Transcom boundary layer model-data comparison

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1. Introduction

The purpose of this protocol is to set out thegra experimental design for comparing modeled and observed planetary boundary layer heights, using a new dataset of mixing height estimates derived from radiosonde profiles.

2. Radiosonde-derived mixing height data

Ally Zhang (Nanjing University) and Dian Seidel (NOAA Air Resources Laboratory) have extracted mixing-height (MH) estimates from the IGRA [footnote 1] radiosonde dataset. Based on the criteria of producing a uniform observational criterion on MH, of creating an observational constraint that is directly comparable to the same quantity in a model, and considering the quality of radiosonde data available, the bulk Richardson number method of Volgelzang and Holtslag (1996) was selected. The resulting MH-Rib dataset is documented in Seidel et al. (2011), where it was used to compute a MH climatology for comparison with climate models.

IGRA data are available for stations worldwide at the synoptic times of 0Z and 12Z ("Z" means UTC). At any given time, there are generally around 1000 stations reporting radiosonde profiles, although data availability varies in time and space. Zhang and Seidel have computed mixing heights for available individual profiles around the world from 1971 to 2010, at a total of 986 stations. A sample of this dataset showing mixing heights for June 15, 2010 12Z is shown in figure 1.

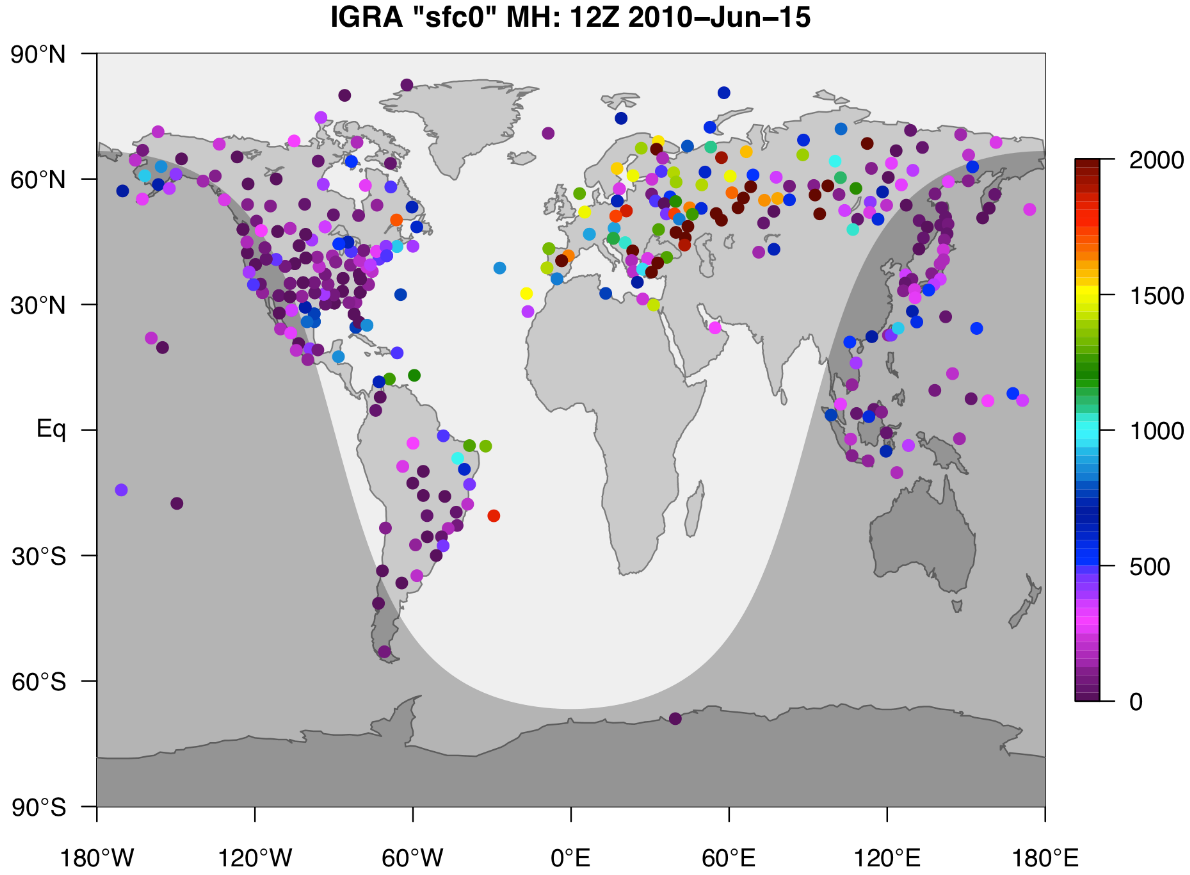

Figure 1. IGRA mixing heights (in meters above ground level) for June 15, 2010. Data from Seidel et al. 2012.

3. Bulk Richardson number Mixing Heights

To retrieve the MH-Rib, modelers need access to model values of virtual potential temperature (or potential temperature and water vapor mixing ratio), model layer heights, and wind speeds. Virtual potential temperature (cf. Stull section 1.5) is computed using potential temperature with a correction due to the water vapor mass mixing ratio. If the model also tracks condensed phase water, a correction for liquid water mixing ratio can be included (see Stull for details).

Thus, if the model does not already offer virtual potential temperatures, participants will need access to the water vapor mixing ratio of the source meteorology. If neither virtual potential temperature nor water vapor mixing ratio are available for a given model, we could consider using forecast model analyses or reanalysis values for water vapor mixing ratio in conjunction with the model potential temperature.

The bulk Richardson number characterizing the air between the surface and a level "h" is defined as:

$$Ri_b = \left(\frac{g}{\theta_{vs}}\right)\frac{(\theta_{vh} - \theta_{vs})(h - z_s)}{(u_h - u_s)^2 + (v_h - v_s)^2}\ , \tag{1}$$

where

g is the acceleration due to gravity,
θ_{vs} is the virtual potential temperature at the surface,
θ_{vh} is the virtual potential temperature at model level "h",
h is the model level geopotential height,
z_s is the surface geopotential height,
$u_h$is the zonal wind speed at model level "h",
u_s is the zonal wind speed at the surface,
v_h is the meridional wind speed at model level "h",
and v_s is the meridional wind speed at the surface.

Ri_b diagnoses the probability of turbulence within the layer of air between the surface and model level "h". The numerator in equation 1 represents buoyancy destruction of turbulence and the denominator represents shear production of turbulence. Production of turbulence is favored when Ri_b is small and the layer is expected to be turbulent if Ri_b is less than a critical value, generally taken to be 0.25 (although both smaller and larger values are used in some models). The model mixing height is estimated by starting at the lowest model level and scanning upward. At each level the Ri_b is computed, and if Ri_b is greater than 0.25, the scanning stops. Mixing height is then computed by linear interpolation to the geopotential height at which Ri_b actually crosses the critical value of 0.25. Note also that this expression for the bulk Richardson number excludes the u^* term which is used in some applications.

Sample code for computing mixing height from model fields is included in Appendix 1.

3.1 Treatment of surface conditions. Surface winds and temperatures are often poorly distinguished from quantities in the model's lowest layer. These quantities are also not available directly from the IGRA dataset. Zhang and Seidel have developed a workable compromise by assuming that surface winds are identically zero. The impacts of this assumption are evaluated for sonde data in the Zhang et al manuscript, and are generally modest in comparison to differences between models and observations. We will adopt this convention, and will therefore modify equation 1 with $u_s = v_s = 0$. It is also preferable to use zero surface winds for the present effort because many models also would have difficulty estimating 2m winds without further assumptions.

4. Proposed Simulations and Output

Preferred format for model output will be for Rib-MH (and, if available, any internal model values for BLH or mixing height) at 0Z and 12Z for the 986 IGRA stations listed in the file ftp://ftp.cmdl.noaa.gov/pub/andy/transcom_blh/igra.stations.nc. Output should be for instantaneous times, not temporal averages around 0Z and 12Z. As described in section 3.1, surface winds should be assumed to be zero.

Timeline

1 October 2012 – deadline for comments on this protocol
1 December 2012 – deadline for model submissions

Issues to consider. It has been suggested that modelers should interpolate winds and virtual potential temperature to IGRA levels, but reported levels vary by sounding and interpolation also will tend to smooth information from the models. Extrapolation to the surface to infer u_s and v_s would impose further assumptions. Use of lowest-level winds to represent u_s and v_s would cause differences among models due to vertical resolution differences. Lateral interpolation to IGRA stations is discouraged since that also tends to destroy raw model information. **Proposed solution:** modelers will not interpolate meteorological information laterally or vertically. The only interpolation is to estimate the geopotential height at which Ri_b equals the critical value of 0.25, given two model layers bracketing this critical Ri_b.

Modelers should provide output for all 986 stations for the 1971-2010 or whatever subspan of that period is covered by their integrations. In case of difficulty extracting profiles at IGRA stations from model fields, contact Andy Jacobson to discuss how we might proceed. If water vapor mixing ratios are not available, please contact Andy.

Andy will develop sample netCDF files for desired model output [TO BE COMPLETED.]

4.1 Model physics survey. We will request that each model participating in this exercise provide some standard information about the physics used for transport in the model. This will include:

a. Model lateral and vertical resolution, including details on the vertical coordinate scheme,
b. Model surface elevation at each IGRA site,
c. Details on the PBL mixing scheme used by the model and/or parent ("online") model.

4.2 Mixing heights from common reanalyses. Protocol organizers will extract MH estimates from reanalyses commonly used for driving meteorology by Transcom models (ERA-Interim, MERRA, NCEP-II). MHs will be extracted at the highest available resolution from archived output from those analyses. If your model is driven by any of those analyses, results may differ due to differences in spatial resolution and internal model manipulation or preprocessing of those fields. **We are actively soliciting help with this part of the analysis.** If your model is driven by any of these reanalysis products, please consider performing the analysis on the raw "parent" model output.

5. Proposed analysis

Analysis will begin by collecting model-observation differences in MH for each available profile. For each station, each model's mean bias, seasonal errors, and synoptic-time scale errors will be characterized.

A suitable period will be chosen for reporting on general performance of models compared to observations. This will probably be in the decades of the 1990s and 2000s, but will depend on model submissions. A manuscript describing the comparison will be developed from this subset.

Modelers will have access to all results. Other uses of the results from this experiment will be encouraged.

Footnote 1. IGRA is the Integrated Global Radiosonde Archive. Its content can be explored at http://www.ncdc.noaa.gov/oa/climate/igra/.

References

Seidel, D. J., Y. Zhang, A. Beljaars, J.-C. Golaz, A. R. Jacobson, and B. Medeiros, 2012: Climatology of the planetary boundary layer over the continental United States and Europe, J. Geophys. Res., 117, D17106, doi:10.1029/2012JD018143

Stull, Roland B. (1988), An Introduction to Boundary Layer Meteorology, Kluwer Press.

Vogelzang, D., and A. Holtslag, 1996: Evaluation and model impacts of alternative boundary-layer height formulations. Bound.-Layer Meteor., 81, 245-269.

Appendix 1. Sample FORTRAN code for diagnosing *Rib*-MH from a model profile. This code can be downloaded from ftp://ftp.cmdl.noaa.gov/pub/andy/transcom_blh/mixing_properties.f.

mixing_properties.f **1/2**

```
c------------------------------------------------------------------------------
c Subroutine to compute mixing for an input profile.
c
c Input:
c   nmax       : number of levels
c   z(nmax)    : level height above ground [m]. z(nmax) is closest to
c                    the surface.
c   pres(nmax) : pressure [Pa]
c   temp(nmax) : temperature [K], temp(nmax) is closest to the surface.
c   qv(nmax)   : water vapor specific humidity [kg/kg]
c   u(nmax)    : u wind [m/s]
c   v(nmax)    : v wind [m/s]
c
c Output
c   freq       : Mixing depth "frequency": 1 if a mixing depth is diagnosed,
c                                          0 otherwise
c   depth      : Mixing depth [m] or -999.0 if not detected.
c
c Authorship
c   original code by Chris Golaz (GFDL) and Sungsu Park (NCAR)
c   later comments by Andy Jacobson, NOAA

      subroutine mixing_properties(nmax,z,pres,temp,qv,u,v,freq,depth)
      implicit none

      real, parameter :: kappa = 287.04/1004.67
      real, parameter :: p00 = 1000.0e2
      real, parameter :: grav = 9.81
      real, parameter :: eps = 1.0e-8
      real, parameter :: Ri_crit = 0.25

      integer, intent(in) :: nmax
      real, intent(in), dimension(nmax) :: z, pres, temp, qv, u, v
      real, intent(out)                 :: freq, depth

      real thetavs, zs, us, vs
      real thetavh, vv
      real Ri(nmax)

      integer k

!     Lowest model level properties

c      Note here that the GFDL atmospheric model indexes its layers
c      from the top of atmosphere down to the surface, whereas many
c      other models start with layer 1 being closest to the surface.
c      Should your model be in the latter camp, use k=1 below instead
c      of k=nmax.  -Andy Jacobson

      k = nmax
      thetavs = temp(k) * (p00/pres(k))**kappa
     .                  * ( 1.0 + 0.61*qv(k)/(1.0-qv(k)) )
      zs = z(k)

c      The draft protocol favors assuming that surface winds are
c      identically zero, and if we go that route, please use:
c    us = 0.
c    vs = 0.
c      instead of u(k) and v(k).   -ARJ

      us = u(k)
      vs = v(k)

      Ri(k) = 0.0
      freq = 0
      depth = -999.0

!     Vertical upward loop

c     Here again is the top-down indexing.  For bottom-up,
c     use "do k=2,nmax".  -ARJ

      do k = nmax-1,1,-1
```

```fortran
         thetavh = temp(k) * (p00/pres(k))**kappa
     .                     * ( 1.0 + 0.61*qv(k)/(1.0-qv(k)) )

         vv = max( (u(k)-us)**2 + (v(k)-vs)**2, eps )
c        For us=vs=0,  vv = max( (u(k)**2 + v(k)**2), eps )  -ARJ

         Ri(k) = grav * (thetavh-thetavs) * (z(k)-zs) / (thetavs*vv)
         if (Ri(k) >= Ri_crit) then
           depth = z(k+1)
     .             + (Ri_crit-Ri(k+1))/(Ri(k)-Ri(k+1))*(z(k)-z(k+1))
c        For bottom-up indexing:
c           depth = z(k-1)
c     .             + (Ri_crit-Ri(k-1))/(Ri(k)-Ri(k-1))*(z(k)-z(k-1))
           freq = 1
           exit
         end if

       end do

       end
```