



RAMS: Beyond v6.0

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ATMET

ATmospheric, Meteorological and Environmental Technologies



Planned developments

- Lambert-Conformal projection
- Double precision “*time*”
- Funded by US Air Force Technical Applications Center (AFTAC)
 - RRTM radiation schemes
 - TEB urban canopy
 - ISAN replacement
- Post-processing



Lambert-Conformal Projection

- Primarily for compatibility with other models and applications
 - Example: For air quality applications in the US, EPA and the states use MM5 mostly. This is run in LC projection, so CAMx and CMAQ is run in LC. Most emission inventories are prepared in LC to avoid interpolations.



Double precision time

- To allow longer climate runs
 - Current single precision variable can run into problems after ~ 120 days on 32-bit machines
 - Double precision will allow $\sim 3,000,000$ years (if timestep is > 1 sec)
 - Minor changes to RAMS and post-processing apps



RRTM Radiation schemes

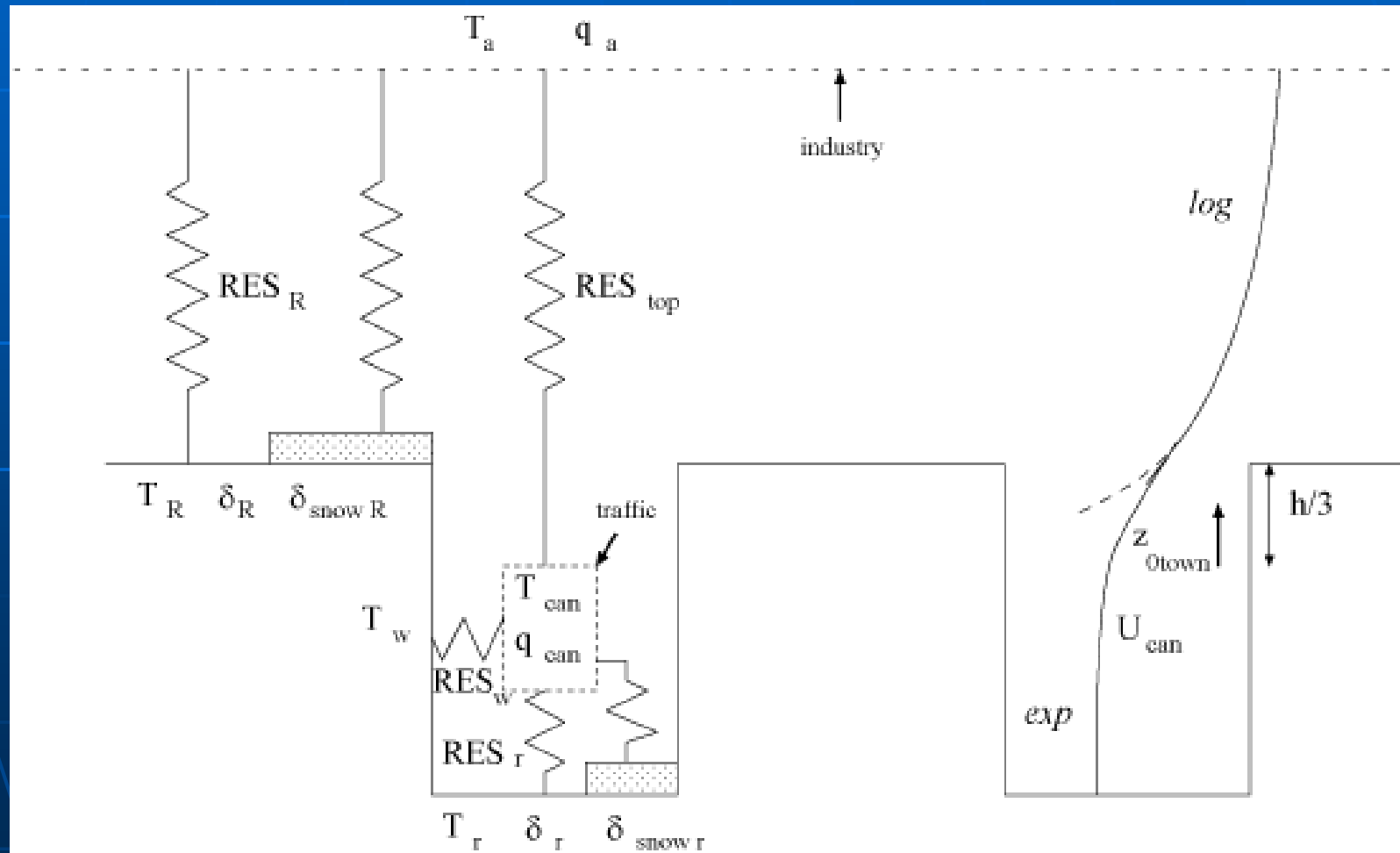
- US-government funded software from AER, Inc.
- Validated by using line-by-line models
- Shortwave scheme uses up to 35 species (usually 7, O₂, CO, CO₂, etc.), 16 bands, clouds, aerosols
- BIG problem: original code takes 6 seconds per column on Athlon! Will investigate speed-ups
- Longwave scheme implemented in MM5 and WRF, so it “should” be reasonable.

TEB Urban Canopy

- Developed by Valery Masson from Meteo-France (sent latest version a few months ago)
- We have received permission to distribute as part of RAMS
- Following figures from Meteo-France web site...

TEB Urban Canopy Features

Processes:

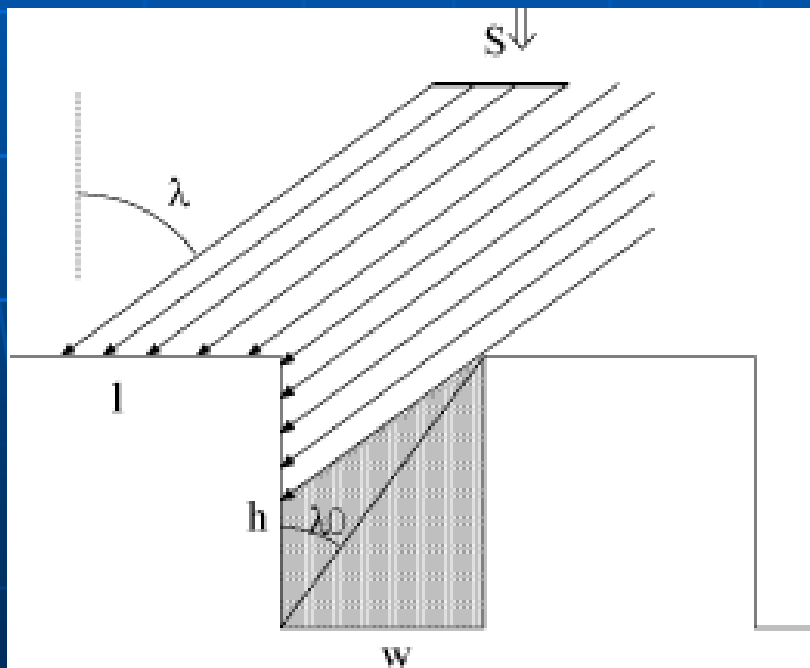


Aerodynamical resistances

wind profile

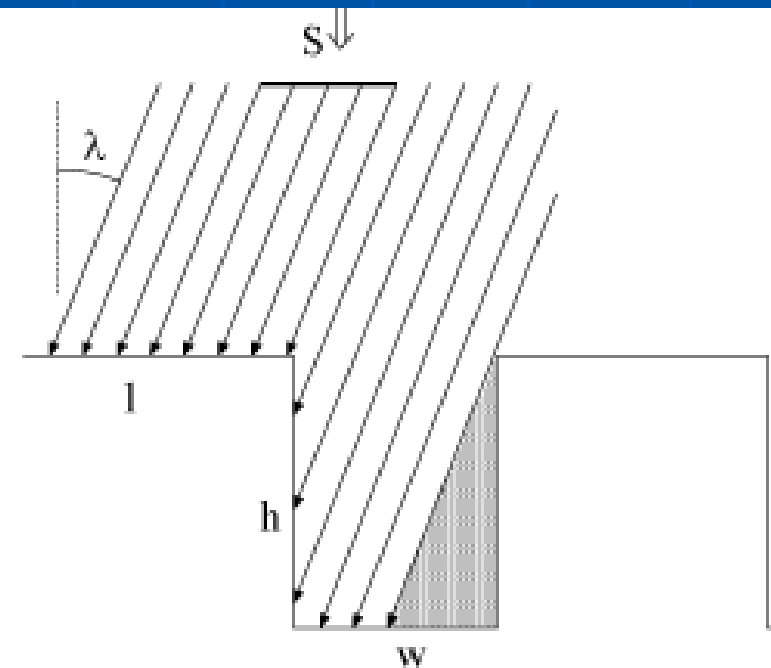
TEB Urban Canopy Features

Radiation:



road perpendicular to sun direction

Sun low over the horizon $\lambda > \lambda_0$



road perpendicular to sun direction

Sun high over the horizon $\lambda < \lambda_0$

TEB Urban Canopy Features

Inputs:

| symbol | designation of symbol | unit |
|--|--|-----------------|
| geometric parameters | | |
| a_{town} | fractional area occupied by artificial material | - |
| a_{Mtd} | fractional artificial area occupied by buildings | - |
| $1 - a_{Mtd}$ | fractional artificial area occupied by roads | - |
| h | building height | m |
| h/l | building height/width ratio | - |
| h/w | canyon height/width ratio ¹ | - |
| Ψ_r | sky-view factors for road: $\Psi_r = [(h/w)^2 + 1]^{1/2} - h/w$ | - |
| Ψ_w | sky-view factors for one wall: $\Psi_w = \frac{1}{2} \{ h/w + 1 - [(h/w)^2 + 1]^{1/2} \} / (h/w)$ | - |
| $z_{0_{urban}}$ | dynamical roughness length for the buildings/canyons system | m |
| radiative parameters | | |
| $\alpha_R, \alpha_r, \alpha_w$ | roof, road and wall albedos | - |
| $\epsilon_R, \epsilon_r, \epsilon_w$ | roof, road and wall emissivities | - |
| thermal parameters | | |
| d_{Rk}, d_{rk}, d_{wk} | thickness of the k^{th} roof, road or wall layer | m |
| $\lambda_{Rk}, \lambda_{rk}, \lambda_{wk}$ | thermal conductivity of the k^{th} roof, road or wall layer | $Wm^{-1}K^{-1}$ |
| C_{Rk}, C_{rk}, C_{wk} | heat capacity of the k^{th} roof, road or wall layer | $Jm^{-1}K^{-1}$ |

TEB Urban Canopy Features

Computed:

| symbol | designation of symbol | unit |
|--------------------------------------|--|------------|
| prognostic variables | | |
| T_{Rk}, T_{rk}, T_{wk} | temperature of the k^{th} roof, road or wall layer | K |
| W_R, W_r | roof and road water interception reservoir | kgm^{-2} |
| W_{snowR}, W_{snowr} | roof and road snow interception reservoir | kgm^{-2} |
| T_{snowR}, T_{snowr} | roof and road snow temperature | K |
| $\rho_{snowR}, \rho_{snowr}$ | roof and road snow density | kgm^{-3} |
| $\alpha_{snowR}, \alpha_{snowr}$ | roof and road snow albedo | - |
| diagnostic variables | | |
| T_{can} | canyon air temperature | K |
| q_{can} | canyon air specific humidity | kg/kg |
| U_{can} | along canyon horizontal wind | ms^{-1} |
| α_{town} | town effective albedo | - |
| T_{sttown} | town area averaged radiative surface temperature | K |
| input energy fluxes | | |
| L^{\downarrow} | downwards infra-red radiation on an horizontal surface | Wm^{-2} |
| S^{\downarrow} | downwards scattered solar radiation on an horizontal surface | Wm^{-2} |
| S^{\downarrow} | downwards direct solar radiation on an horizontal surface | Wm^{-2} |
| $H_{traffic}$ | anthropogenic sensible heat flux released by in the canyon | Wm^{-2} |
| $LE_{traffic}$ | anthropogenic latent heat flux released by the canyon | Wm^{-2} |
| $H_{industry}$ | anthropogenic sensible heat flux released by industries | Wm^{-2} |
| $LE_{industry}$ | anthropogenic latent heat flux released by industries | Wm^{-2} |
| other energy input | | |
| T_{bid} | building interior temperature | K |
| output energy fluxes | | |
| $S_{Ri}^*, S_{ri}^*, S_w^*$ | net solar radiation budget for roofs, roads and walls | Wm^{-2} |
| $L_{Ri}^*, L_{ri}^*, L_w^*$ | net infra-red radiation budget for roofs, roads and walls | Wm^{-2} |
| H_{Ri}, H_{ri}, H_w | turbulent sensible heat flux for roofs, roads and walls | Wm^{-2} |
| LE_{Ri}, LE_{ri}, LE_w | turbulent latent heat flux for roofs, roads and walls | Wm^{-2} |
| $G_{Rk,k+1}, G_{rk,k+1}, G_{wk,k+1}$ | conduction heat flux between k^{th} and $k+1^{th}$ roof, road or wall layers | Wm^{-2} |
| H_{town} | town averaged turbulent sensible heat flux | Wm^{-2} |
| LE_{town} | town averaged turbulent latent heat flux | Wm^{-2} |



ISAN Replacement

- Project last year to perform review of current state of 3DVAR, 4DVAR, and Ensemble Kalman Filter and tested WRF 3DVAR scheme
- Expected to recommend general usage of WRF 3DVAR (it has been advertised so much!)
- But... group funding the study (AFTAC) needs data analyses for past events
- 3DVAR relies on error matrices, statistical relationship between grid point values and observations. Can be thought of as smoothing weights.
- Best if error matrices computed from a historical set of runs (like in operational settings).
- Not available for past runs. Ensembles can be generated, but if we need an ensemble, easier to use EKF scheme.



ISAN Replacement

- So...we decided to pursue an existing data analysis package that ingests a wide range of current observations...
- LAPS – Limited-area Analysis and Prediction package
- Developed at NOAA/FSL (Now NOAA/ESRL/GSD (Earth System Research Laboratory/Global Systems Division))



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LAPS slides from:

Local Data Assimilation and Modeling
Applicable to NWS WFO Operations

Brent L. Shaw *

Local Analysis and Prediction Branch

Forecast Research Division

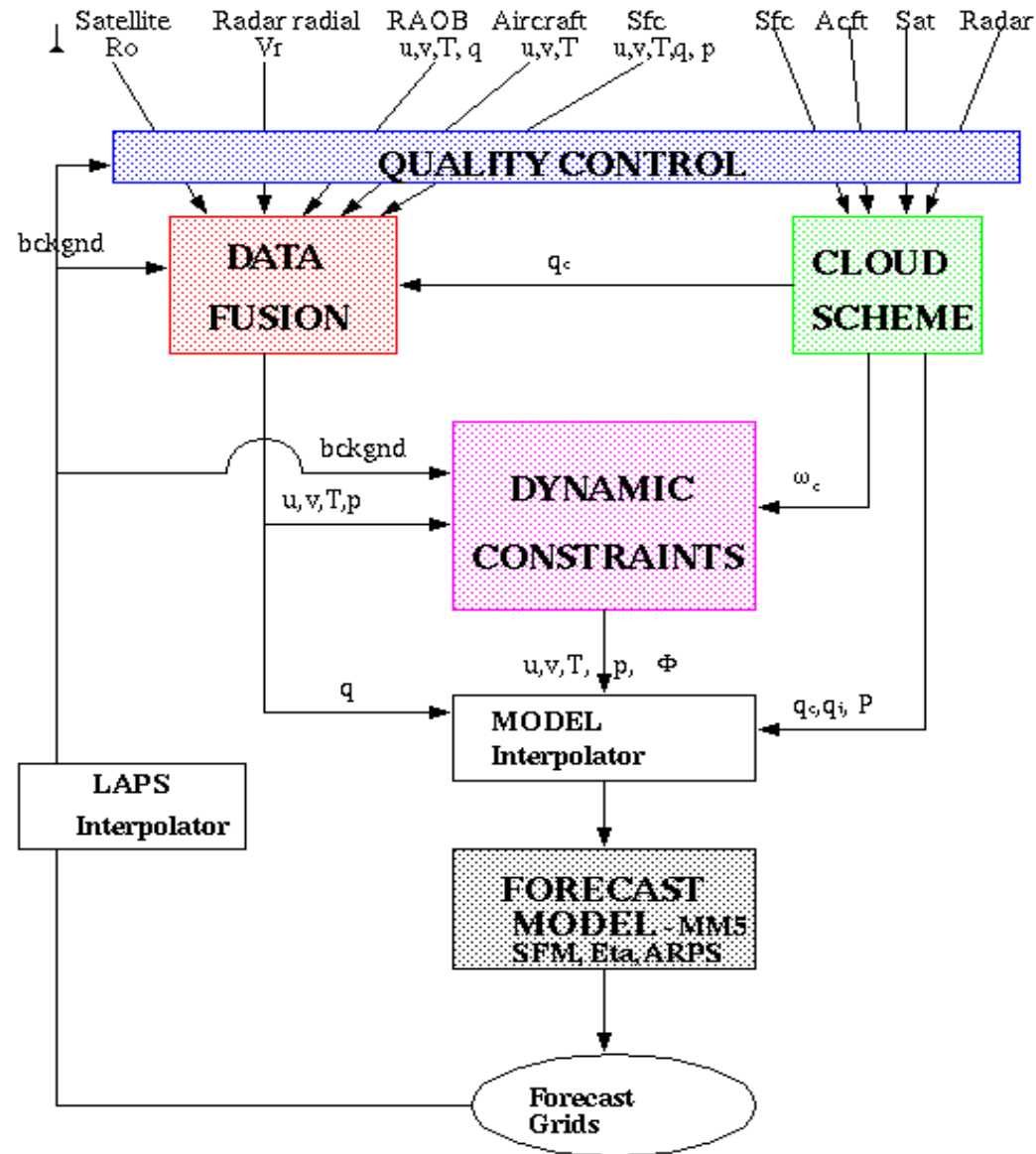
NOAA Forecast Systems Laboratory



LAPS Analysis Components

- ☀ Raw data ingest and quality control
- ☀ Analysis of state variables
 - Temperature
 - Winds
 - Moisture
- ☀ Cloud analysis
- ☀ Diagnostic variables
- ☀ Dynamic balance

LAPS II Flow Diagram



Data Ingest

☀ Use all available sources

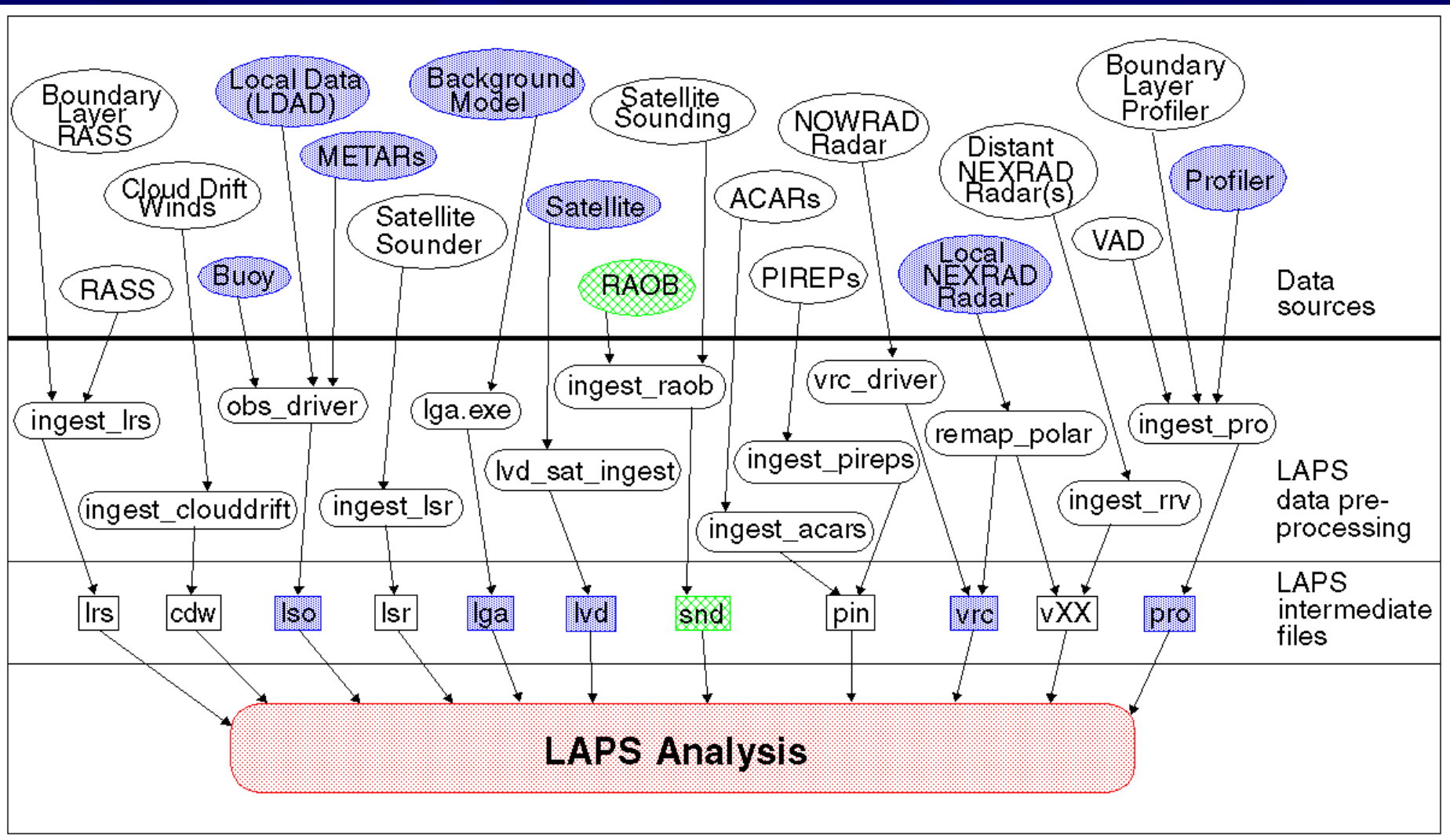
• National data

- Model grids from RUC or Eta for first-guess fields
- METARs, satellite, wind profilers, ACARS, RAOBs, etc.

• **Local data** - Often not available to national data assimilation systems!

- Highway departments
- Agricultural networks
- Amateur radio (APRS) network
- Universities
- Private industries
- Experimental data sources

Data Ingest

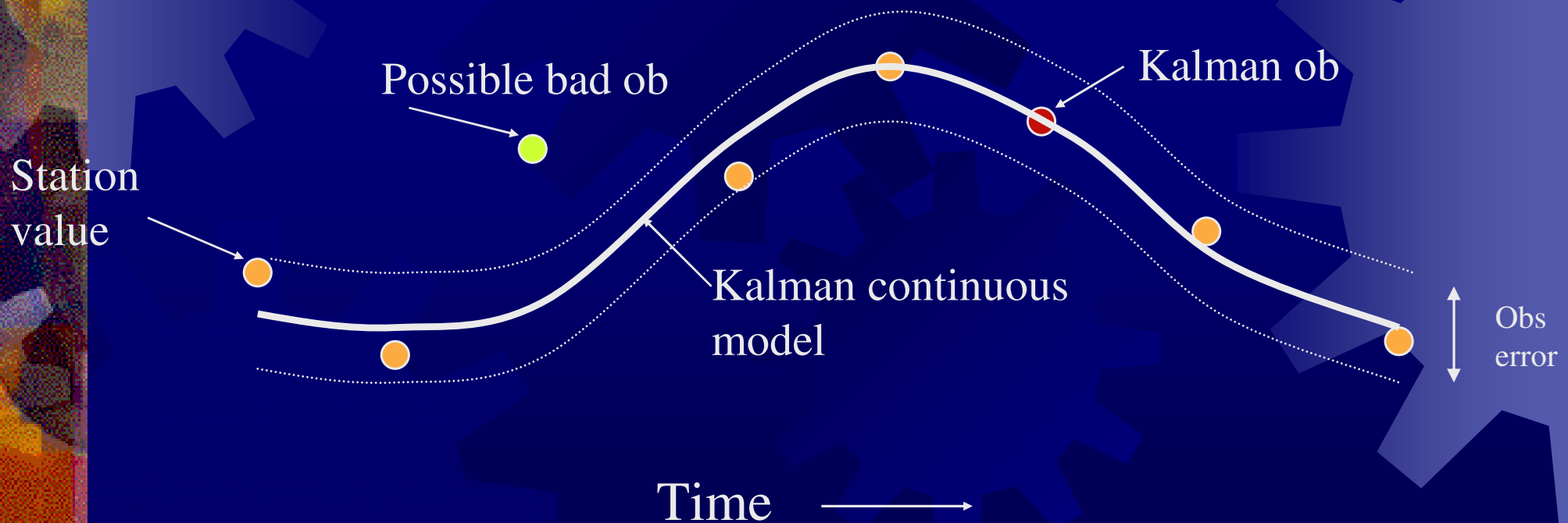


Quality Control

- ★ Local data sets present QC challenges:
 - Poor siting
 - Poor maintenance
 - Poor communications
- ★ Result: Inaccurate, irregular observations, leading to inconsistent analysis products and poor forecast initialization
- ★ Consider the following scenario...

Solution: Kalman Filter

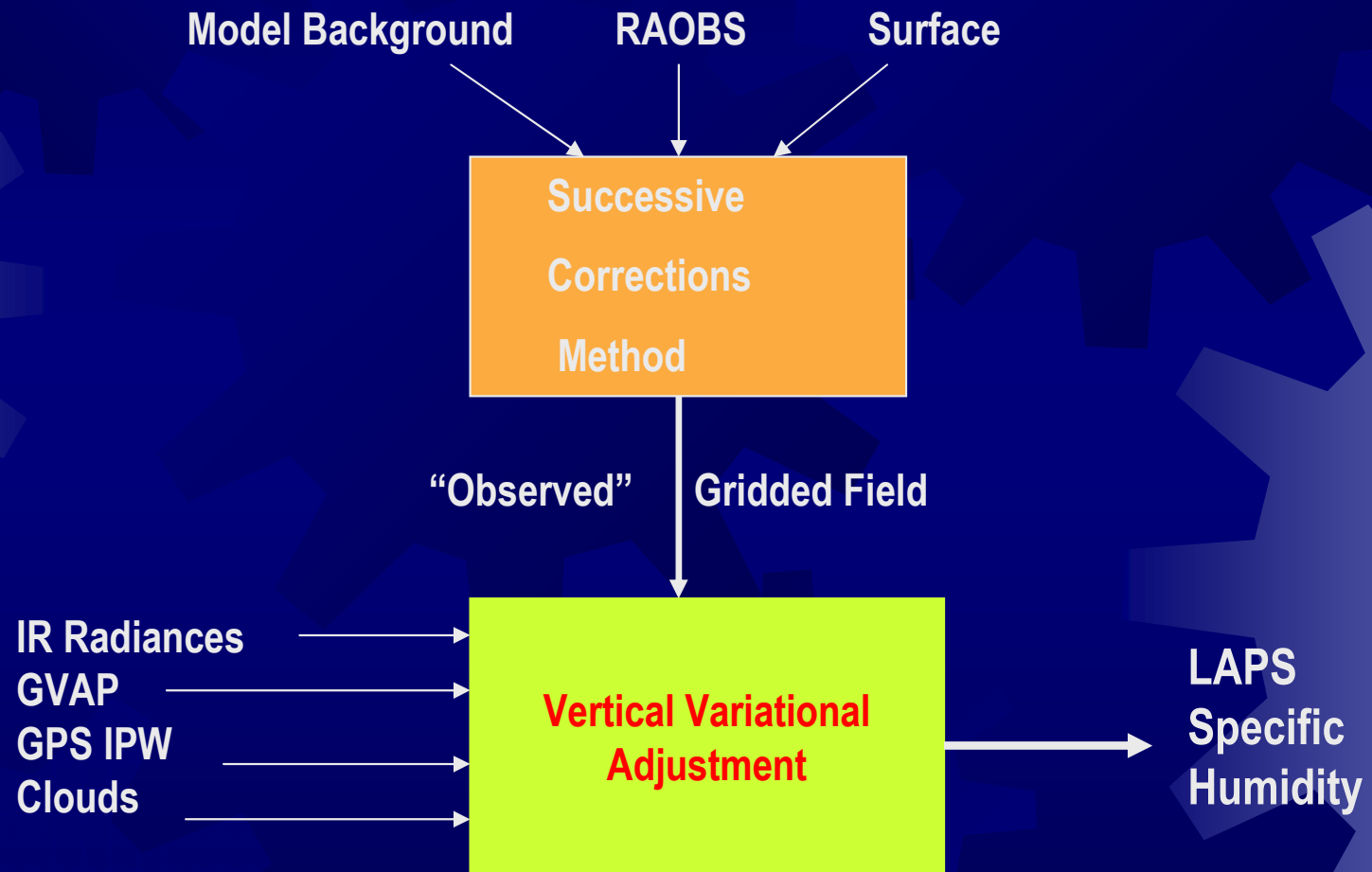
- Provides a continuous station estimate of observation based on self trend, buddy trends, and NWP – use for quality checking
- With missing obs – maintain constant station count



Kalman QC Advantages

- ✦ Adaptable to small workstations – works in observation space
- ✦ Accommodates models of varying complexity-Model error is a dynamic quantity within the filter, thus the scheme adjusts as model skill varies
- ✦ The Kalman Filter creates a data continuum not dependent on data density or observational regularity – products can be generated at any desired time.

Moisture Analysis



Moisture Analysis

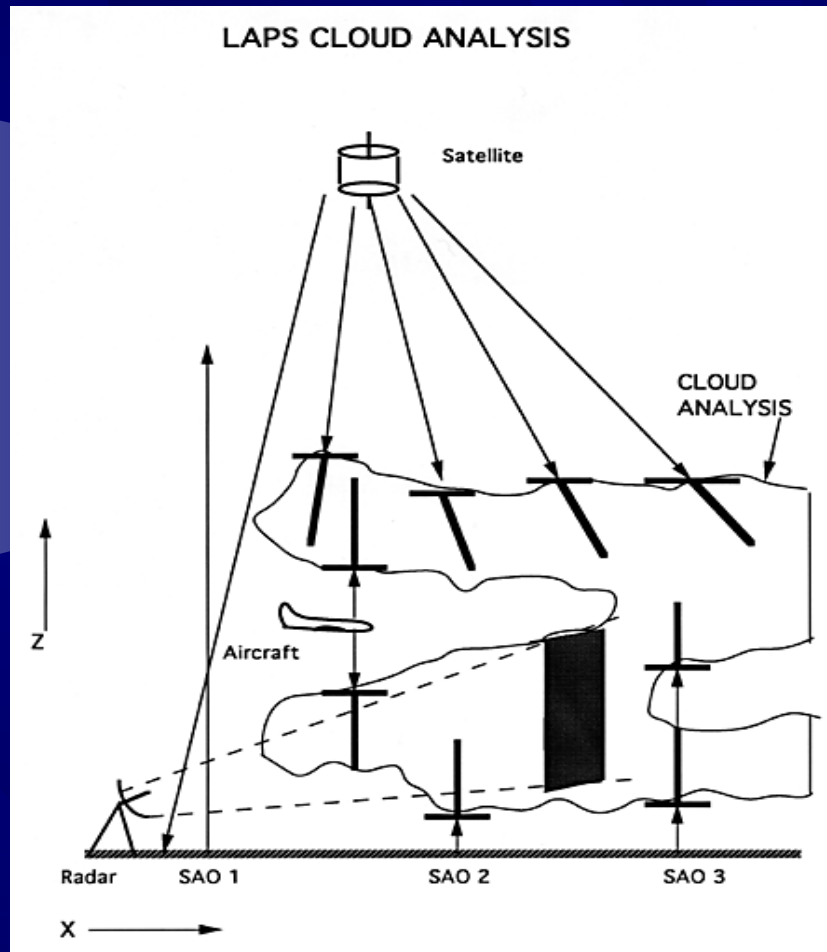
Variational Adjustment

Minimize

$$J = \sum_{i=1}^{n_{chan}} (R_i(T, O_3, cq) - R_i^o)^2 / E_{i,rad}^2 + \left(\sum_{k=1}^{n_{lvl}} c_k q_k - Q_{gps}^o \right)^2 / E_{gps}^2$$
$$+ \sum_{j=1}^{n_{gvap}} \left(\sum_{k=1}^{n_{lvl}} P_{jk} c_k q_k - Q_j^o \right)^2 / E_{j,gvap}^2 + \sum_{k=1}^{n_{lvl}} C_k (c_k q_k - q_s(T))^2 / E_{k,cld}^2$$
$$+ \sum_{k=1}^{n_{lvl}} (1 - c_k)^2 * E_{k,adj}^2 / E_{k,obs}^2$$

Solve for c_k

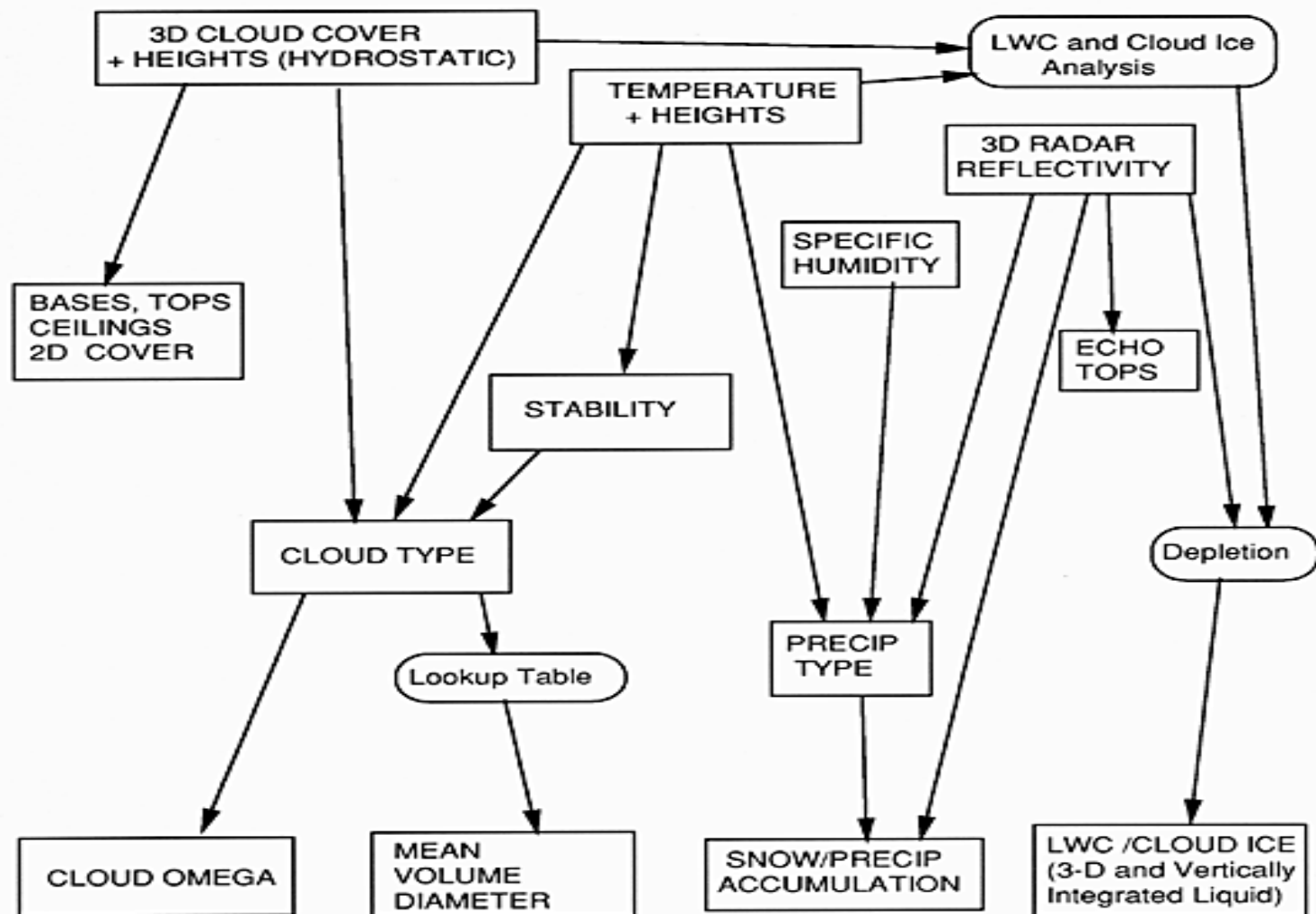
Cloud Analysis Scheme



- ✦ Uses satellite (Vis and IR)
- ✦ Aircraft observations
- ✦ Surface observations
- ✦ Radar
- ✦ Interpolates cloud obs to grid
- ✦ Cloud feeds back into water vapor analysis

Cloud Model

LAPS DERIVED CLOUD/HYDROMETEOR FIELDS





Dynamic Adjustment

- ✦ Final step required for consistency between cloud and moisture analysis and the mass and momentum fields
- ✦ Retrieval of “observed” cloud vertical motion from LAPS cloud analysis and a simple 1-D cloud model
- ✦ Integral variational analysis constrained by full equations of motion and continuity, allowing clouds to impact mass and motion fields
- ✦ Explicit representation of model background error over entire grid



Dynamic Adjustment

- ✦ Adjustments are applied on increment from background field
- ✦ Minimization of time tendencies ensure smooth model start

Dynamic Balance Equations

Dynamic Balancing and Continuity Formalism

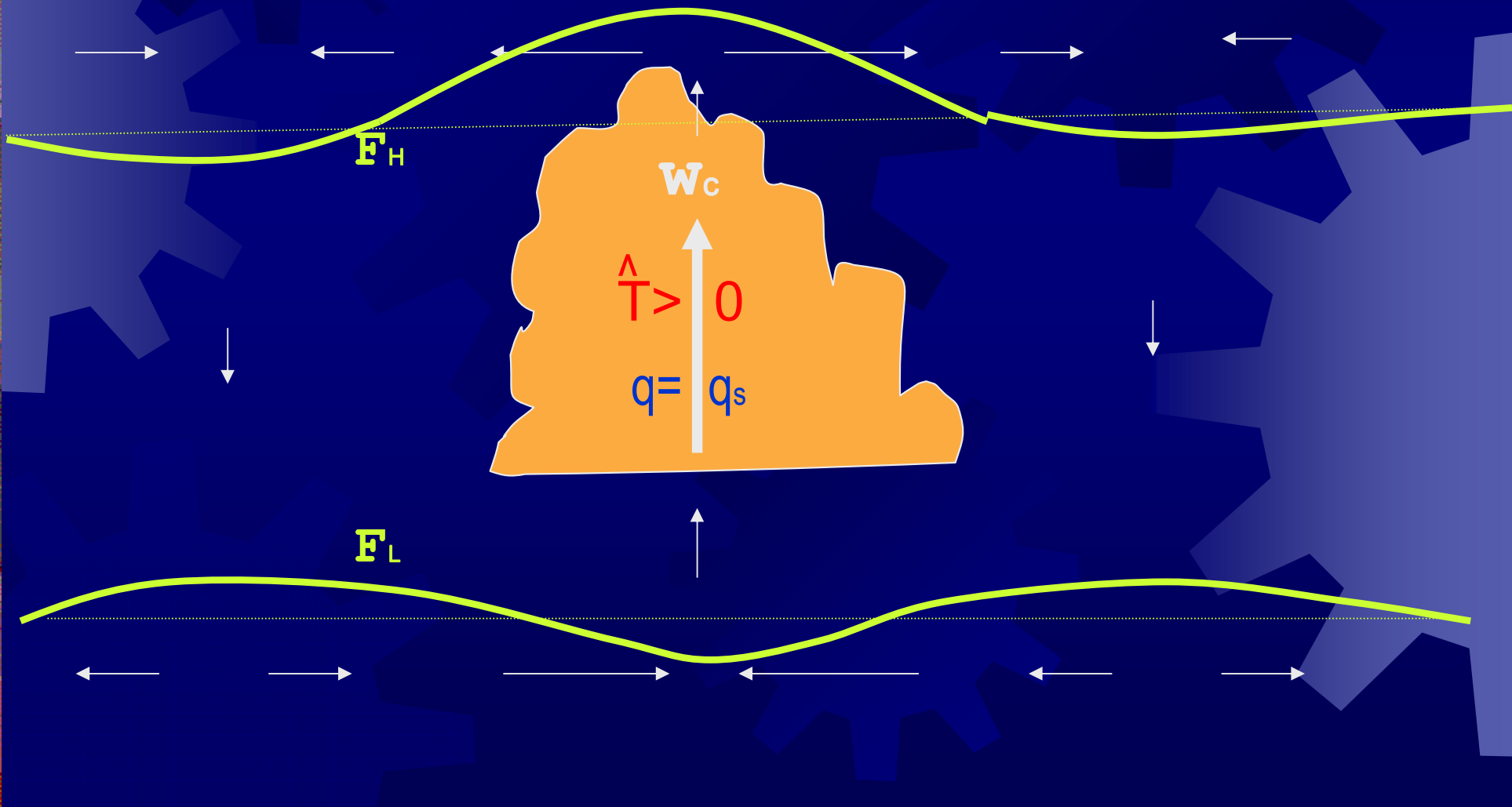
$$J = \sum_k \sum_j \sum_i O_V (\hat{u} - u')^2 + O_V (\hat{v} - v')^2 + O_\omega (\hat{\omega} - \omega'_c)^2 + O_\Phi (\hat{\Phi} - \Phi')^2 \\ + \mu (\hat{u}_t)^2 + \mu (\hat{v}_t)^2 + \lambda (\hat{u}_x + \hat{v}_y + \hat{\omega}_p) \\ + B_V \hat{u}^2 + B_V \hat{v}^2 + B_\Phi \hat{\Phi}^2 + B_\omega \hat{\omega}^2$$

$$\hat{u}_t = -(u_b \hat{u}_x + \hat{u} u_{bx} + v_b \hat{u}_y + \hat{v} u_{by} + \omega_b \hat{u}_p + \hat{\omega} u_{bp}) - \hat{\Phi}_x + f \hat{v} - D(\hat{u})$$

$$\hat{v}_t = -(u_b \hat{v}_x + \hat{u} v_{bx} + v_b \hat{v}_y + \hat{v} v_{by} + \omega_b \hat{v}_p + \hat{\omega} v_{bp}) - \hat{\Phi}_y - f \hat{u} - D(\hat{v})$$

() b are background quantities; (^) are solution increments from background;
()' are observation differences from background

Cloud, Wind and Mass Dynamic Adjustment



Results of Analysis

- ★ 3D Grids suitable for nowcasting

- ★ T, p, u, v, w

- ★ $q_{\text{vapor}}, q_{\text{cloud}}, q_{\text{rain}}, q_{\text{snow}}, q_{\text{ice}}, q_{\text{graupel}}$

- ★ Derived parameters

- ★ Balance ensures suitability for *diabatic* model initialization

- ★ Hydrometeors initialized at $t=0$

- ★ Elimination of model spin-up problem!

- ★ Question: *Does the diabatic initialization improve explicit short-range NWP forecasts of clouds and precipitation?*



LAPS Deficiencies (Features)

- Pressure vertical coordinate
- Uses a modified Barnes scheme for the majority of the variables
- LAPS can take significant time to execute.
- It can only handle one data time and one grid per execution.
- The code itself is broken into 38 executables, each performing its own distinct task, with its own memory structure, etc. PERL scripts control processing.



LAPS Development Tasks

- 1) Separate ISAN completely from RAMS
 - Use ISAN as a top-level driver for the LAPS code
 - Set up a common memory structure
 - Handle the calling of the various LAPS components, which will be converted from separate executables to subroutines.
 - This structure will also handle executing multiple data times and grids.
 - MPI calls (mostly) at this level



LAPS Development Tasks

- 2) Implement distributed memory parallelism (MPI) on the slowest LAPS components.
 - With a common memory structure, this task will be easier to implement and maintain.
 - MPI calls (mostly) at the driver lever.

LAPS Development Tasks

- 3) Implementation of a generalized height coordinate.
 - An “arbitrary” 3d array of heights defines the levels on which the processing is done. These heights can be defined in numerous ways: geopotential (to emulate pressure coordinates), terrain-following (as in RAMS), Cartesian, or any mixture that makes sense. WRF sigma-p coordinates should be able to be input easily.
 - Each LAPS component will need to be converted from the pressure coordinate to a height coordinate.
 - This cannot emulate isentropic coordinates, so we will explore the possibility of a hybrid coordinate.



LAPS Development Tasks

- 4) Explore Barnes alternatives.
 - Numerous possibilities
 - We will perform preliminary testing of various schemes, comparing with the current scheme, see how they perform, then implement the most reasonable.



LAPS Development Tasks

5) Observation file formats

- LAPS uses specific ASCII formats, different than the RAMS GDF (Ralph) formats.
- Numerous other RAMS-related applications (ODA, revu_st, ODV, etc.) that uses the observational data
- Either a set of converters will be necessary, or if possible, come into agreement with FSL on a common data format.

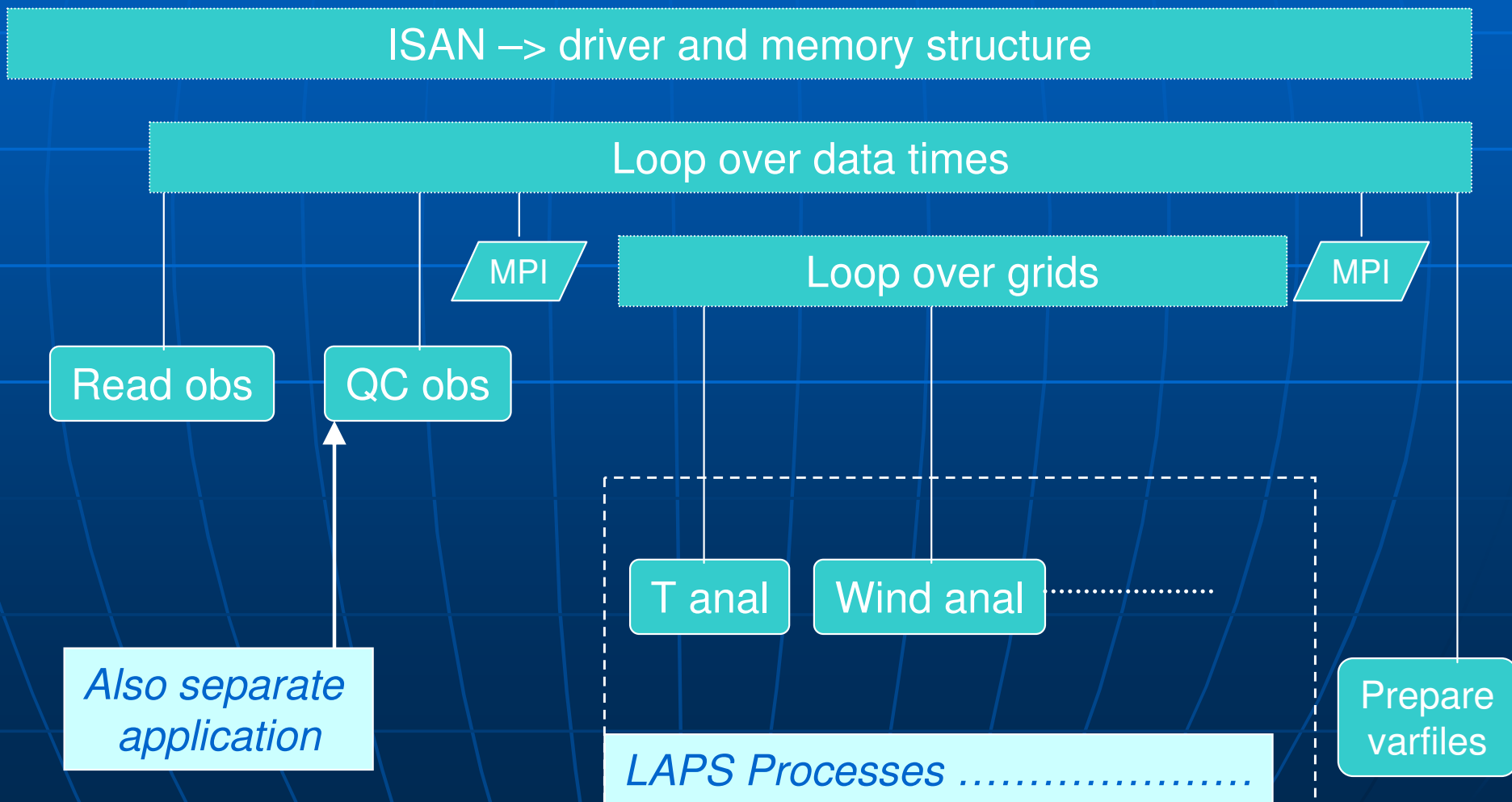


LAPS Development Tasks

6) Observation quality control

- Several types of quality control are done as part of the current LAPS processing.
- However, the QC is done as part of the LAPS processing stream, meaning that LAPS has to be run with the observational components activated.
- Configure the general QC components into a separate application.
- Can include the things in our standalone package along with the various LAPS techniques. The new (hopefully standardized) file formats would have QC flags, like the current Ralph format, which the individual applications can use.

LAPS New Structure Schematic





Changes for v6.0

- HDF5 file formats (developed and maintained at NCSA)
- Advantages
 - Standard, well documented. Effort underway to merge with netCDF
 - More efficient compression (V-format: 75% vs. binary (32-bit), HDF5: 75% vs. V-format)
 - Unlike V-format, exact binary is recovered on read...
 - ... allows the removal of separate history files
 - HDF5 handles all bookkeeping, no need to keep track of where fields start on file
 - Fields and attributes can create a self-describing file (*head.txt files will eventually disappear)
 - Numerous 3rd-party apps to perform various tasks (h5diff, hdfview, etc.), some without need of file conversion
 - Can extract data to ASCII format (h5dump) without need of REVU (DUMP option)
- Disadvantages
 - Need to install another library (frequently requires a compile)
 - Some performance issues, especially on writes



Post-processing apps

- HYPACT 1.5 – v1.2 converted for HDF5 state files
- v1.9 in beta, some new developments (a few users have it)
- v2.0 in development, new dry deposition and “history” starts



Post-processing apps

- REVU-v2.5 released (v2.3.1 converted for state files)
- REVU_pl to be released soon
 - Mostly new, script-driven REVU
 - Multiple models runs at once
 - RAMS, GRIB (NCEP GFS), MM5 (AFWA GRIB), WRF
 - Can add/subtract fields from same or different runs
- iVAN – interactive Visualization and ANalysis package (formerly, RINGI)
 - GUI support for REVU_pl features



Graphical User Interfaces

- RAMS
- CAMx
- iVAN
- New LAPS
- Observational Data Viewer (ODV)
- Emergency response system