA – SHOWING THE CORRELATION BETWEEN LORAN PHASE AND DRY TERM VARIATIONS

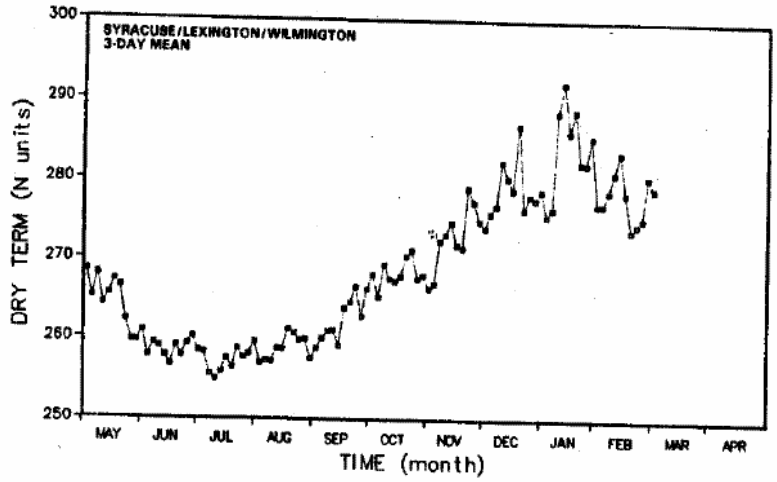
R-85123

Note summer "plateau"



a) TDY

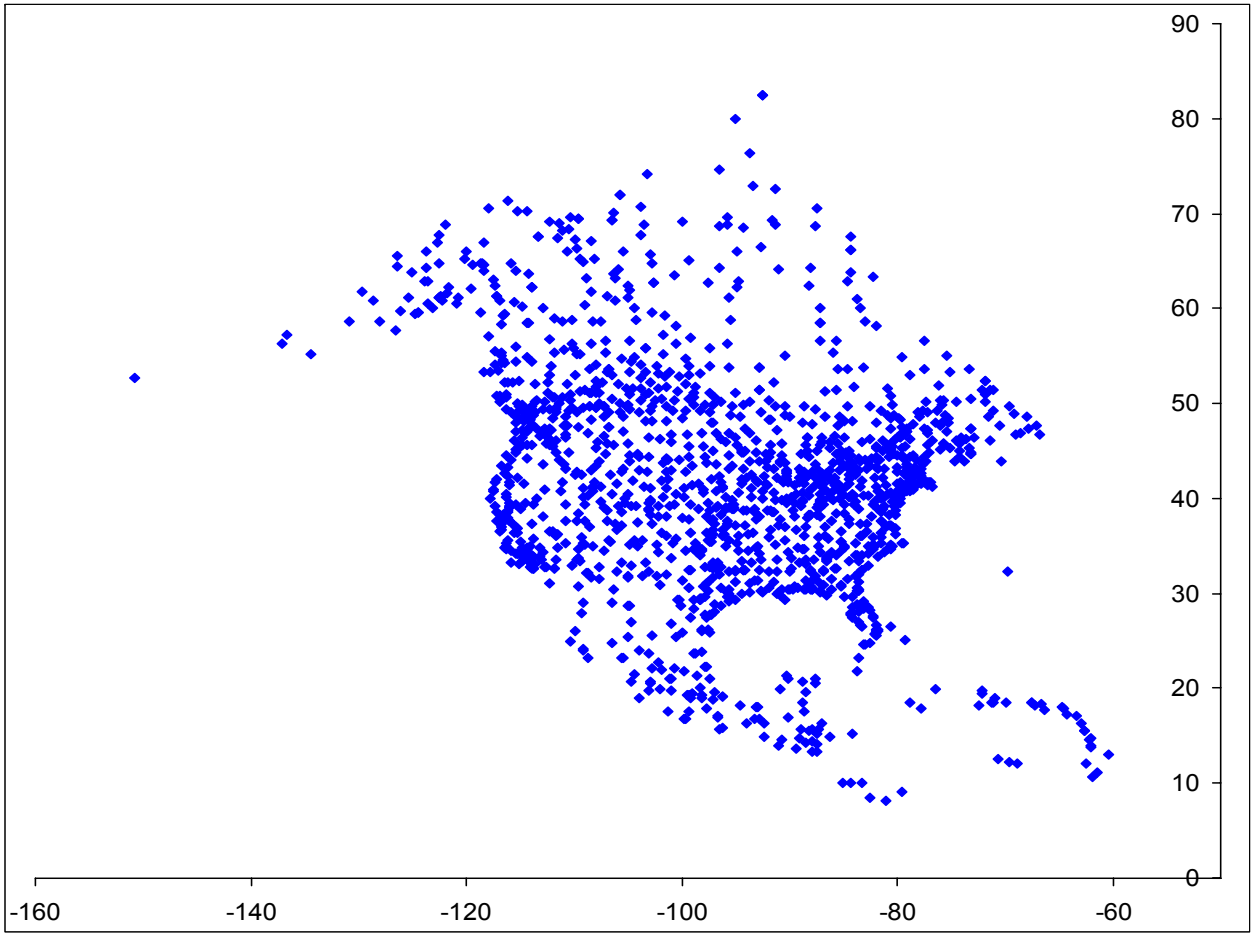
Note no summer "plateau"



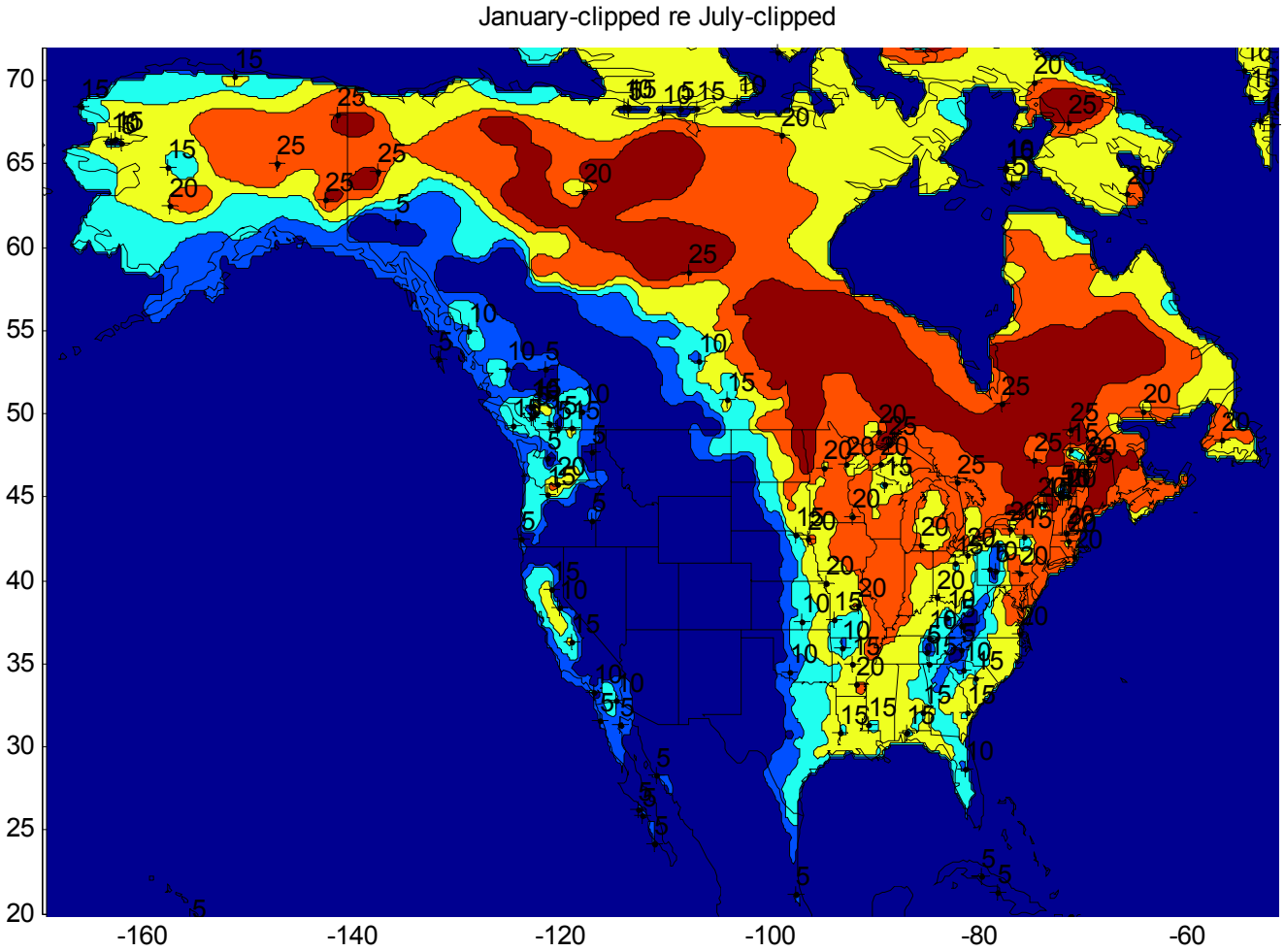
b) Refractivity Dry Term

INITIAL STEPS TO IMPLEMENT A WEATHER-BASED MODEL

- OUR FIRST ATTEMPT RETAINED THE GOAL OF **ONLY** TRYING TO PREDICT PEAK-TO-PEAK ANNUAL VARIATIONS
- BASED ON A NON-LINEAR CORRECTION TO THE WINTER-TO-SUMMER DRY TERM VARIATIONS AT AVAILABLE WEATHER STATION DATA:



THE RESULT IS A REPLACEMENT FOR THE CONTOUR SHOWN EARLIER THAT WAS USED IN THE MARCH 2004 REPORT TO DOT



THE NEW CONTOUR IMPROVED THE PERFORMANCE SOMEWHAT

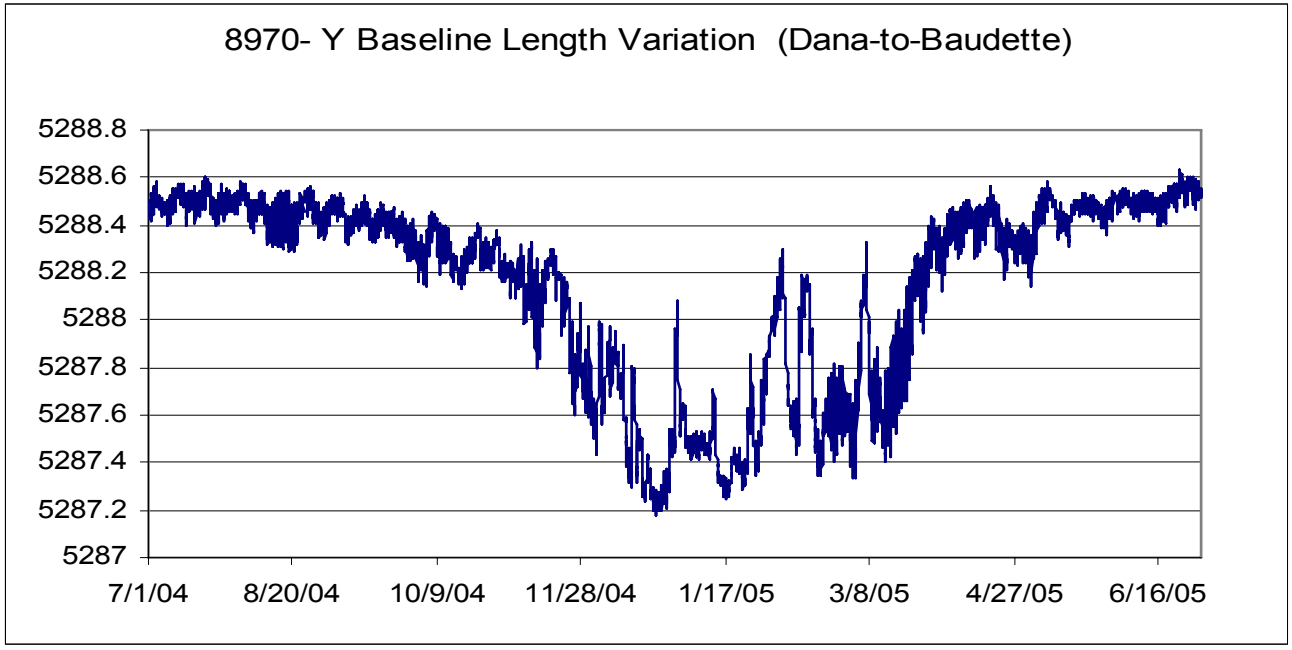
- USING THIS NEW CONTOUR, WE RECALIBRATED THE CORRELATED AND UNCORRELATED TERMS FOR THE SEASONAL VARIATION PREDICTION SUB-MODEL
- WE THEN RAN ANOTHER PERFORMANCE ASSESSMENT, CONCLUDING THAT THIS DRY TERM-BASED MODEL IS SLIGHTLY BETTER THAN THE PREVIOUS MODEL
    - ON THE ORDER OF 10% SMALLER ERRORS, ON AVERAGE
    - NOTABLY SMALL OVERBOUNDING IN MANY EXTREME CASES

- WE WERE THINKING THE NEXT LOGICAL STEP MIGHT BE TO INCLUDE CONSIDERATIONS OF THE PARTIAL VAPOR PRESSURE
- BEFORE PROCEEDING, WE ENCOUNTERTED AN ADDITIONAL APPLICATION FOR THE MODEL THAT PROMPTED CONSIDERATION OF GREATLY EXPANDING WHAT WE WERE ATTEMPTING TO ACCOMPLISH

ILLUSTRATION OF THE AIRPORT CALIBRATION ISSUE

TO ILLUSTRATE THE CONCERN, RECALL THE MODELING IN THE REPORT TO DOT WAS BASED ON A SINGLE CALIBRATION VALUE AT ANY GIVEN LOCATION - I.E., WE “LIVE WITH” THE TEMPORAL VARIATION

IN VIEW OF THE VARIATIONS IN THE PLOT, PONDER DERIVING THE MAXIMUM ANNUAL VALUE FROM A CALIBRATION MEASUREMENT TAKEN AT ANY ARBITRARY TIME OF THE YEAR



ONCE AGAIN, GOING BACK TO THE WEATHER MODEL

$N_{DRY} = 77.6P/T$

$N_{TOTAL} = (77.6/T)\,(P + 4810\, e/T)$

where T is still in ^{o}K,
P is still in mb
and e is the partial water vapor pressure, in mb .

TO USE THIS TO PREDCIT THE VARIATION IN A SIGNAL AT A LOCATION AT ANY SPECIFIC TIME, WE INTEND TO:

- SEGMENT THE PROPAGATION PATH FROM THE TRANSMITTER TO THAT LOCATION
- COMPUTE N **FOR THAT SPECIFIC TIME** AT THE MID-POINT OF EACH SEGMENT
- COMPUTE AN EFFECTIVE PATH INTEGRAL OF N, **AT THAT SPECIFIC TIME**, ALONG THE PATH

WE NEED TO ESTABLISH THE PROPER WAY TO USE THE "WET" COMPONENT

BOLTON (1980) IS A FORM FOR THE SATURATION VAPOR PRESSURE - **OVER WATER**

Switching units:

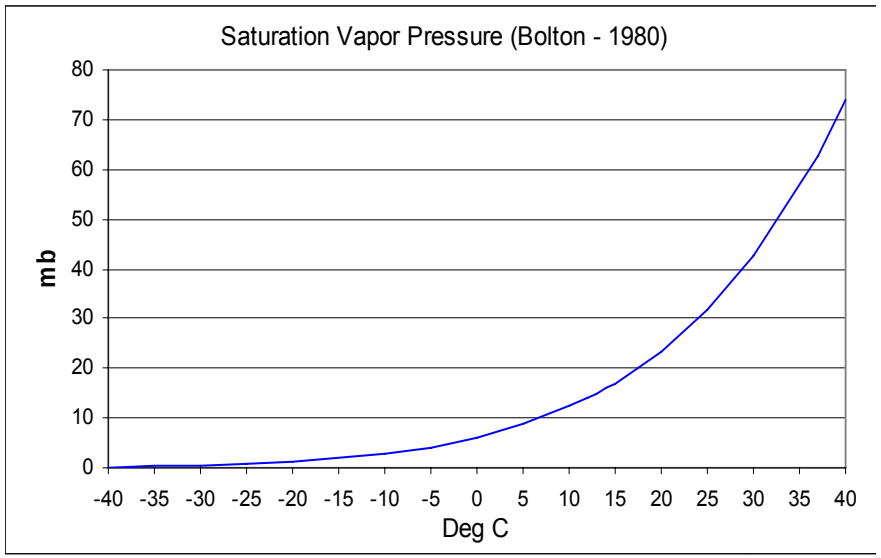
Sat vap pres $= 6.112 \exp(17.67\ T/(T + 243.5))$

T in °C ; in mb

use relative humidity to pick e in mb

SOME (NON-LORAN) LITERATURE SUGGESTS WE SHOULD BE USING THIS FOR LAND PATHS

LORAN DATA DOES NOT SEEM TO AGREE



Source of Meteorological Data

- Defense Meteorological Science Office (DMSO) provides a database known as Master Environmental Library (MEL)
- Within MEL, the best sites for our purposes appear to be the NRL-Monterey data sites
- For these sites, the Coupled Ocean-Atmosphere Mesoscale Prediction System (COAMPS) and NOGAPS models are said to be the best
- Since it has a denser spatial prediction scale, we use COAMPS

COAMPS Data

- We download the following data from the MEL site:
  - Temperature at ground level
  - Relative humidity at 2 meters AGL
  - Barometric pressure at the 1000 hPa “sigma” level
- The data is provided over the following lat/lon intervals at 0.2° resolution:

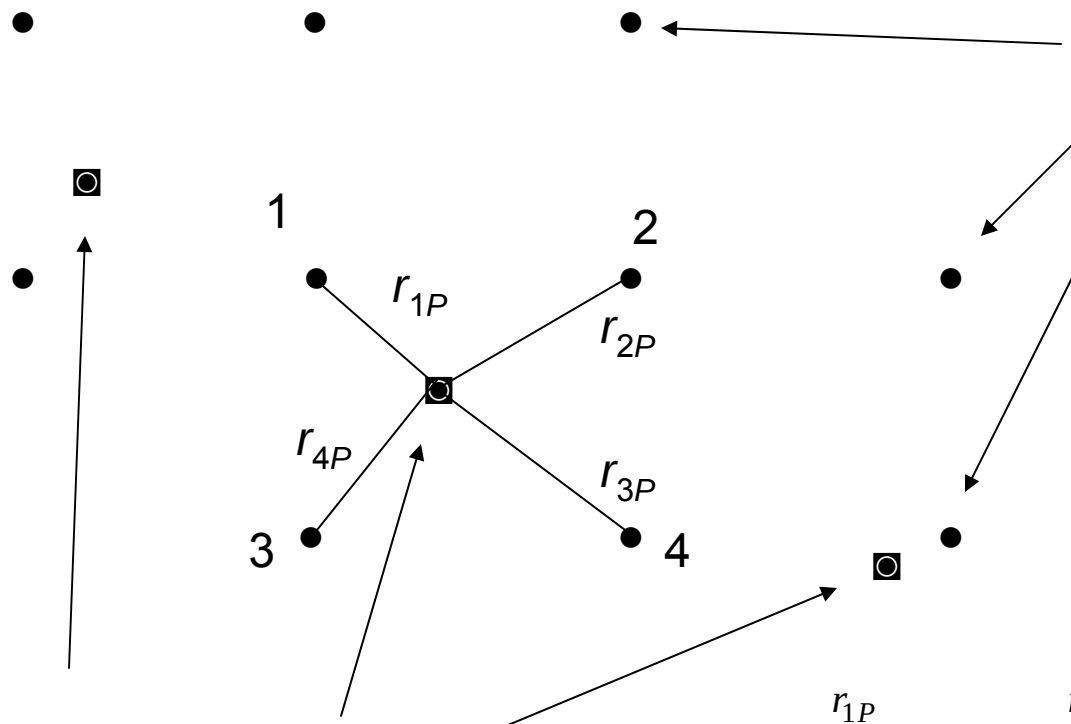
  20° N to 55° N latitude

  93° W to 55° W longitude

COAMPS Data (Cont'd)

- Data is obtained at 0000Z and 1200Z with a 6-hour prediction time
- Because of the volume of data, only 21 days can be downloaded at any one time
- We use 1800Z so that the paths currently under study are fully illuminated

2-D Interpolation Scheme



$D = 0.2\sqrt{2}$ °

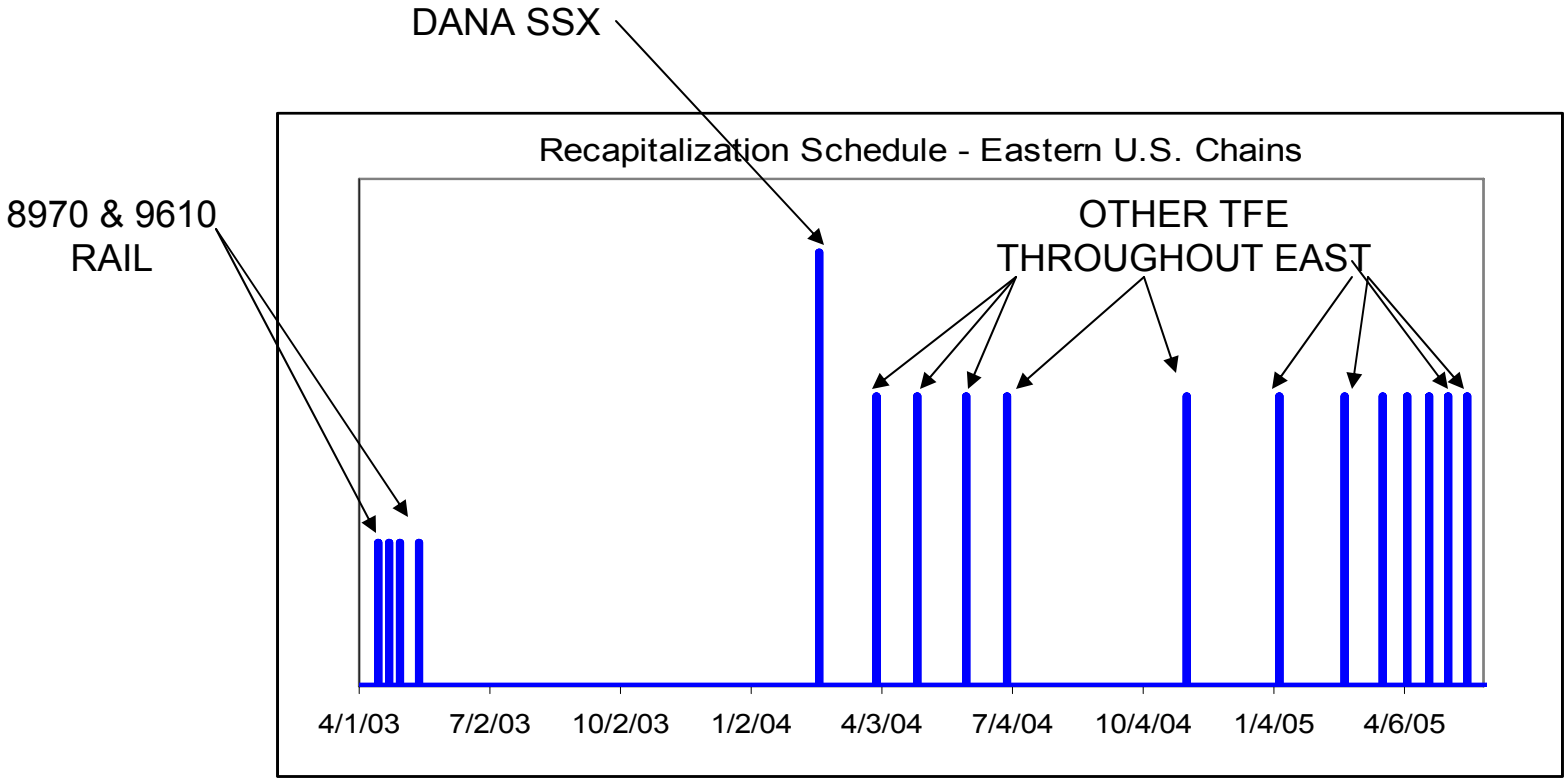
$$T = \frac{T_1 e^{-\frac{r_{1P}}{D}} + T_2 e^{-\frac{r_{2P}}{D}} + T_3 e^{-\frac{r_{3P}}{D}} + T_4 e^{-\frac{r_{4P}}{D}}}{e^{-\frac{r_{1P}}{D}} + e^{-\frac{r_{2P}}{D}} + e^{-\frac{r_{3P}}{D}} + e^{-\frac{r_{4P}}{D}}}$$

Temperature shown as an example

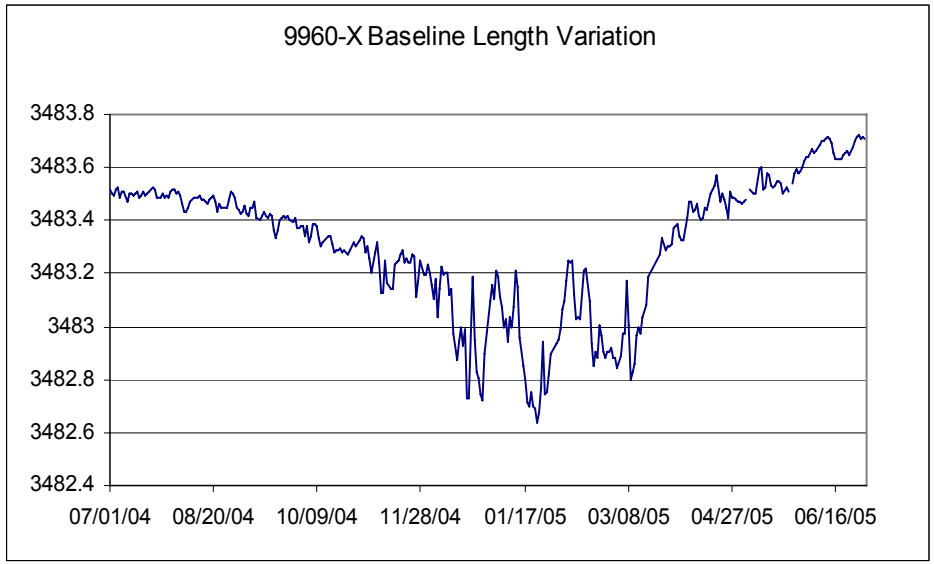
THE MAJOR PROBLEM TO DATE HAS BEEN THE QUALITY OF RELIABLE DATA IN VIEW OF THE MANY EQUIPMENT CHANGES WITH THE SYSTEM ENHANCEMENTS

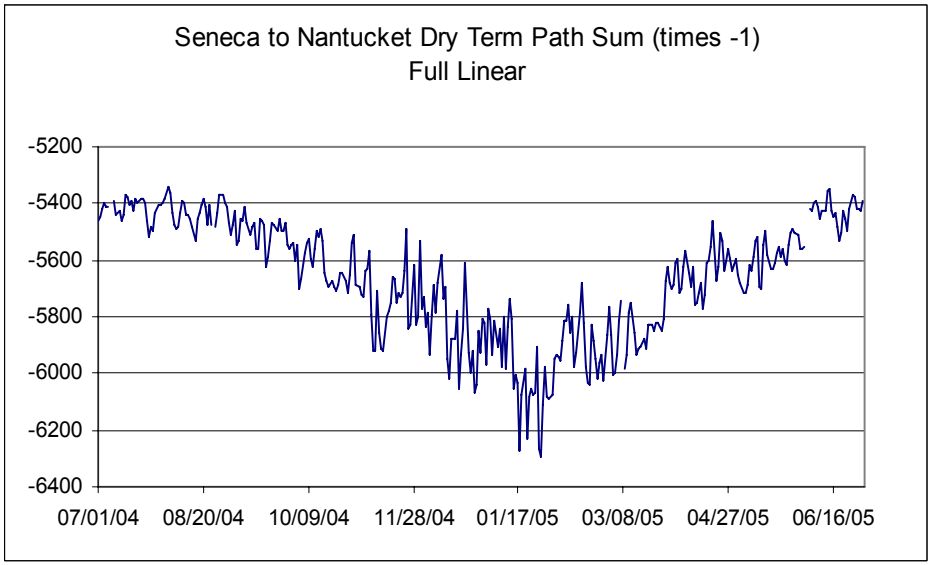
MID-2005 DECISION:

- WAIT UNTIL TUBE TRANSMITTERS REPLACED
- TRY TO WORK AROUND TFE UNAVAILABILITY



A FEW PLOTS ILLUSTRATE WHERE WE STAND



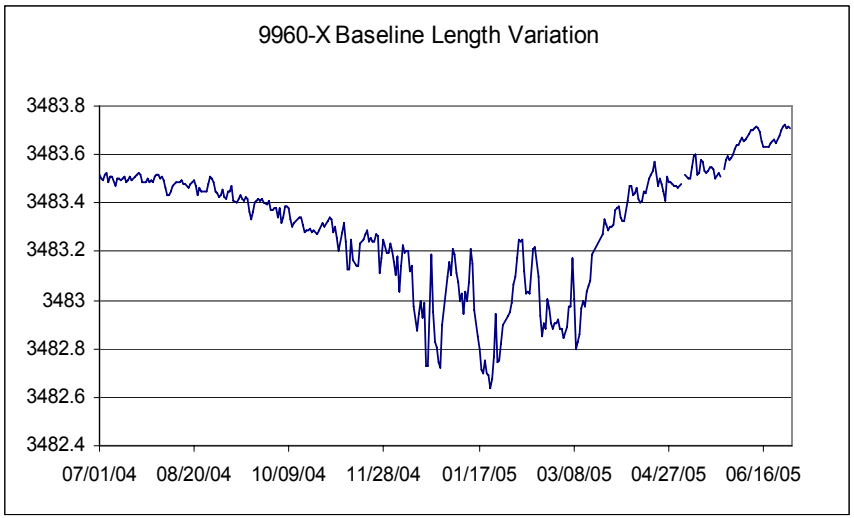


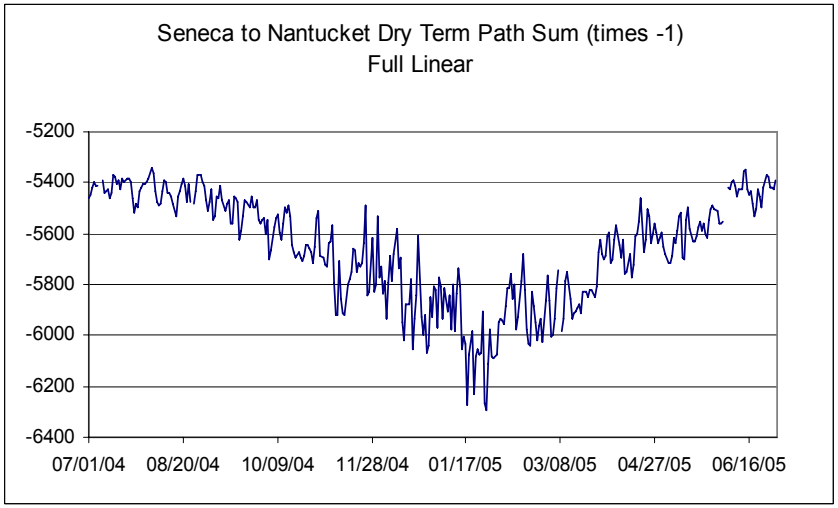
WE KNOW THE LORAN DATE – E.G., THE PLOT ON THE LEFT, SHOULD RETURN TO THE SAME AVERAGE VALUES EACH SUMMER.

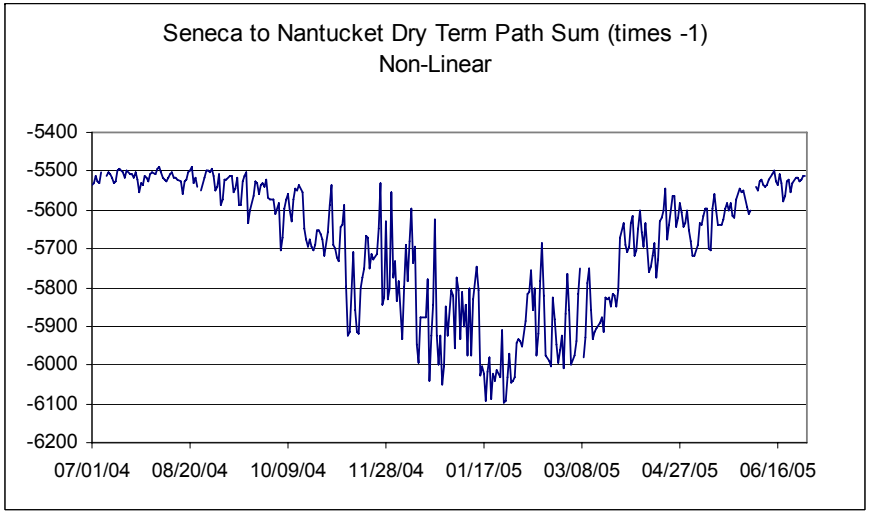
AS SHOWN, IT DOES NOT. THIS IS TYPICAL OF WHAT WE FIND IN THE DATA

TO “FIX THE DATA”, WE BELATEDLY RECOGNIZED THE NEED TO MAKE CORRECTIONS BASED ON DATA NOT EASILY AVAILABLE

THE SAME LORAN DATA, BUT SLIGHT DIFFERENCES IN THE DRY TERM CALCULATION







SUMMARY

- THE TEMPORAL VARIATION SUB-MODEL USED IN THE REPORT TO DOT YIELDED AVAILABILITIES SEEN AS ACCEPTABLE
- THERE ARE SIGNIFICANT MID-CONTINENT IMPROVEMENT OPPORTUNITIES
- CONTOURS BASED ON THE DRY TERM OF THE INDEX OF REFRACTION ARE SLIGHTLY BETTER
- WE HAVE NOT YET ADDED HUMIDITY TO THE **SEASONAL** VARIATION MODEL IT – MAY NOT BE NECESSARY
- CURRENT FOCUS IS TO SUPPORT “ANY TIME OF THE YEAR” AIRPORT CALIBRATIONS
- TOO SOON TO SAY IF SUCH A MODEL CAN BE DEVELOPED
- IF NOT AIRPORT CALIBRATIONS WILL PROBABLY HAVE TO BE LIMITED TO A TIME PERIOD OF ABOUT 6 MONTHS