Impact of Large-Scale Climate Variability to Long-Haul Flight Routes

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Large-scale Climate Variability
1. North Atlantic Oscillation (NAO)

+NAO

-NAO

DJF 2004-2005

DJF 2009-2010
Large-scale climate variability

2. El Nino Southern Oscillation (ENSO)

+ENSO (El Niño)

DJF 1997-1998

-ENSO (La Niña)

DJF 1998-1999
Modeling of Wind-Optimal Route

\[ \frac{d\phi(t)}{dt} = \frac{V_a \cos \psi(t) + U(\phi, \theta, z)}{R \cos \theta(t)}, \]
\[ \frac{d\theta(t)}{dt} = \frac{V_a \sin \psi(t) + V(\phi, \theta, z)}{R}, \]
\[ \frac{d\psi(t)}{dt} = -\frac{F_{\text{wind}}(t)}{R \cos \theta(t)}. \]

- **WOR (Wind-Optimal Route)**

\[ y(t+1) = y(t) + \Delta t \left\{ \frac{dy(t)}{dt} \right\}, \text{ where } y = \phi, \theta, \text{ and } \psi. \]

Kim et al. (2015; 2016), Sridhar et al. (2011), and Williams (2016)
Modeling of Wind-Optimal Route

- **Eastbound Wind-Optimal Route from JFK to LHR (left):**
  
  Optimal route (blue) has the minimum of total flight time to LHR.

- **Westbound Wind-Optimal Route from LHR to JFK (right):**
  
  Optimal route (red) has the minimum of total flight time to JFK.
Upper-Level Winds with NAO Phases

- **+NAO**
  - Averaged horizontal wind speed at 250 hPa in DJF 2004-2005 (left):
    - Jet stream is shifted to northward.

- **-NAO**
  - Averaged horizontal wind speed at 250 hPa in DJF 2009-2010 (right):
    - Jet stream is shifted to southward.
Wind-Optimal Routes with NAO Phases
Variations on Total Flight Time with NAO Phases

Mean flight time:
WOREB in + NAO: 329 min
WORWB in + NAO: 408 min
WOREB in - NAO: 346 min
WORWB in - NAO: 382 min

• Mean of Round-Trip Flight Time:
  + NAO: 737 min  >  - NAO: = 728 min

** Extra cost:
9-min/flight x 1gal/sec x $3/gal
= $145,800/flight for 3-month
Wind-Optimal Routes with ENSO Phases

+ENSO (El Niño)

-ENSO (La Niña)
Variations on Total Flight Time with ENSO Phases

Mean Flight Time:
- WOREB in + ENSO: 227 min
- WORWB in + ENSO: 290 min
- WOREB in - ENSO: 244 min
- WORWB in - ENSO: 266 min

Mean of Round-Trip Flight Time:
- + ENSO: 517 min > - ENSO: 510 min

** Extra cost:
- 7-min/flight × 1gal/sec × $3/gal
  = $113,400/flight for 3-month
Summary and Conclusion

• WORs are different in ±NAO and ±ENSO phases.
• East Bound are faster than West Bound routes.
• Strong jets in +NAO, +ENSO phase shorten (extend) the East Bound (West Bound) flights.
→ Total Round-Trip Flight Times (JFK-LHR and HNL-SFO) are longer in +NAO and +ENSO than –NAO and –ENSO.
→ Expect Extra Fuel Consumptions in +NAO and +ENSO.
• Climate variability (NAO and ENSO) can be a good decision-making indicator for aviation operations.
Thank you

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• Kim et al. (2016):
  • CAT potentials along the Wind-Optimal Route (WOR) are higher in +NAO.
  • Because of stronger wind shear near stronger jet stream along the WORs.
* Kristopher B. Karnauskas et al. (2015): Total flight time (Round trip: Sum of Eastbound and Westbound) correlates well with upper-level U_wind between HNL and SFO.